The Contested Nature of Urban Resilience: Meaning and Models for Green Infrastructure and Climate Change Adaptation Planning

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Natural Resources and Environment) in the University of Michigan 2017

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Dedication

For Fabian

Acknowledgements

This dissertation would not have been possible without the continuous support of so many people. I could not have asked for a better advisor than Josh Newell. He has been an incredible mentor. I am very grateful for how he has pushed me professionally and as a scholar, while also supporting me in maintaining a healthy work-life balance. When I mentor my own students, I will aspire to be as supportive and generous with my time as Josh. I would also like to thank my other three committee members: Maria Carmen Lemos inspires me with her sharp insights, frank advice, and advocacy for us SNRE PhD students. Dan Brown taught me about spatial modeling and his feedback helped me develop the GISP model. Scott Campbell expanded my understanding of urban theory and planning with his thought-provoking questions. I am grateful to Michaela Zint for her mentorship and for helping me to think about pedagogy. I owe a huge debt of gratitude to Missy Stults, who inspires me with her tireless efforts to build a more resilient society and kept me grounded in real-world problems through our collaborative projects.

I am thankful for all my fellow SNRE PhD students, and the strong doctoral student community that we have built together over the last few years. This would have been a long, lonely process without our seminars, happy hours, and trivia nights together. In particular, I have to thank my lab mate Josh Cousins and Anna Harrison for convincing me to come to Michigan and for their friendship. Thanks to the other members of my cohort: Carolina Simao, Joe Krieger, and Scott Kalafatis. I am grateful to James Arnott for always being up for co-organizing workshops, speakers, and conferences. Thanks also to John Graham, Arthur Endsley, James Erbaugh, and others for their friendship and helpful feedback over the years.

As someone who likes to collaborate, I am very grateful to have been affiliated with several groups at UM. I want to thank the other members of the Urban Sustainability Research Group past and present including Alec Foster, Zhenzhen Zhang, Brandon List, Zahra Bahrani Fard, and Tawechote Wongbuphanimitr. Thanks for the support of the Center for Sustainable Systems and affiliated faculty and staff, such as Greg Keoleian and Helaine Hunscher. Thanks also to the other members of the Dow Sustainability Fellows Program and my Rackham interdisciplinary workshops whose interdisciplinary perspectives I benefited enormously from.

Thank you to the numerous scholars and individuals in each of my four case study cities who generously contributed their data, expertise, and time, without which this research would not have been possible. I am also extremely grateful for the generous funding I received from SNRE, Rackham Graduate School, the Dow Sustainability Fellows Program, the Menakka and Essel Bailey Graduate Fellowship, the Marshall Weinberg Population, Development, and Climate Change Fellows Program, the AAG Human Dimensions of Global Change Specialty Group, the Kresge Foundation, the UM Water Center, and NSF (CBET-1444745).

On a more personal note, I also have to thank my Beakes house ‘family’—particularly Brian Smyser, Caitlin Weber, Jordan Dalton, and Alexa Erickson—and the many other amazing friends I have made over the last five years in Ann Arbor. There are simply too many to name. I am of course greatly indebted to my parents Linda and Alan—who taught me to love science and nature—and my siblings Andrew and Erica. Thank you also to my new family members Elise, Alfi, and Marlies, whose support I have come to rely on in the last few years. And last but certainly not least, thank you Fabian. I am forever grateful to have found you during this PhD journey, and I cannot imagine completing it without your unwavering support.

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Abstract

What is urban resilience and how can we make cities resilient in the face of environmental and socioeconomic threats in a way that is sustainable and just? Despite the rapid growth of publications and policy initiatives on urban resilience, there is no consensus on the concept's definition or operationalization. Few empirical studies critically examine the politics and tradeoffs inherent to the application of resilience in different sectors and cities. This dissertation contributes to both research and practice by addressing these gaps through six mixed-method studies of the concept of urban resilience and its empirical application in the context of urban green infrastructure planning and climate change adaptation. The first section helps to clarify the meaning of urban resilience by outlining a broad definition and framework for operationalizing urban resilience that addresses conceptual tensions identified through a bibliometric review of the academic literature. Building on this framework, in the second section of the dissertation I develop a Green Infrastructure Spatial Planning (GISP) model to help decision-makers identify tradeoffs, synergies, and priority areas where green infrastructure can be strategically placed to maximize resilience benefits. I apply this model to four diverse cities: Detroit, New York City, Los Angeles (United States), and Manila (Philippines). The third section focuses on urban climate resilience. I compare resilience definitions and characteristics from the academic literature and a survey of local government officials and find evidence of a science-policy divide. I then use those theorized characteristics to evaluate urban climate resilience in Manila as part of an in-depth case study of the complex global and local factors that shape urban infrastructure planning in a rapidly growing coastal megacity.

Chapter 1 Introduction

Cities are confronted with numerous risks and changes, from rapid urbanization to economic crises to climate change (Seto, Sánchez-Rodríguez, & Fragkias, 2010). Recognizing these challenges, academics and policymakers increasingly emphasize the importance of fostering 'urban resilience,' or the ability of cities to cope with disruptions (Leichenko, 2011). Despite the explosive growth of publications and policy initiatives on urban resilience—such as Rockefeller's *100 Resilient Cities* initiative and the United Nations Office for Disaster Risk Reduction's *Making Cities Resilient* campaign—there is still considerable disagreement about what resilience means or how to operationalize it (Pizzo, 2015). Moreover, few empirical studies critically examine the politics and tradeoffs related to how resilience is applied across disciplines and urban geographies (Chelleri, Waters, Olazabal, & Minucci, 2015). This dissertation helps to fill this gap, contributing to both the research and practice of governing for urban resilience through six mixed-method studies (four published as coauthored journal articles) of the resilience concept and its empirical application in the context of climate change adaptation and green infrastructure planning.

1.1 Research questions and methodology

The overarching question that motivates my past, present, and future research is: *What is urban resilience and how can we make cities more resilient in the face of climate change and other threats in a way that is sustainable and just?* This dissertation is structured around a number of specific questions that fall under this broader research agenda. Here I introduce each of these questions and the methodology that I used—in collaboration with colleagues—to address them.

First, I focus on improving our understanding of how urban resilience is conceptualized across academic disciplines and policy contexts by examining three questions:

1. *How is urban resilience defined and characterized?*
2. *What are the social and ecological implications of these different conceptualizations?*
3. *How can we minimize conceptual confusion and operationalize urban resilience more critically?*

I address these questions by systematically reviewing the academic literature on urban resilience with the assistance of bibliometric analysis (Chapter 2), and by surveying practitioners about their understanding of resilience (Chapter 6). The findings reveal six important discrepancies, or conceptual tensions, in how urban resilience is defined and characterized. The tensions center on: 1) the definition of 'urban;' 2) understanding of system equilibrium; 3) positive vs. neutral (or negative) conceptualizations of resilience; 4) mechanisms for system change; 5) adaptation versus general adaptability; and 6) timescale of action. While other scholars have previously critiqued this conceptual fuzziness (Davoudi et al., 2012; Weichselgartner and Kelman, 2015), I attempt to redeem the concept and move beyond criticisms by proposing a new definition. It is carefully designed so that it is broad enough to be adapted to different contexts and continue to serve a valuable function as a boundary object, but it at least takes an explicit position on each of the six tensions.

I also develop a three-part framework for applying the definition of urban resilience in different empirical contexts, providing a heuristic to help make the normative and contested aspects of resilience projects and policies explicit by carefully thinking through questions and tradeoffs related to resilience for whom, of what to what, when, where and why. I refer to these questions as the 'Five Ws' of urban resilience (Chapter 3). When applying resilience in a specific context, this 'Five Ws' framework suggests a need to negotiate, for example, whose resilience is prioritized and what is included and excluded from the urban system. This is important because the answers to these questions shape how resilience is operationalized and who benefits as a result.

Second, I use green infrastructure planning as a lens through which to examine the potential social and environmental justice implications of these decisions. Expanding green infrastructure is commonly cited in both academic and policy discourse as a way for cities to enhance resilience. For example, the United States Environmental Protection Agency defines green infrastructure as "a cost-effective, *resilient* approach to managing wet weather impacts that provides many community benefits." (US EPA, 2017, emphasis added). I use a hypothetical example of green infrastructure planning in Los Angeles to illustrate the importance of the 'Five Ws' (Chapter 3). I also develop the Green Infrastructure Spatial Planning (GISP) model as a transferable approach for assessing spatial synergies and tradeoffs between different resilient benefits of green infrastructure (Chapter 4 and Chapter 5). The GISP model is used to examine two research questions:

4. *How do decisions related to resilience for whom, what, when, where, and why impact spatial priorities, and what are the social and environmental justice implications?*
5. *What are the political and scalar dimensions and tradeoffs associated with planning green infrastructure to enhance social-ecological resilience?*

The GIS-based multi-criteria model integrates different datasets related to 1) stormwater management; 2) social vulnerability; 3) access to green space; 4) air quality; 5) urban heat island;

and 6) landscape connectivity. Criteria are weighted to reflect local expert stakeholders' priorities as determined through surveys and workshop meetings, and the combined results are visualized for decision-makers in a web-based interface. I apply the approach first in Detroit, and then create three preliminary models for the coastal 'megacities' of Los Angeles, New York City, and Manila (Philippines). I complement this quantitative modeling with fieldwork and interviews, providing a deeper understanding of local planning priorities and challenges (Chapter 7).

The GISP model empirically illustrates the inherently contested nature of planning for resilience. Because of the inevitability of tradeoffs and differing priorities, spatial outcomes will vary depending on who makes decisions, and on what basis. It also underscores that it is critical to examine local priorities and spatial tradeoffs and synergies as part of a strategic resilience planning process. This connects to the final research question:

6. *What are the opportunities and challenges for enhancing urban climate resilience?*

In an attempt to answer this question, I first compare definitions and characteristics of urban climate resilience in the academic literature and a survey of 134 local government officials from across the United States (Chapter 6). I then apply these characteristics in an in-depth case study of infrastructure planning and climate resilience in Manila, Philippines (Chapter 7). This last chapter is based on several extended fieldwork trips to the Philippines, nearly 40 expert interviews, and two workshops with local government officials.

To summarize, this dissertation employs a mixed methods approach to address six research questions, combining qualitative methods (fieldwork, interviews), quantitative methods (bibliometric analysis and surveys), and spatial analysis (GIS modeling). With the exception of one nation-wide survey of US local officials, the empirical components of my research focus on four diverse cities (a multisite approach): Detroit, New York, Los Angeles, and Manila. An introduction to each city is provided in section 1.3, but first I will briefly situate myself as a scholar.

1.2 Theoretical framework

My research sits at the intersection of urban planning and geography within the context of the human dimensions of global change. I emphasize problem-driven and collaborative research and draw on various literatures. For example, I look to the field of environmental planning for insights on how to balance economic, environmental, and equity concerns in planning sustainable cities (Beatley, 2011; Campbell, 1996; Wolch, Byrne, & Newell, 2014). Research on environmental governance helps me to understand decision-making processes and how institutions interact at various scales (Adger, Arnell, & Tompkins, 2005; Bulkeley & Betsill, 2005). I also draw from the burgeoning literature on social-ecological systems that highlights the interconnections between nature and society and how these complex systems are in a constant state of flux (Folke, 2006; Gunderson & Holling, 2002; Pickett, McGrath, Cadenasso, & Felson, 2014). Political ecology research provides me with a more critical perspective on these human-environment interactions and their embeddedness within the broader political economy (Heynen, Kaika, & Swyngedouw, 2006; Pelling, 1999). In trying to understand resilience in the face of global environment change, I also draw on the long legacy of research on hazards and vulnerability (Cutter, Boruff, & Shirley, 2003; Godschalk, 2003).

In this dissertation, I build on existing scholarship across these research domains as it relates specifically to urban resilience, climate change adaptation, and green infrastructure. More extensive literature reviews are provided in the individual chapters, but some of the most relevant concepts, debates, and gaps in the literature are summarized below.

1.2.1 Urban Resilience

In the academic literature, the concept of resilience is commonly traced back to a seminal article by ecologist C.S. Holling (1973) in which he described resilience as an ecosystem's ability to maintain basic functional characteristics in the face of disturbance. Holling's concept of resilience was based on new evidence that ecosystems have multiple stable states and are in a constant state of flux. This shift towards a dynamic view of ecosystems as complex adaptive systems has also influenced understandings of sustainability in social-ecological systems (SESs) (Folke, 2006).

Increasingly, resilience theory is being applied to cities in relation to their capacity to respond to climate change and other hazards (Godschalk, 2003; Leichenko, 2011; Wilkinson, 2012). There are several reasons for the growing interest in urban resilience: the fact that it provides a theory for examining how SESs can persist in the face of uncertainty, disruption, and change (Albers & Deppisch, 2013; Davoudi et al., 2012); the literature's helpful recommendations for effectively governing complex SESs (Wilkinson, 2012); and the presumed positive societal connotation of the term 'resilience' (Boyd et al., 2008; McEvoy, Fünfgeld, & Bosomworth, 2013; O'Hare & White, 2013; Shaw & Maythorne, 2012). Moreover, the concept has been embraced by a wide array of disciplines and stakeholders, enabling it to serve an important role as a "boundary object" (Brand & Jax, 2007) or "bridging concept" (Beichler, Hasibovic, Davidse, & Deppisch, 2014), which can facilitate interdisciplinary collaboration.

Nevertheless, the proliferation of resilience discourse has resulted in a multitude of definitions, making resilience problematic to operationalize or measure (Gunderson, 2000; Vale, 2014). Besides concerns of conceptual ambiguity, another criticism of resilience theory more broadly is that it downplays the importance of political and cultural factors and power inequities

(Brown, 2013; Cote and Nightingale, 2011; Leach, 2008; Lebel et al., 2006; MacKinnon and Derickson, 2012). Critical analyses of resilience in policy discourse also suggest that the concept may be used to support the status quo, including unequal global capitalist structures (Brown, 2012; Pelling & Manuel-Navarrete, 2011). In light of these critiques, a growing number of scholars call for greater conceptual clarity and more careful consideration of the normative and contested aspects of resilience (Brown, 2013; Cote and Nightingale, 2011; Weichselgartner and Kelman, 2015).

1.2.2 The urban climate challenge

The concept of resilience is applied to numerous urban risks (e.g. terrorism, earthquakes), but is often used in the context of climate change (Leichenko, 2011). Cities are central to the climate change challenge (Johnson, Toly, & Schroeder, 2016). On the one hand, urban areas are concentrated centers of economic activity, production, and consumption, and urban residents are responsible for the majority of greenhouse gas emissions (Hoornweg, Hosseini, Kennedy, & Behdadi, 2016). This makes cities crucial for effective climate change mitigation. On the other hand, urban areas are often particularly vulnerable to climate impacts, such as sea level rise, extreme heat, and flooding, making cities a focus for adaptation efforts (OECD, 2010). Climate risks are not equitably distributed within or among cities, with the poor and cities of the Global South disproportionately affected (Hunt & Watkiss, 2010). To further complicate matters, unequal climate impacts are often exacerbated by other political and economic processes, such as globalization (Leichenko & O'Brien, 2008).

While there is no denying the scope of the challenge, research suggests that city governments are playing an important role in addressing climate change and implementing innovative policy solutions, particularly when national policies are lacking (Bulkeley & Betsill, 2013; Castán Broto & Bulkeley, 2013). Increasingly, these efforts are framed around building 'urban resilience,' and the body of academic and policy literature on planning for urban climate resilience is rapidly expanding (Leichenko, 2011). Despite this growing focus on urban climate resilience and adaptation planning, strategies, characteristics, and metrics of success are still contested (Doherty, Klima, & Hellmann, 2016; Tyler & Moench, 2012).

1.2.3 Green infrastructure

Green infrastructure is one popular strategy that cities can use to enhance resilience, (Ahern, 2013; Kearns, Saward, Houlston, Rayner, & Viraswamy, 2014). Like resilience itself, there are many definitions of green infrastructure, but it generally refers to the network of natural or built vegetation in cities, including parks, bioswales, rain gardens, and green roofs (Benedict & McMahon, 2002). It is promoted for its multiple social and environmental benefits including stormwater management, mitigation of the urban heat island effect and air pollution, improved mental and physical health for urban residents, and improved wildlife habitat, among others (Tzoulas et al., 2007). Often these benefits are classified as provisioning, regulating, supporting, and cultural services using the popular "ecosystem services" framework (Ahern, 2007; Andersson et al., 2014; Hansen & Pauleit, 2014). Green infrastructure is also commonly advocated as a climate adaptation strategy (Foster, Lowe, & Winkelman, 2011; Gill, Handley, Ennos, & Pauleit, 2007; Stults & Woodruff, 2016).

While the literature on green infrastructure services is extensive, considerably less research has examined trade-offs between these different benefits or who profits most from them and why (Ernstson, 2013; Hansen & Pauleit, 2014; Lovell & Taylor, 2013). For example, if reducing flood risk is the primary determinant of where to locate green infrastructure, could this mean green spaces are not developed in areas where residents lack access to parks or where urban heat island effects are most pronounced? These questions are highly salient because in recent years, many governments and organizations have begun actively advocating for green infrastructure, and individual municipalities such as New York City have budgeted millions of dollars to implement green infrastructure plans as part of their sustainability and resilience goals (Kremer, Hamstead, & McPhearson, 2016).

1.3 City case selection

This dissertation uses a multisite case study approach to contribute to these research domains, balancing the need for in-depth understanding of resilience planning processes in individual cities and broader generalizability (Bishop, Mills, Durepos, & Wiebe, 2012; Herriot & Firestone, 1983). I selected four very different case study cities—with varying climates, natural hazards, population trends, levels of green infrastructure planning, and spatial data availability—to better reflect the diversity of cities. Key statistics for the three cities are summarized in Table 1.

Table 1 Case study city statistics

City	City of Detroit	New York City	City of Los Angeles	Metropolitan Manila
Urban agglomeration population 2010, in millions (UNDESA, 2014)	3.73	18.37	12.16	11.89
City population 2010, in millions (Philippine Statistics Authority, 2016; US Census Bureau, 2015)	0.72	8.18	3.79	11.86
City area, square kilometers (Department of Environment and Natural Resources, 2017; US Census Bureau, 2015)	359	784	1260	636
A.T. Kearney's Global Cities Ranking (ATKearney, 2017)	N/A	1	8	66

Detroit served as the pilot case for the GISP model because being nearby, data was readily available and green infrastructure has great potential there due to availability of vacant land (Schilling & Logan, 2008). As a legacy or 'shrinking' city, Detroit faces different challenges than the other three cases. In recent years, the City of Detroit has experienced severe socio-economic problems, a loss of manufacturing, population, and tax revenue base, and high vacancy rates (Schilling & Logan, 2008). The city has over 20 square miles of vacant residential, commercial, and industrial land. This represents approximately a quarter of Detroit's properties (around 100,000 in total) (Nassauer & Raskin, 2014). The city also lacks the funds to fix its aging infrastructure, which is being strained by the increasing volume and intensity of precipitation associated with climate change (Karl, Melillo, & Peterson, 2009).

While there are many problems with Detroit's current conditions, extensive vacant land also provides an opportunity, and green infrastructure is one of the redevelopment strategies being employed by the city and other nongovernmental actors (Berkooz, 2011). The Detroit Water and Sewerage Department, for example, has committed to investing over $3 million in green infrastructure including bioretention, green streets, and tree planting with the expressed goal of reducing runoff to the city's combined sewer system (Detroit Water and Sewerage Department, 2015).

Unlike Detroit, New York City's population is increasing (US Census Bureau, 2015). The city continues to grow despite the fact that it is vulnerable to climate change impacts including increased precipitation, sea level rise, extreme heat, and coastal storms like 2012's Hurricane Sandy. Since 2007, the City of New York has institutionalized sustainability planning through *PlaNYC*, overseen by the Mayor's Office of Long-Term Planning and Sustainability. In the wake of Sandy, *PlaNYC* added a resilience mandate. The Mayor's Office of Recovery and

Resilience was created and the plan for a *Stronger, More Resilient New York* released. This resiliency plan includes specific references to green infrastructure initiatives, highlighting its ability to simultaneously "absorb storm water, mitigate local flooding, decrease urban heat island effect, increase pedestrian and traffic safety, and beautify neighborhoods" (The City of New York, 2013, p. 199). The City of New York also has a designated Green Infrastructure Plan, billed as a "sustainable strategy for clean waterways" with the stated aim of managing ten percent of runoff in watersheds with combined sewers through green infrastructure and other "source controls" and gaining other "sustainability benefits" (PLANYC, 2010). The original plan was created in 2010 and has been updated annually by the NYC Department of Environmental Protection.

Los Angeles, like NYC, has a growing population and is vulnerable to climate change impacts such as sea level rise and extreme heat. Additionally, there is concern about drought (City of Los Angeles, 2008). While LA does not have a comprehensive green infrastructure plan like NYC's, the city's interest in planning for green infrastructure is evident from a number of existing plans and initiatives, such as the *Green Streets* program and the *Emerald Necklace Forest to Ocean Extended Vision Plan* (environmentla.org). The "greening" or redevelopment of back alleys is one popular green infrastructure approach used in Los Angeles, which has over 900 linear miles of alleys (Newell et al., 2013). The Los Angeles Department of Public Works created a special Green Alleys Subcommittee and the City Council officially approved the program in 2008. Several pilot projects have since been completed, with plans for additional projects underway (Newell et al., 2013).

Metropolitan Manila, the National Capital Region of the Philippines, exemplifies many of the social, ecological, economic, and political challenges that rapidly developing megacities face. Manila provides the additional opportunity of testing the GISP model in a less industrialized country and a relatively data scarce environment. Metro Manila's population is rapidly increasing since the Philippines is the fastest urbanizing country in East Asia and has one of the highest birth rates in the region (World Bank, 2013). Metro Manila has also been identified as one of the world's most vulnerable cities to climate change (Maplecroft, 2013). The city is already struggling to cope with disasters, and devastating floods are a regular occurrence (World Bank, JICA, & ADB, 2010). The country experiences an average of over eight tropical storms annually, like 2013's catastrophic Typhoon Haiyan, and the incidence and intensity of these extreme events is expected to increase with climate change (Brown, 2013).

Metro Manila does not have an overarching green infrastructure plan or policies. Centralized planning is a challenge for the city because Metro Manila is made up of 17 separate municipalities and over 1700 *barangays,* or neighborhood jurisdictions, with only a weak Metropolitan Manila Development Authority, and no centrally elected official. The Philippine government's 2013 *Flood Management Master Plan for Metro Manila,* which calls for over eight million dollars of improvements, does not even mention green infrastructure. Nevertheless, individual municipalities within the metro region have various greening initiatives. Pasig City, for example, has the *Pasig Green City Program: Toward a Healthy Environment and Climate Change Mitigation and Adaptation*. The program encompasses various projects, such as the planting of over 70,000 trees, green space development, and rainwater harvesting at the city hall.

1.4 Dissertation Outline

This dissertation is divided into eight chapters. Chapters 2-7 are structured as independent academic papers, four of which have already been published as coauthored articles in different journals. The chapters do, however, still build off of one another. *Chapter 2: Defining urban* *resilience: A review* presents a bibliometric review of the academic literature on urban resilience. I find that existing definitions are inconsistent or fail to address six conceptual tensions. These observations lead me to propose a new definition, conceptual schematic of the urban system, and the 'Five Ws' framework.

I expand on this framework in *Chapter 3: Urban resilience for whom, what, when, where, and why?* In this study I focus on addressing emerging critiques of the urban resilience agenda, and propose a three-phase process for grappling with the politics of urban resilience. In this chapter I first introduce green infrastructure as an urban resilience strategy, and use a hypothetical example of green infrastructure planning for the city of Los Angeles to illustrate the important implications of questions of resilience for whom, what, when, where, and why.

This simple illustrative example in Chapter 3 serves as the basis for the GISP model, which I introduce and develop for Detroit in *Chapter 4: Spatial Planning for Multifunctional Green Infrastructure: Growing Resilience in Detroit.* I use the model to assess spatial synergies and tradeoffs between resilience planning priorities and also compare modeled green infrastructure hotspots with the locations of existing projects. In *Chapter 5: A Green Infrastructure Spatial Planning model for evaluating ecosystem service tradeoffs and synergies in three coastal megacities* I test the transferability of the GISP methodology and generalizability of stakeholder priorities and spatial synergy and tradeoff patterns by attempting to apply the model to three diverse coastal megacities.

In *Chapter 6: Comparing conceptualizations of urban climate resilience in theory and practice*, I return to a more conceptual focus on urban resilience. The chapter draws on definitions and characteristics identified through the literature review in Chapter 2, and compares academic conceptualizations with local government officials' as determined through a national survey.

I use the 16 characteristics of urban climate resilience identified in Chapter 6 to structure my analysis of Manila's resilience in *Chapter 7: Double exposure, infrastructure planning, and urban climate resilience in coastal megacities: A case study of Manila.* In this chapter I examine how 'double exposure' to climate change and globalization shapes metro-wide infrastructure planning in Manila (with a particular focus on green and electricity infrastructure), and how this influences the city's resilience.

In *Chapter 8: Conclusion* I summarize the key findings and theoretical and practical implications of each of these six studies. I argue that the most significant contributions of my dissertation research include a better understanding of the various definitions and characteristics of urban resilience, a general framework for critically operationalizing urban resilience in different contexts, and the development of the Green Infrastructure Spatial Planning modeling approach for the strategic planning of multifunctional green infrastructure. I conclude by identifying a number of potential avenues for future research that would build on the foundation developed in this dissertation.

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Chapter 2 Defining urban resilience: A review[1]

Abstract: Fostering resilience in the face of environmental, socioeconomic, and political uncertainty and risk has captured the attention of academics and decision makers across disciplines, sectors, and scales. Resilience has become an important goal for cities, particularly in the face of climate change. Urban areas house the majority of the world's population, and, in addition to functioning as nodes of resource consumption and as sites for innovation, have become laboratories for resilience, both in theory and in practice. This paper reviews the scholarly literature on urban resilience and concludes that the term has not been well defined. Existing definitions are inconsistent and underdeveloped with respect to incorporation of crucial concepts found in both resilience theory and urban theory. Based on this literature review, and aided by bibliometric analysis, the paper identifies six conceptual tensions fundamental to urban resilience: (1) definition of 'urban'; (2) understanding of system equilibrium; (3) positive vs. neutral (or negative) conceptualizations of resilience; (4) mechanisms for system change; (5) adaptation versus general adaptability; and (6) timescale of action. To advance this burgeoning field, more conceptual clarity is needed. This paper, therefore, proposes a new definition of urban resilience. This definition takes explicit positions on these tensions, but remains inclusive and flexible enough to enable uptake by, and collaboration among, varying disciplines. The paper concludes with a discussion of how the definition might serve as a boundary object, with

[1] Published as Meerow, Sara, Newell, Joshua P, & Stults, Melissa. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, *147*, 38–49. http://doi.org/10.1016/j.landurbplan.2015.11.01ro

the acknowledgement that applying resilience in different contexts requires answering: Resilience for whom and to what? When? Where? And why?

2.1 Introduction

In recent years, the popularity of “resilience” has exploded in both academic and policy discourse, with numerous explanations for this dramatic rise (Brown, 2013; Cascio, 2009; Meerow & Newell, 2015). Above all perhaps, resilience theory provides insights into complex socio-ecological systems and their sustainable management (Folke, 2006; Pickett, Cadenasso, & McGrath, 2013), especially with respect to climate change (Leichenko, 2011; Pierce, Budd, & Lovrich, 2011; Solecki, Leichenko, & O’Brien, 2011; Zimmerman & Faris, 2011). As socio-ecological resilience theory understands systems as constantly changing in nonlinear ways, it is a highly relevant approach for dealing with future climate uncertainties (Rodin, 2014; Tyler & Moench, 2012). As a term, resilience also has a positive societal connotation (McEvoy, Fünfgeld, & Bosomworth, 2013; O’Hare & White, 2013; Shaw & Maythorne, 2012), leading some to suggest that it is preferable to related, but more charged concepts like “vulnerability” (Weichselgartner & Kelman, 2014, p. 10).

In particular, resilience has emerged as an attractive perspective with respect to cities, often theorized as highly complex, adaptive systems (Batty, 2008; Godschalk, 2003). Unprecedented urbanization has transformed the planet from 10 percent urban in 1990 to more than 50 percent urban in just two decades (United Nations Department of Economic and Social Affairs [UNDESA], 2010). Although urban areas (at least 50,000 residents) cover less than three percent of the Earth’s surface, they are responsible for an estimated 71 percent of global energy-related carbon emissions (International Panel on Climate Change [IPCC], 2014). As cities continue to grow and grapple with uncertainties and challenges like climate change, urban resilience has become an increasingly favored concept (Carmin, Nadkarni, & Rhie, 2012; Leichenko, 2011).

But what exactly is meant by the term 'urban resilience'? The etymological roots of resilience stem from the Latin word *resilio*, meaning "to bounce back" (Klein, Nicholls, & Thomalla, 2003). As an academic concept, its origins and meaning are more ambiguous (Adger, 2000; Friend & Moench, 2013; Lhomme, Serre, Diab, & Laganier, 2013; Pendall, Foster, & Cowell, 2010). Resilience has a conceptual fuzziness that is beneficial in enabling it to function as a "boundary object," a common object or concept that appeals to multiple "social worlds" and can, therefore, foster multidisciplinary scientific collaboration (Star & Griesemer, 1989). The meaning of resilience is malleable, allowing stakeholders to come together around a common terminology without requiring them to necessarily agree on an exact definition (Brand & Jax, 2007). But this vagueness can make resilience difficult to operationalize, or to develop generalizable indicators or metrics for (Gunderson, 2000; Pizzo, 2015; Vale, 2014).

To better understand how the term has been defined and used across disciplines and fields of study, this paper reviews four decades of academic literature on urban resilience beginning in 1973. Guided by bibliometric analysis, the paper identifies the most influential thinkers and publications in this rapidly expanding research area. This review reveals that definitions of urban resilience from this period are underdeveloped in the sense that they have not explicitly addressed important conceptual tensions apparent in the urban resilience literature. Moreover, where papers do discuss these tensions, the authors' positions are often inconsistent. The first five tensions (also evident in the broader resilience literature) are as follows: 1) equilibrium vs. non-equilibrium resilience; 2) positive vs. neutral (or negative) conceptualizations of resilience; 3) mechanism of system change (i.e., persistence, transitional, or transformative); 4) adaptation vs. general adaptability; and 5) timescale of action. The sixth conceptual tension is specific to the urban resilience literature and has to do with how 'urban' is defined and characterized.

Using the resilience concept in urban research and for policy contexts hinges on coming to terms with these tensions. Thus, to advance scholarship and practice, this paper proposes a new definition of urban resilience, one that explicitly includes these six conceptual tensions, yet remains flexible enough to be adopted by a range of disciplines and stakeholders. This definition is as follows:

> *Urban resilience refers to the ability of an urban system—and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.*

In this definition, urban resilience is dynamic and offers multiple pathways to resilience (e.g., persistence, transition, and transformation). It recognizes the importance of temporal scale, and advocates general adaptability rather than specific adaptedness. The urban system is conceptualized as complex and adaptive, and it is composed of socio-ecological and socio-technical networks that extend across multiple spatial scales. Resilience is framed as an explicitly desirable state and, therefore, should be negotiated among those who enact it empirically.

The remainder of this paper focuses on the theoretical rationale for this definition. Section 2.2 describes the methodology used to conduct the literature review, including the classification of previous definitions of urban resilience. Section 2.3 analyzes the field's influential literature and expands on the six conceptual tensions. Section 2.4 parses the specific components of this new definition and the rationale for their selection. The paper concludes with a discussion of how urban resilience as a term can serve as a boundary object, enabling the collaboration necessary to contemplate resilience for whom, for what, for when, for where, and why.

2.2 Materials and methods

The academic literature on urban resilience was reviewed to 1) identify the most influential studies, 2) trace the theoretical origins and development of the field, 3) compare how urban resilience is defined across studies and disciplines, and 4) develop a refined definition of urban resilience that is grounded in the literature and addresses conceptual tensions.

First, Elsevier's Scopus and Thompson Reuters Web of Science (WoS) citation databases were used to identify the literature on urban resilience over a 41-year period, beginning in 1973 (when Holling wrote his seminal article on resilience) and ending in 2013. Although relatively comprehensive, these databases do not generally include books, and by focusing mainly on English-language publications, they have an Anglo-American bias (Newell & Cousins, 2015). Given the rapid development of the urban resilience field, additional definitions may have been published since the analysis was conducted. The search terms "urban resilience" and "resilient cities" yielded 139 results in Scopus and 100 in WoS. When combined, the urban resilience dataset included 172 unique publications from a variety of disciplines (i.e., articles, book chapters, conference proceedings, reviews, and editorials). "Discipline" in this paper refers to an "organized perspective on phenomena that is sustained by academic training or the disciplining of the mind" (Turner, 2006, p. 183) and "publication" is used to denote a specific academic study (journal article, book chapter, etc.).

Co-citation analysis was then conducted on this urban resilience dataset. Co-citation analysis is a bibliometric method used to quantitatively evaluate academic literature based on the rationale that shared references imply an intellectual relationship (Newell & Cousins, 2015; Noyons, 2001; Small, 1973). Co-citations measure how often two or more studies are cited together within a body of literature, thereby identifying influential publications and scholars in a given research domain and providing insight into a field's intellectual origins.

To assess these co-citations, the bibliometric software Bibexcel (Persson, Danell, & Schneider, 2009) was used. Files generated in Bibexcel were then imported into the open-source software Gephi (Bastian & Heymann, 2009) to visualize and analyze the co-citation network, thereby revealing the "intellectual structure" of the literature (Yu, Davis, & Dijkema, 2013, p. 281). Node size in the network reflects degree centrality (i.e., the more edges that connect to a node, the larger its size) and serves as an indicator of a study's influence.

The 172 studies were then reviewed to determine if they actually defined urban resilience. They were excluded if they a) failed to define the term or b) used another scholar's definition. This analysis unveiled twenty-two distinct definitions. Three additional definitions (Alberti et al., 2003; Tyler & Moench, 2012; Brown, Dayal, & Rumbaitis Del Rio, 2012) were uncovered during the review of the aforementioned articles, leading to a total of twenty-five definitions of urban resilience. Table 2 lists the twenty-five major definitions of urban resilience identified in the literature by citation count and their Scopus subject area.

These definitions were then compared and categorized based on their positions with respect to six conceptual tensions that were identified in the urban resilience literature. None of the definitions explicitly addressed all six tensions, so the authors' positions had to be inferred based on a reading of the publication. Although resulting categorizations admittedly represent a simplification of complex concepts and studies, the objective was to provide a general representation of how definitions theorize these tensions. Finally, a new definition of urban resilience and a conceptual schematic of the urban system were developed by drawing on this literature and the reviewed resilience and urban literatures more broadly.

2.3 Urban resilience research: Influential thinkers, definitions, and conceptual tensions

Although the concept has a long history of use in engineering, psychology, and disasters literature (Matyas & Pelling, 2014), ecologist C.S. Holling's seminal paper (1973) on the resilience of ecological systems is often cited as the origin of modern resilience theory (Folke, 2006; Klein et al., 2003; Meerow & Newell, 2015). Holling's study is the largest node in the co-citation network (Figure 1), confirming its central importance for the urban resilience field. By recognizing ecosystems as dynamic with multiple stable states, Holling's work was a marked departure from the traditional "stability" paradigm of ecology often associated with the work of Clements (1936). Effectively, Holling used resilience to describe the ability of an ecological system to continue functioning—or to "persist"—when changed, but not necessarily to remain the same. This contrasts with "engineering resilience," which focuses on a single state of equilibrium or stability to which a resilient system would revert after a disruption (Holling, 1996). Non-equilibrium resilience is now paradigmatic in ecology, and Holling's writing on resilience sparked a rich body of work at the socio-ecological interface (Folke, 2006; Wu & Wu, 2013). Within the socio-ecological systems (SES) framework, resilience is often defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling, Carpenter, & Kinzig, 2004, p. 1).

Table 2 Definitions of urban resilience

	Author (Year)	Subject area	Citation count	Definition
1	**Alberti et al. (2003)**	Agricultural and biological sciences; Environmental science	212	". . .the degree to which cities tolerate alteration before reorganizing around a new set of structures and processes" (p. 1170).
2	**Godschalk (2003)**	Engineering	113	". . . a sustainable network of physical systems and human communities" (p. 137).
3	**Pickett et al. (2004)**	Agricultural and biological sciences; Environmental science	101	". . . the ability of a system to adjust in the face of changing conditions" (p. 373).
4	**Ernstson et al. (2010)**	Environmental science; Social sciences	46	"To sustain a certain dynamic regime, urban governance also needs to build transformative capacity to face uncertainty and change" (p. 533).
5	**Campanella (2006)**	Social sciences	44	". . . the capacity of a city to rebound from destruction" (p. 141).
6	**Wardekker et al. (2010)**	Business management and accounting; Psychology	30	". . . a system that can tolerate disturbances (events and trends) through characteristics or measures that limit their impacts, by reducing or counteracting the damage and disruption, and allow the system to respond, recover, and adapt quickly to such disturbances" (p. 988).
7	**Ahern (2011)**	Environmental science	24	". . . the capacity of systems to reorganize and recover from change and disturbance without changing to other states … systems that are "safe to fail" (p. 341).
8	**Leichenko (2011)**	Environmental science; Social sciences	20	". . . the ability . . . to withstand a wide array of shocks and stresses" (p. 164).
9	**Tyler and Moench (2012)**	Environmental science; Social sciences	11	". . . encourages practitioners to consider innovation and change to aid recovery from stresses and shocks that may or may not be predictable" (p. 312).
10	**Liao (2012)**	Environmental science	6	". . . the capacity of the city to tolerate flooding and to reorganize should physical damage and socioeconomic disruption occur, so as to prevent deaths and injuries and maintain current socioeconomic identity" (p. 48).
11	**Brown et al. (2012)**	Environmental science; Social sciences	5	". . . the capacity . . . to dynamically and effectively respond to shifting climate circumstances while continuing to function at an acceptable level. This definition includes the ability to resist or withstand impacts, as well as the ability to recover and re-organize in order to establish the necessary functionality to prevent catastrophic failure at a minimum and the ability to thrive at best" (p. 534).
12	**Lamond and Proverbs (2009)**	Engineering	5	". . . encompasses the idea that towns and cities should be able to recover quickly from major and minor disasters" (p. 63).
13	**Lhomme et al. (2013)**	Earth and planetary sciences	4	". . . the ability of a city to absorb disturbance and recover its functions after a disturbance" (p. 222).

14	**Wamsler et al. (2013)**	Business management and accounting; Energy; Engineering; Environmental science	3	"A disaster resilient city can be understood as a city that has managed . . . to: (a) reduce or avoid current and future hazards; (b) reduce current and future susceptibility to hazards; (c) establish functioning mechanisms and structures for disaster response; and (d) establish functioning mechanisms and structures for disaster recovery" (p. 71).
15	**Chelleri (2012)**	Earth and planetary Sciences; Social sciences	2	". . . should be framed within the resilience (system persistence), transition (system incremental change) and transformation (system reconfiguration) views" (p. 287).
16	**Hamilton (2009)**	Engineering; Social sciences	2	"ability to recover and continue to provide their main functions of living, commerce, industry, government and social gathering in the face of calamities and other hazards" (p. 109)
17	**Brugmann (2012)**	Environmental Science; Social sciences	1	"the ability of an urban asset, location and/ or system to provide predictable performance − benefits and utility and associated rents and other cash flows − under a wide range of circumstances" (p. 217).
18	**Coaffee (2013)**	Social sciences	1	". . .the capacity to withstand and rebound from disruptive challenges …" (p. 323).
19	**Desouza and Flanery (2013)**	Business management and accounting; Social sciences	1	"ability to absorb, adapt and respond to changes in urban systems" (p. 89).
20	**Lu and Stead (2013)**	Business management and accounting; Social sciences	1	". . .the ability of a city to absorb disturbance while maintaining its functions and structures" (p. 200).
21	**Romero-Lankao and Gnatz (2013)**	Environmental science; Social sciences	1	". . . a capacity of urban populations and systems to endure a wide array of hazards and stresses" (p. 358).
22	**Asprone and Latora (2013)**	Engineering	0	". . . capacity to adapt or respond to unusual often radically destructive events" (p. 4069).
23	**Henstra (2012)**	Social sciences	0	"A climate-resilient city . . . has the capacity to withstand climate change stresses, to respond effectively to climate-related hazards, and to recover quickly from residual negative impacts" (p. 178).
24	**Thornbush et al. (2013)**	Energy; Engineering; Social sciences	0	". . . a general quality of the city's social, economic, and natural systems to be sufficiently future-proof" (p. 2).
25	**Wagner and Breil (2013)**	Agricultural and biological sciences	0	". . . the general capacity and ability of a community to withstand stress, survive, adapt and bounce back from a crisis or disaster and rapidly move on" (p. 114).

This work led to the formation of the Resilience Alliance, an interdisciplinary research network devoted to resilience thinking (Walker & Salt, 2006). Key members of the Resilience Alliance collaborated to develop the panarchy model, essentially a heuristic for understanding how complex systems progress over time through multi-scalar adaptive cycles of destruction and reorganization (Gunderson & Holling, 2002). Thus, the theory was extended from Holling's definition of resilience as a measurable, descriptive concept to "a way of thinking" (Folke, 2006, p. 260). As a result, resilience evolved from a system characteristic, which could be positive or negative, to more of a normative vision (Cote & Nightingale, 2011). The influence of established SES resilience scholars on the urban resilience literature is also evident; some of the most prominent nodes in the co-citation network are Folke (2006), Gunderson and Holling (2002), and Carpenter, Walker, Anderies, & Abel (2001).

However, resilience theory is by no means limited to ecological or SES research. It is increasingly applied across a growing number of fields and focus areas, including natural disasters and risk management (Jon Coaffee, 2008; Cutter et al., 2008; Gaillard, 2010; Rose, 2007); hazards (Godschalk, 2003; Klein et al., 2003; Serre & Barroca, 2013); climate change adaptation (Nelson, Adger, & Brown, 2007; Tanner, Mitchell, Polack, & Guenther, 2009; Tyler & Moench, 2012); international development (Brown & Westaway, 2011; Perrings, 2006); engineering (Fiksel, 2006); energy systems (McLellan, Zhang, Farzaneh, Utama, & Ishihara, 2012; Meerow & Baud, 2012; Molyneaux, Wagner, Froome, & Foster, 2012; Newman, Beatley, & Boyer, 2009); and planning (Ahern, 2011; Davoudi et al., 2012; Wilkinson, 2011), among others.

As evidenced by the co-citation network (Figure 1), the urban resilience literature spans and draws from diverse research domains. This includes work by urban ecologists (i.e., Grimm et al., 2008; Grimm, Grove, Pickett, & Redman, 2000) and urban theorists more generally (Harvey, 1996; Jacobs, 1961; McHarg, 1969). Also featuring prominently is Adger's (2000) research on social resilience and Cutter, Boruff, & Shirley's (2003) on social vulnerability. A predominant topical focus of the literature is coping with disturbances due to climate change (Leichenko, 2011; Wardekker, de Jong, Knoop, & van der Sluijs, 2010) or hazards and disasters (Burby, Deyle, Godschalk, & Olshansky, 2000; Campanella, 2006; Godschalk, 2003; Pelling, 2003).

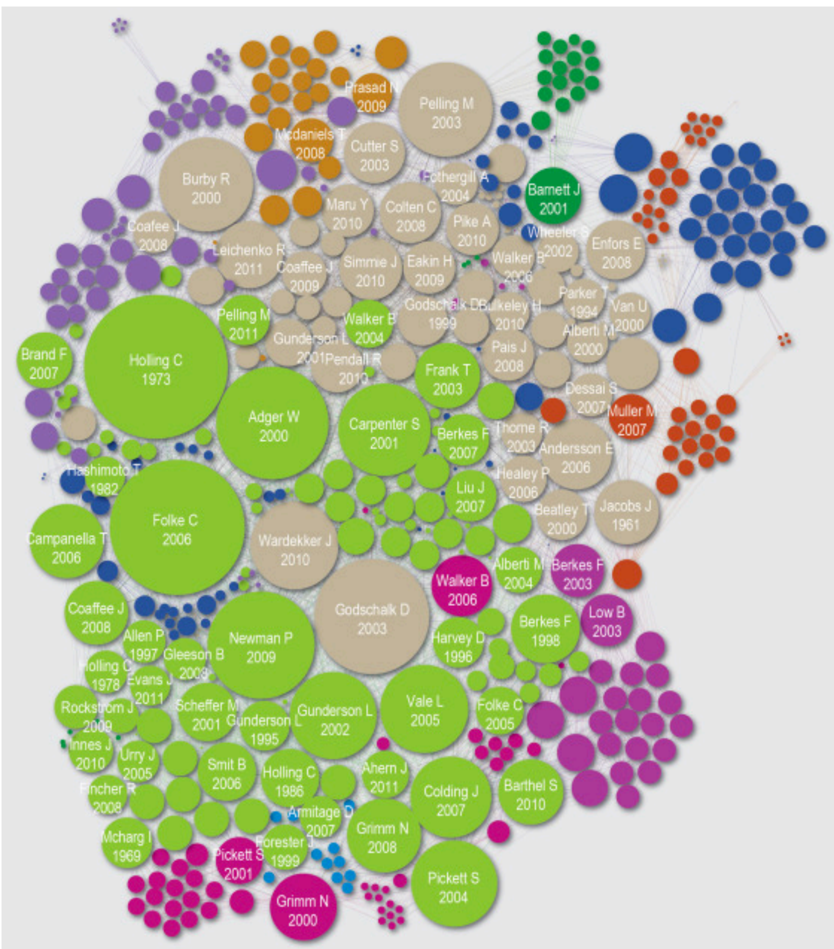

Figure 1 Influential publications in the urban resilience literature

Note: This figure illustrates the co-citation network for the compiled WoS dataset on urban resilience. The nodes or circles represent specific references cited, while edges (connecting lines) signify that two references are cited together. Nodal size reflects the number of connections a reference has in the network (degree centrality). Colors represent communities of more closely related publications. Nodes with degree values > 45 are labeled with the lead author's last name, first initial, and year of publication. The figure used the Force Atlas algorithm for the layout, where more clustering indicates a closer relationship.

2.3.1 *Existing definitions of urban resilience*

As noted earlier, our review identified twenty-five definitions of urban resilience in the literature (Table 1). A reading of these definitions and the publications in which they appear confirms that urban resilience is a contested concept and lacks clarity due to inconsistencies and ambiguity. Given the challenges associated with defining and characterizing "urban" and "resilience" individually, and the numerous disciplines engaged in this field of study (da Silva, Kernaghan, & Luque, 2012), it is not surprising that multiple definitions and conceptual tensions persist. What is surprising is just how few definitions of urban resilience explicitly address these tensions. In some cases an author's perspective on a particular tension can be inferred from the discussion, but, in many instances, it is unclear. These conceptual inconsistencies make it difficult to apply or test the theory empirically, although a few specific resilience metrics and indices have been suggested (i.e., Cutter, Burton, & Emrich, 2010; Orencio & Fujii, 2013). As Klein et al. (2003, p. 42) rather pessimistically argue, "The problem with resilience is the multitude of different definitions and turning any of them into operational tools… After thirty years of academic analysis and debate, the definition of resilience has become so broad as to render it almost meaningless."

To briefly summarize the scope of the challenge, roughly half of the definitions are presented in the context of a specific threat (e.g., climate change or flooding), while the other half focus on the resilience of an urban system to respond to all risks. Definitions uniformly portray urban resilience as a desirable goal, a stance problematized by research that questions who benefits and who loses under resilience regimes. Fifteen definitions adopt non- or multi-equilibrium resilience, with ten focusing on static resilience. More than half emphasize high levels of general adaptive capacity as opposed to adaptedness. But only eleven include a mechanism for changing from an undesirable state, and even fewer mention a timescale for action, post-disturbance. A majority of definitions fail to take a clear position on at least one of the six conceptual tensions. Figure 2 summarizes how these six conceptual tensions are understood in the 25 publications that defined urban resilience. In the next section we analyze these conceptual tensions in detail.

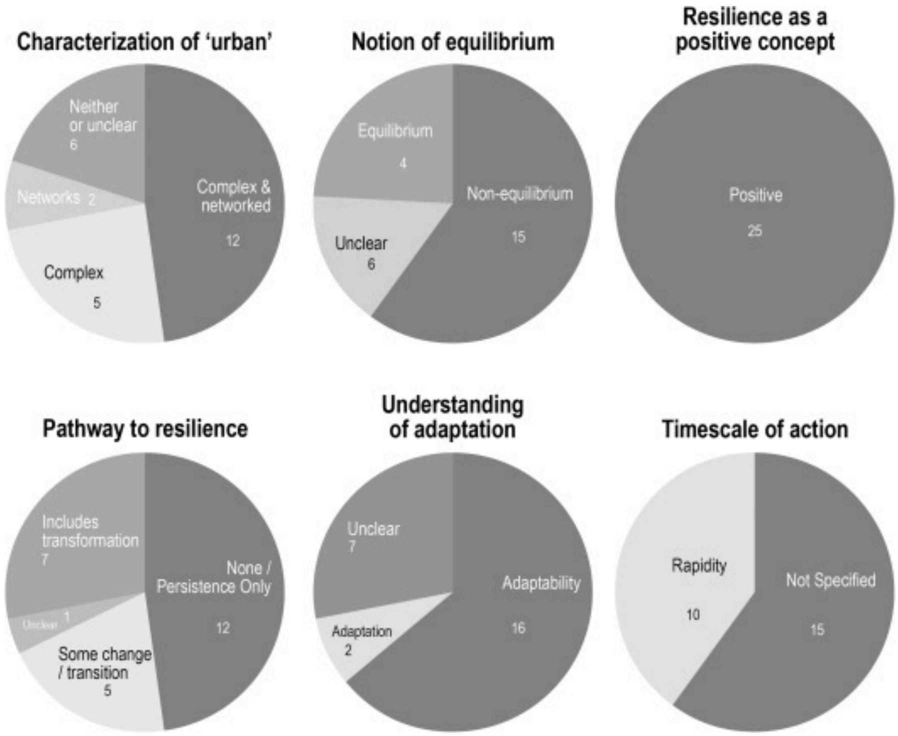

Figure 2 Six conceptual tensions in definitions of urban resilience

2.3.2 Characterization of "urban"

To clearly define urban resilience, it is necessary to first specify what is meant by 'urban.' This can vary widely depending upon the discipline or theoretical construct through which it is viewed (da Silva et al., 2012; Godschalk, 2003; Jabareen, 2013; Salat & Bourdic, 2011). Unfortunately, most definitions of urban resilience are rather vague with respect to what constitutes an urban area or city (i.e., Campanella, 2006; Lu & Stead, 2013). Seventeen of the 25 studies do acknowledge that urban areas are complex, with a number of these referring to cities as “complex systems” (Brugmann, 2012; Cruz, Costa, de Sousa, & Pinho, 2013; da Silva et al., 2012; Lhomme et al., 2013). Furthermore, 14 out of 25 publications theorize urban systems as being composed of “networks.” Still others refer to cities as comprised of both systems and networks. Desouza and Flanery (2013, p. 91), for example, understand “cities as networked complex systems.” Godschalk (2003, p. 141) characterizes cities as “complex and dynamic metasystems” composed of “dynamic linkages of physical and social networks.”

Urban systems indeed represent a conglomeration of ecological, social, and technical components; however, the terminology and focus varies across the literature. In urban ecology scholarship, for example, cities are often places where human and natural patterns and processes interact, evolving to form an “urban ecosystem” or an SES (Alberti et al., 2003; Pickett et al., 2013; Resilience Alliance, 2007). In urban and sustainability transitions literature, the connections between social and technical system interactions are emphasized, often using the term “socio-technical networks” (Graham & Marvin, 2001; Guy, Marvin, & Moss, 2001; Romero-Lankao & Gnatz, 2013). SES scholarship, however, rarely considers the dynamics of technological change in much detail (Smith & Stirling, 2010). This is problematic given socio-technical networks often profoundly affect the resilience of the SES’s within which they are embedded. Consequently, some scholars like Ernstson, Barthel, & Andersson (2010) call for cities to be framed as complex socio-ecological systems composed of networks that are *both* socio-ecological and socio-technical.

The spatial and temporal scale considered also fundamentally shapes how urban resilience is characterized and, in this respect, the urban resilience literature is also inconsistent (Alberti et al., 2003; Brown, Dayal, & Rumbaitis Del Rio, 2012; Desouza & Flanery, 2013; Ernstson et al., 2010). Globalization processes have intertwined cities with distant places and spaces through system interactions that include the exchange of materials, water, energy, capital (of many forms), and the like (Armitage & Johnson, 2006; Elmqvist, Barnett, & Wilkinson, 2014). City and ‘hinterland’ are highly interdependent, making clear delineation of urban boundaries problematic. Some urban resilience scholars recognize the multi-scalar dimensions of these social, ecological, and technical systems by illustrating how they extend beyond the boundary of the city proper (Desouza & Flanery, 2013; Elmqvist, 2014; Ernstson et al., 2010). However, many do not. Inconsistencies in how the various definitions address temporal scale are considered in Section 2.3.7 (Timescale of action).

2.3.3 Notions of equilibrium

In the resilience literature, a divide exists between single-state equilibrium, multiple-state equilibrium, and dynamic non-equilibrium (Davoudi et al., 2012; Folke, 2006; Holling, 1996). Single-state equilibrium refers to the capacity of a system to revert to a previous equilibrium post-disturbance (Holling, 1996). Often identified as “engineering resilience,” single-state equilibrium is also prevalent in the fields of disaster management, psychology, and economics (Pendall et al., 2010). Multiple-state equilibrium resilience (also known as “ecological resilience”) posits that systems have different stable states and, in the face of a disturbance, may be transformed by tipping from one stability domain to another (Holling, 1996). In recent years, the concept of equilibrium has been challenged by notions of dynamic non-equilibrium, which suggests that systems undergo constant change and have no stable state (Pickett, Cadenasso, & Grove, 2004). This development has moved theory away from the idea of resilience as “bouncing back” (Matyas & Pelling, 2014, p. 54).

Urban resilience scholarship is also trending slightly more toward multi- or non-equilibrium conceptualizations of resilience (15 of the 25 definitions adopt such a position). For example, Ahern (2011, p. 341) maintains that resilient urban systems are "safe-to-fail" as opposed to "fail-safe," reflecting a non-equilibrium perspective. Similarly, for communities at risk from natural hazards, Liao (2012, p. 47) claims engineering resilience is an "outdated equilibrium paradigm." Alberti et al. (2003, p. 1170) point to a "newer non-equilibrium paradigm," stressing that "inherently unstable equilibria" exist "between the endpoints of the urban gradient." Other definitions do not take an explicit stance, but nonetheless acknowledge that cities are constantly changing (Desouza & Flanery, 2013) and may not return to a prior state (Lhomme et al., 2013; Lu & Stead, 2013). Nevertheless, some definitions suggest that recovering a previous equilibrium may be possible. For example, Campanella (2006, p. 141) focuses on a city's ability to "rebuild" and "recover" and Wagner and Breil's (2013, p. 114) definition stresses the capacity to "bounce back."

2.3.4 Resilience as a positive concept

The definitions analyzed uniformly embrace resilience as a desirable attribute. As Leichenko (2011, p. 166) writes, the "idea that resilience is a positive trait that contributes to sustainability is widely accepted." Brown et al.'s (2012, p. 534) definition is the most explicitly positive: Urban resilience as the ability not only to maintain basic functions but to improve and prosper.

There is an emerging debate, however, about whether resilience is always a positive concept (Cote & Nightingale, 2011; Nelson et al., 2007), or even whether it should be conceptualized as such (Elmqvist, 2014; Elmqvist et al., 2014). In more equilibrium-focused definitions, urban resilience is understood to mean the ability to return to a "normal" or steady state after a disturbance (i.e., Campanella, 2006; Coaffee, 2013; Lhomme et al., 2013). But what if the original state is undesirable? Certain conditions (e.g., poverty, dictatorships, fossil fuel dependence) can be highly undesirable yet quite resilient (Gunderson & Holling, 2002; Scheffer, Carpenter, Foley, Folke, & Walker, 2001; Wu & Wu, 2013). Determining what is or is not a desirable state requires normative judgments (Brown, 2013; Cote & Nightingale, 2011; Liao, 2012; Weichselgartner & Kelman, 2014). Not all stakeholders will benefit equally from resilience-based actions, and the concept may be used to promote a neoliberal agenda or retain systemic inequality (Friend & Moench, 2013; Joseph, 2013; MacKinnon & Derickson, 2012). Thus, social theorists are asking "resilience for whom?" and of "what to what?" (Davoudi et al., 2012; Vale, 2014). Power inequalities can also determine whose resilience agenda is prioritized (Cote & Nightingale, 2011). Despite these tenable insights, just a small minority of the urban resilience literature explicitly acknowledges the socially constructed and contested nature of resilience (Brown et al., 2012; Liao, 2012; Romero-Lankao & Gnatz, 2013; Tyler & Moench, 2012).

2.3.5 Pathways to urban resilience

The literature indicates three mechanisms or pathways to a resilient state: persistence, transition, and transformation (Chelleri, Waters, Olazabal, & Minucci, 2015; Chelleri & Olazabal, 2012; Elmqvist, 2014; Matyas & Pelling, 2014). Persistence reflects the engineering principle that systems should resist disturbance (i.e., buildings being robust to storm impacts) and try to maintain the status quo (Chelleri, 2012). While retaining function is an important component of most definitions, many definitions also refer to the ability to incrementally adapt (transition) or more radically transform (Brown et al., 2012; Folke et al., 2002; Romero-Lankao & Gnatz, 2013). In particular, when a system is in a robustly undesirable state, efforts to build resilience might seek to purposefully and fundamentally change its structures (Folke, 2006; Jerneck & Olsson, 2008).

Urban resilience definitions focus largely on persistence, with more than half (13 out of 25) omitting a mechanism for change. Seven include transformation, five mention adapting or incremental change, and one does not take an explicit position. Only Chelleri's (2012) definition explicitly identifies resilience as consisting of all three (persistence, transition, and transformation). However, Brown et al. (2012, p. 534) suggest that transition falls somewhere in between, as resilience is "a spectrum from avoidance of breakdown to a state where transformational change is possible." Similarly, Wamsler, Brink, and Rivera (2013, p. 71) recognize that actions to forge a resilient city can be both "incremental and transformational." Several definitions include or acknowledge the need to adapt (Desouza & Flanery, 2013; Godschalk, 2003; Wardekker et al., 2010). However, this literature differs in its conceptualization and emphasis on transition versus transformation as the ideal mechanism of change. Some focus specifically on incremental changes or transition (Ernstson et al., 2010; Liao, 2012; Pickett et al., 2004), while others argue for transformation (Brown et al., 2012; Liao, 2012; Romero-Lankao & Gnatz, 2013; Thornbush, Golubchikov, & Bouzarovski, 2013; Wamsler et al., 2013). How "transition" is defined also differs, with some some viewing it as closely aligned with incrementalism (Chelleri, 2012) and others with transformation (Ernstson et al., 2010).

2.3.6 Understanding of adaptation

The fourth conceptual tension relates to the distinctions between specific adaptations (i.e., high adaptedness) to known threats and more generic adaptability (Cutter et al., 2008; Elmqvist, 2014; Nelson et al., 2007; Pelling & Manuel-Navarrete, 2011). This is what Miller et al. (2010, p. 3) refer to as "specified" versus "general" resilience. It is argued that focusing too much on specified resilience undermines system flexibility, diversity, and ability to respond to inevitable unexpected threats (Wu & Wu, 2013). Cutter et al. (2008) use the terms "inherent" versus "adaptive," stating specifically that inherent qualities are better under normal conditions and adaptive qualities during disasters. Furthering this point, Pike et al. (2010) highlight the distinction and potential tension between short-term adaptation—which means becoming highly specialized—and longer-term adaptability, as well as how this may explain differences in economic resilience between places.

SES scholars tend to view adaptability as synonymous with adaptive capacity, or flexibility necessary for confronting unexpected hazards (Carpenter & Brock, 2008; Folke et al., 2002; Pelling & Manuel-Navarrete, 2011; Zurlini, Petrosillo, Jones, & Zaccarelli, 2012). While leading SES scholars Walker and Salt (2006, p.121) do not contrast adaptability or adaptive capacity and adaptedness, they do emphasize the importance of maintaining "general" resilience to unforeseen threats in addition to "specified" resilience to known risks.

This tension is also apparent in the urban resilience literature. More than half of the definitions stress generic adaptability, flexibility, or adaptive capacity (Ahern, 2011; Brugmann, 2012; Chelleri, 2012; Coaffee, 2013; Desouza & Flanery, 2013; Godschalk, 2003; Leichenko, 2011; Liao, 2012; Lu & Stead, 2013; Pickett et al., 2004; Romero-Lankao & Gnatz, 2013;

Schmitt, Harbo, Diş, & Henriksson, 2013; Tyler & Moench, 2012; Wardekker et al., 2010). One definition explicitly mentions both as being critical (Wamsler et al., 2013), and seven definitions take no clear position (e.g., Alberti et al. 2003, Campanella 2006). Just one emphasizes adaptations based specifically on disaster risks (Lamond & Proverbs, 2009). Scholars focusing on resilience to climate change align with Brown et al. (2012) in arguing that urban resilience should focus on adaptive capacity rather than specific adaptations.

2.3.7 Timescale of action

With respect to timescale of action, some definitions view rapidity of recovery as an essential characteristic. Temporal emphasis is often contingent on whether the focus is on rapid-onset disasters or more gradual climactic change (Wardekker et al., 2010). Just ten definitions mention timescale at all, and these come from the literature on disasters (Asprone & Latora, 2013; Lamond & Proverbs, 2009; Wamsler et al., 2013), climate change (Henstra, 2012; Leichenko, 2011; Tyler & Moench, 2012; Wardekker et al., 2010), and natural hazards (Lhomme et al., 2013; Liao, 2012; Wagner & Breil, 2013). All acknowledge the importance of rapid recovery post-disturbance. As an example, Wagner and Breil (2013, p. 114) include the capacity to "rapidly move on," noting that "the time required to return to a previous stable state after a disturbance" can be used to measure resilience. But in these definitions, what 'rapid' denotes exactly (e.g., hours, weeks, years) is unclear. In contrast, other definitions make no mention of the speed of recovery. Emphasis in these definitions is placed on returning to a pre-disturbance level (or better) of function and structure, but the time necessary to do so is not specified.

2.4 An integrative definition of urban resilience

Given the inconsistencies in the literature, a definition of urban resilience needs to incorporate these conceptual tensions (or at least take an explicit position on them) and do so in a flexible and inclusive way so as to allow different perspectives and emphases to remain and flourish. With this in mind, we propose urban resilience be defined as the following:

> *Urban resilience refers to the ability of an urban system—and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.*

This definition is carefully worded to articulate a position on each of the six conceptual tensions (Table 3). Urban resilience operates in non-equilibrium, is viewed as a desirable state, recognizes multiple change pathways (persistence, transition, and transformation) and emphasizes the importance of adaptive capacity and timescales. This section elaborates on this definition by parsing its major components, beginning with an explanation of what is meant by the urban system and then addressing the five remaining conceptual tensions in turn.

Table 3 Addressing conceptual tensions in urban resilience

Conceptual tensions	Our position
Conceptualization of "urban"	Complex, multi-scalar systems composed of socio-ecological and socio-technical networks that encompass governance, material and energy flows, infrastructure and form, and social-economic dynamics.
Notion of equilibrium	Non-equilibrium with a focus or the ability to retain key desirable functions.
Resilience as a positive concept	A contested, normative vision that cities strive to attain.
Pathway to resilience	Different degrees of change may be required; this can be seen as a continuum from persistence to transformation.
Understanding of adaptation	Should not become highly adapted to current conditions at the expense of general adaptive capacity.
Timescale of action	The speed of recovery or transformation after a disturbance is critical.

‘Urban systems’ are conceptualized as complex, adaptive, emergent ecosystems composed of four subsystems—governance networks, networked material and energy flows, urban infrastructure and form, and socioeconomic dynamics—that themselves are multi-scalar, networked, and often strongly coupled. A simplified schematic of the urban system (Figure 3) provides the reader with a picture of these systems, drawing on other conceptual diagrams, including the global economy by geographer Dicken (2011), urban metabolism by industrial ecologist Kennedy, Cuddihy, & Engel-yan (2007), urban ecosystems by urban ecologists Alberti et al. (2003), and urban resilience research themes by the Resilience Alliance (2007). For example, the latter identifies the four major subsystems of the urban system as being composed of “governance networks,” “metabolic flows,” the “built environment,” and “social dynamics.” In this schematic (Figure 3), governance networks refer to the diverse range of actors and institutions whose decisions shape urban systems. This includes the levels of government (denoted by “states”), nongovernmental organizations (NGOs), and businesses (industry). Networked material and energy flows refer to the myriad materials that are produced or consumed in or by an urban system, such as water, energy, food, and waste flows, often collectively referred to as the “urban metabolism” (Kennedy et al., 2007). Urban infrastructure and form encompass the built environment such as buildings, transportation networks, energy, and water grids (utilities), along with urban green space and parks (Wolch, Byrne, & Newell, 2014). Categorizing urban ecological structure and function as such is obviously a simplification of the biological and ecological processes underway in urban areas. Finally, socio-economic dynamics such as monetary capital, demographics, and justice and equity shape the other subsystems and the livelihoods and capacities of urban citizens (Resilience Alliance, 2007). This schematic emphasizes the interconnections both within and between the four complex and adaptive sub-systems, which interact at multiple spatial and temporal scales. For a comprehensive assessment of urban resilience, these subsystems and their elements need to be considered. To capture system interdependence across spatial and temporal scales, urban systems must be conceptualized as entities embedded in broader “networks” of global resources, commodities, communication, and multilevel governance. These networks are essential to their functioning (Hodson & Marvin, 2010; Seitzinger et al., 2012). As Desouza and Flanery (2013, p. 98) write of resilient cities, "Both physical and social processes can be understood as spatial and temporal interactions across networks, and it is the flow into, out of, and within cities which is of paramount concern for enhancing beneficial operations and suppressing harmful ones. People, activities, institutions, resources, and processes interact in emergent patterns." In essence, Figure 3 provides a heuristic for thinking through these complex urban structures and dynamics.

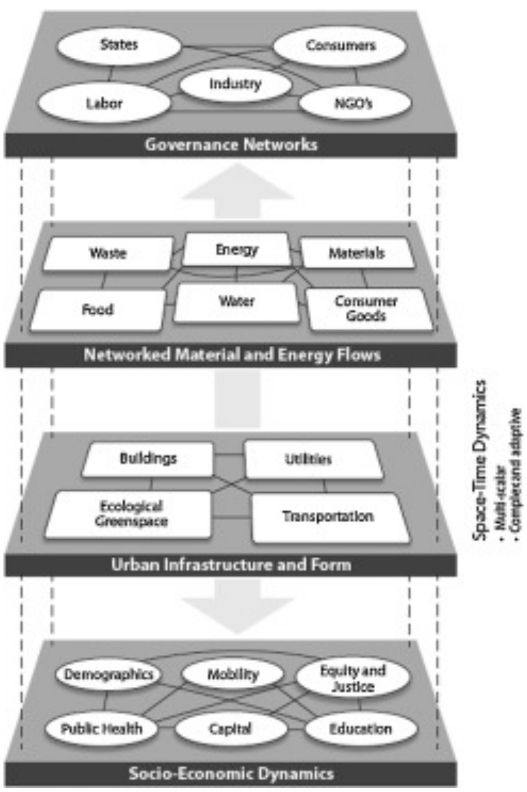

Figure 3 A simplified conceptual schematic of the urban 'system'

Note: Schematic design inspired by Dicken (2011)

The complex and dynamic character of urban systems makes a post-disturbance return to a previous state highly improbable (Barata-Salgueiro & Erkip, 2014; Klein et al., 2003). Climate change and urbanization will likely exacerbate the already unstable nature of cities. Thus, this definition conceptualizes urban resilience as operating in a state of non-equilibrium, whereby resilience reflects a system's capacity to maintain key functions, but not necessarily to return to a prior state. Second, resilience is posited as a normative vision or "agenda" that cities should strive for (Weichselgartner and Kelman 2014, p. 2). However, as will be discussed in the conclusion, defining this vision should be a highly contested, political, and participatory process.

Building resilient urban systems requires different degrees of alteration, thus "transitional," "incremental," or "transformational" changes may all be relevant (Chelleri et al., 2015; Pearson & Pearson, 2014). In the definition, the phrasing "to maintain . . . desired functions," "to adapt," and "to transform" denotes a continuum of actions, from resistance to change (i.e., persistence) to radical transformation. All are potentially relevant for a particular urban area. Persistence may be desirable for certain components (e.g., a building remaining intact through a storm); while for others incremental transition or transformation may be necessary. Efforts to build resilience should focus on transforming systems that are inequitable (e.g., poverty traps) or hinder individuals or communities from developing adaptive capacity.

Given the uncertainties and risks cities face—from climate change to the instability of financial markets—building resilience hinges on general flexibility and adaptability (denoted by "adaptive capacity" in the definition), rather than becoming highly adapted to specific threats. To borrow an illustration from Chelleri and Olazabal (2012, p. 70), developing an electricity system based entirely on wind might be a positive adaptation to immediate energy and climate concerns, but a more diverse and flexible energy portfolio would enhance adaptability to future changes.

A critical feature of a resilient city is the speed of action and recovery. It is obviously preferable to rapidly reestablish critical functions following a disturbance than to experience long delays. The speed in which telecommunication and energy systems recover post-disaster, for example, directly affects the degree, breadth, and duration of impacts experienced. This definition does not necessarily posit, however, that a return to a pre-disaster state of operations is always desirable. As cities regularly operate in a state of non-equilibrium, speed of recovery encompasses both a rapid return to a pre-disaster state and a rapid evolution to a new state of operations.

2.5 Conclusion

We are experiencing a "resilience renaissance" (Bahadur, Ibrahim, & Tanner, 2010). In particular, there is a growing emphasis on enhancing the resilience of cities in the face of unprecedented urbanization and climate change. A diverse group of academics and practitioners have adopted the term urban resilience. As demonstrated by literature review and bibliometric analysis, however, definitions of urban resilience are contradictory and beset by six conceptual tensions. To foster resilience in urban settings and to encourage collaboration among and between researchers and stakeholders, this paper has introduced a new definition of urban resilience. This definition balances the need to clarify theoretical inconsistencies while retaining requisite flexibility.

Although the primary purpose has been to review the literature on urban resilience and to provide an inclusive definition for it, we conclude this paper by offering two final points. First, building on the work of Brand and Jax (2007) and others, we argue that urban resilience serves an important function as a boundary object, and this can be facilitated by the proposed definition and conceptual schematic of the urban system (Figure 3). The meaning of a boundary object is "malleable," allowing it to be adapted by diverse disciplines and stakeholders (Brand & Jax, 2007, p. 1). This is especially important for work on cities, which are complex systems and therefore require the expertise of multiple disciplines and stakeholders. As Vale (2014, p. 198) argues, "The biggest upside to resilience is the opportunity to turn its flexibility to full advantage by taking seriously the actual interconnections among various domains that have embraced the same terminology." Other scholars have previously identified the potential for resilience to function in this way (Beichler, Hasibovic, Davidse, & Deppisch, 2014; Brand & Jax, 2007; Coaffee, 2008).

Table 4 Fundamental questions related to urban resilience

<table>
<tr><th></th><th></th><th>Questions to Consider</th></tr>
<tr><td>Who?</td><td rowspan="5">T
R
A
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F
S
?</td><td>Who determines what is desirable for an urban system?
Whose resilience is prioritized?
Who is included (and excluded) from the urban system?</td></tr>
<tr><td>What?</td><td>What perturbations should the urban system be resilient to?
What networks and sectors are included in the urban system?
Is the focus on generic or specific resilience?</td></tr>
<tr><td>When?</td><td>Is the focus on rapid-onset disturbances or slow-onset changes?
Is the focus on short-term resilience or long-term resilience?
Is the focus on the resilience of present or future generations?</td></tr>
<tr><td>Where?</td><td>Where are the spatial boundaries of the urban system?
Is the resilience of some areas prioritized over others?
Does building resilience in some areas affect resilience elsewhere?</td></tr>
<tr><td>Why?</td><td>What is the goal of building urban resilience?
What are the underlying motivations for building urban resilience?
Is the focus on process or outcome?</td></tr>
</table>

Second, enacting urban resilience is inevitably a contested process in which diverse stakeholders are involved and their motivations, power dynamics, and trade-offs play out across spatial and temporal scales. Therefore, we propose that we carefully consider *resilience for whom, what, when, where, and why*. These 'five Ws of urban resilience' extend work by scholars who stress the importance of asking resilience 'for whom and of what to what?' (Brown, 2013; Carpenter et al., 2001; Elmqvist, 2014; Vale, 2014). Table 4 provides an initial list of such questions that might be considered in the process of understanding resilience in specific urban areas.

To conclude, let's briefly consider the 5 Ws in relation to the definition proposed. In this definition, resilience is recognized as a desirable state, but who determines what is 'desirable' and for whom? Urban resilience is shaped by who defines the agenda, whose resilience is being prioritized, and who benefits or loses as a result. We have argued in favor of building general adaptive capacity over adapting to specific threats, but priority areas, sectors, and hazards will undoubtedly differ from city to city. Contextual factors also shape the temporal and spatial scales at which urban resilience is applied (Chelleri, Waters, Olazabal, & Minucci, 2015). Thinking through 'resilience for when' entails deciding whether the focus is on short-term disruptions (i.e., storms) or long-term stressors (i.e., climate change) and translating the phrases "rapidly return" or "quickly transform" in the definition to a particular setting. Similarly, 'resilience for where' refers to the challenge of delineating spatial boundaries for an urban system with a complex set of often global networks, and how shifts in one location or at one scale impact those at others. Finally, why is resilience being promoted and what are underlying motivations for doing so? There are no right or easy answers to these questions, but grappling with them collectively through an inclusive and open discourse is fundamental if we hope to forge cities that are indeed resilient.

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Chapter 3 Urban Resilience for whom, what, when, where, and why?[2]

Abstract: In academic and policy discourse, the concept of urban resilience is proliferating. Social theorists, especially human geographers, have rightfully criticized that the underlying politics of resilience have been ignored and stress the importance of asking “resilience of what, to what, and for whom?” This paper calls for careful consideration of not just resilience for whom and what, but also where, when, and why. A three-phase process is introduced to enable these “five Ws” to be negotiated collectively and to engender critical reflection on the politics of urban resilience as plans, initiatives, and projects are conceived, discussed, and implemented. Deployed through the hypothetical case of green infrastructure in Los Angeles, the paper concludes by illustrating how resilience planning trade-offs and decisions affect outcomes over space and time, often with significant implications for equity.

3.1 Introduction

Urbanization processes drive change in the Anthropocene, presenting environmental and social challenges that are unprecedented in scale, scope, and complexity (Seto et al., 2010). Climate change introduces additional uncertainties, placing pressure on local institutions to adapt. To marshal the actors and resources necessary for cities to effectively adjust and sustain key

[2] Published as Meerow, Sara, & Newell, Joshua P. (2016). Urban resilience for whom, what, when, where, and why? *Urban Geography*. http://doi.org/10.1080/02723638.2016.1206395

functions, academics and policymakers are turning to the concept of 'urban resilience' as an organizing principle (Leichenko, 2011). In both the broader academy and public discourse, the concept's growing popularity is evident. Figure 4 illustrates the exponential increase in studies that apply the concept of resilience to cities, a trend especially pronounced in the fields of climate change and hazards (Beilin & Wilkinson, 2015). Policy initiatives related to urban resilience are also proliferating[3] (Vale, 2014).

One of the attractions of the resilience concept is its ability to serve as a "boundary object" (Brand & Jax, 2007) or "bridging concept" (Beichler et al., 2014), thereby allowing multiple knowledge domains to interface. The shared concept of urban resilience, for example, has helped fuse the "climate change adaptation" and "disaster risk reduction" agendas (ARUP, 2014, p. 3), as well as security and sustainability priorities (Coaffee, 2008). But the term's flexibility and inherent inclusiveness has also led to conceptual confusion, especially in relation to like-minded terms, such as sustainability, vulnerability, and adaptation (Elmqvist, 2014). These concepts are all commonly used in urban studies and policy, but in a multitude of ways, including as measurable characteristics, descriptive concepts, metaphors, and modes of thinking or paradigms.

Nevertheless, the theoretical roots of resilience give it a particular focus and connotation that makes a resilience approach related to, but distinct from, sustainability, adaptation, and vulnerability.[4] In the influential ecological and social-ecological systems (SES) resilience literature, systems thinking is pervasive. The focus in this work has traditionally been on

[3] Examples of international resilience policy initiatives include the Rockefeller Foundation's '100 Resilient Cities' campaign, the United Nations Office for Disaster Risk Reduction's (UNISDR) 'Making Cities Resilient' program, and ICLEI's 'Resilient Cities' program.

[4] Why resilience seems to have become more of a buzzword than vulnerability or adaptation is unclear. One explanation is that resilience is more politically tractable than vulnerability or adaptation simply because of its positive connotation (McEvoy et al., 2013; O'Hare & White, 2013; Sudmeier-Rieux, 2014).

quantitative modeling rather than the interactions between individual components and dynamics within the boundaries of a system (Turner, 2014). The most trenchant critiques of resilience scholarship come from social theorists, who take issue with the ways in which ecological models are applied to social structures and the general lack of attentiveness to issues of politics, power, and equity (Cote & Nightingale, 2011; Cretney, 2014; Evans, 2011; MacKinnon & Derickson, 2012; Weichselgartner & Kelman, 2014). These scholars rightfully assert the need to consider questions of "resilience of what to what?" and "resilience for whom?" (Carpenter, Walker, Anderies, & Abel, 2001; Lebel et al., 2006; Vale, 2014), as well as to reflect on scalar and temporal trade-offs (Chelleri, Waters, Olazabal, & Minucci, 2015).

Yet the popularity of resilience, especially in policy discourse, continues to grow. As Weichselgartner and Kelman (2014, p. 6) recognize, "While the academic debate on describing resilience continues, governments around the world have developed plans and programs that aim to guide cities, communities and authorities towards achieving it."

In this paper, we argue that the resilience concept is redeemable. What is missing is a process by which to incorporate these important critiques. The primary objective of this paper, therefore, is to introduce such a process, which can be divided into three phases. The first involves the establishment of urban resilience as a boundary object, in which collaborators share a common definition of resilience and come to a basic agreement on what is 'urban.' The second phase entails critically thinking through resilience for whom, what, when, where, and why. These '5 Ws of urban resilience' shape how resilience is operationalized and mapped over time and space. The third phase then explores urban resilience in empirical contexts. Taken together, this approach engenders a politics of resilience that includes grappling with trade-offs and scalar complexities and delineating how political context and power dynamics shape resilience policies, with inevitable winners and losers.

The next section briefly reviews the origins of the resilience concept and compares it with sustainability, vulnerability, and adaptation. Then section 3.3 introduces the three-phase process designed to foster a politics of urban resilience, detailing in particular the 5 Ws. This is followed by section 3.4, which uses a hypothetical example of green infrastructure planning for the city of Los Angeles to illustrate the ways in which questions of who, what, when, where, and why have wide-ranging implications for communities, institutions, and ecologies. The paper concludes by considering how geographers could enrich urban resilience research.

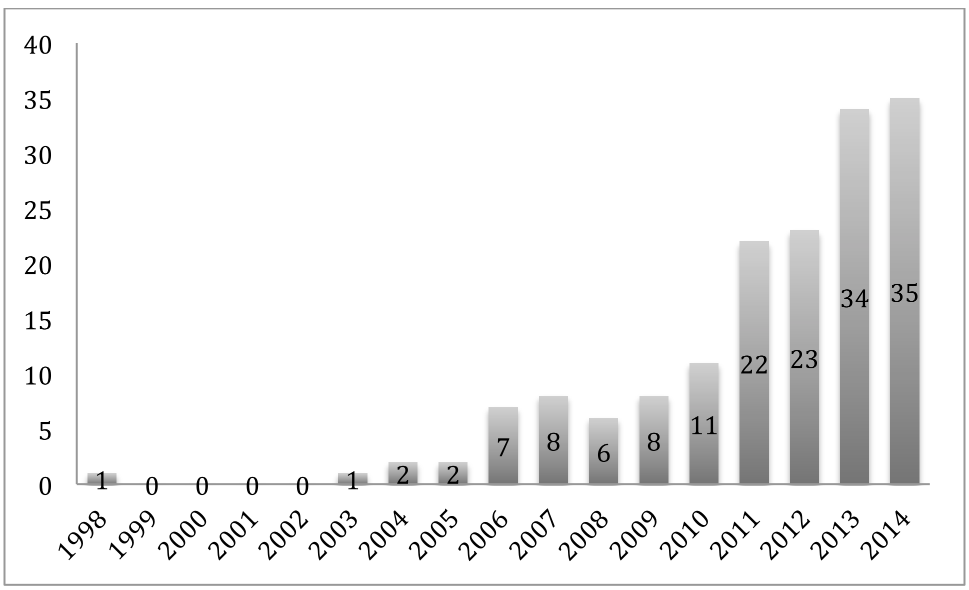

Figure 4 The rapid rise of urban resilience research
A graph showing the number of publications in the Web of Science database for each year from 1998-2014 with the terms "urban resilience", "resilient city" or "resilient cities" in the title, abstract or keywords. *Note:* This may be an underestimate as Web of Science has stronger coverage of the natural sciences and engineering than social sciences.

3.2 The concept of resilience in the literature

Understanding the concept of urban resilience requires knowledge of how resilience theory has developed. Although the term has a long history of use in psychology and engineering, in the global environmental change literature, resilience is commonly traced back to ecologist C.S. Holling (1973) (Brown, 2013; Garschagen, 2013; Meerow & Newell, 2015). Holling defined resilience as an ecosystem's ability to maintain basic functional characteristics in the face of disturbance. Characterizing ecosystems as having multiple stable states and in a constant state of flux, Holling (1996) later distinguished between *static* "engineering" resilience, referring to a system's ability to bounce back to its previous state, and *dynamic* "ecological" resilience, which focuses on maintaining key functions when perturbed.

This ecological framing of resilience and understanding of ecosystems as dynamic, complex, and adaptive was seminal to the development of socio-ecological system (SES) theory, led by a group of interdisciplinary-minded ecologists (Folke, 2006; Gunderson & Holling, 2002). SES theory effectively extended Holling's ecological concepts to the 'social' by conceptualizing nature-society as an intertwined, co-evolving system. In the SES literature, resilience is identified as a product of: 1) the amount of perturbation a system can endure without losing its key functions or changing states; 2) the system's ability to self-organize; and 3) the system's capacity for adaptation and learning (Folke et al., 2002).

The resilience concept has been applied in a wide range of empirical contexts, extending it from a descriptive term (i.e. reflecting how an ecosystem functions) to a normative approach or "way of thinking" (Folke, 2006, p. 260). This approach has become foundational for thinking through how complex systems can persist in the face of uncertainty, disruption, and change (Davoudi et al., 2012; Matyas & Pelling, 2014). Cities have been identified as the "example par excellence of complex systems" (Batty, 2008, p. 769), therefore it is no surprise that resilience theory is increasingly applied in urban studies (Elmqvist, 2014; Leichenko, 2011; Meerow, Newell, & Stults, 2016). In its original, more descriptive form, resilience can be both positive and negative, however, 'resilience thinking' and the concept of 'resilient cities' have emerged as normative, desired goals in both academic and policy arenas (Cote & Nightingale, 2011; Vale, 2014). These different uses of the term have led to a multitude of definitions and confusion about what resilience means and how it relates to other key concepts like sustainability, vulnerability, and adaptation, which we turn to next.

3.2.1 Parsing differences: Resilience, sustainability, adaptation, vulnerability

Conceptually, the relationship between resilience and sustainability is often muddled (Redman, 2014). Sustainability is usually linked to "sustainable development," defined in the Brundtland Report (WCED, 1987) as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Elmqvist, Barnett, & Wilkinson, 2014). In some instances sustainability and resilience are used interchangeably, in others resilience is presented as an important component of broader sustainability goals, and resilience has even been heralded as a new and improved paradigm (Derissen, Quaas, & Baumgärtner, 2011). Leading resilience scholars have generally argued that system resilience is crucial for achieving sustainability in "a world of transformations" (Folke et al., 2002). Thus, as a descriptive concept, resilience does not necessarily conflict with sustainability. Due to different theoretical legacies, however, when conceived as a way of thinking, or as a paradigm of environmental change and management, there are notable distinctions.

In the SES resilience literature, systems exist in a constant state of flux, requiring flexible planning and management (Folke, 2006). In comparison, some resilience thinkers find sustainability management approaches that seek an optimal balance between current and future needs problematically “static” (Cascio, 2009, p. 92). In other words, rather than predicting and planning for a more sustainable future, resilience stresses uncertainty and building systems-based adaptive capacity to unexpected future changes. There are situations in which this conflicts with traditional sustainability goals. Sustainability measures often seek to optimize eco-efficiency, yet research suggests that functional redundancy fosters resilience (Korhonen and Seager, 2008). So, “an efficient optimal state outcome” (Walker & Salt, 2006, p. 9) could conceivably reduce resilience rather than foster it. Similarly, Redman (2014, p. 8) points out that so-called “smart cities” are often presented as more sustainable, yet the increased efficiency and interconnectedness of smart cities suggests “an inflexibility and extreme hypercoherence that resilience theorists have often warned against.”

There are other important differences. Resilience emphasizes systems-based modeling, and relies on SESs as the basic unit of analysis. This can obfuscate inequalities within the system, fail to account for the range of social actors involved, and pay insufficient attention to social dynamics (Bahadur & Tanner, 2014; Leach, 2008).[5] In the sustainability literature, there is a strong emphasis on balancing economic, environmental, and social justice goals (Brand & Jax, 2007). In the resilience scholarship, concepts like social justice and equity receive less attention (Friend & Moench, 2013).

Concern with social equity and political issues also distinguish the vulnerability and adaptation scholarship from the resilience literature. Although all three research domains share an interest in linked human-natural systems and how these SESs cope with disruptions and

[5] Vale (2014) provides a helpful anecdote: In Sri Lanka, poor fishing villages were relocated inland following the 2004 tsunami, and more robust hotel structures built in their place. If the “system” is defined as the entire city, this would seem a positive development, but closer examination reveals that wealthy hotel owners benefitted, while the fishing communities lost their livelihoods.

change, as Miller et al., (2010, p. 6) observe, adaptation and vulnerability research provides a "more politically nuanced understanding of social change and equity." In contrast to work on resilience, constructivist social scientists have heavily influenced the vulnerability and adaptation research (Miller et al., 2010). By focusing on studies of human actors and communities and how the environment poses a threat or provides resources to them, this research also tends to be more anthropocentric than resilience studies (Turner, 2010). While adaptation and vulnerability research is somewhat interconnected, resilience scholarship is more isolated (Janssen, Schoon, Ke, & Börner, 2006). Collaboration between these research communities may be undermined by conceptual confusion. In some instances, as with sustainability and resilience, the terms are used interchangeably. At other times they are inversely related, with resilience seen as the flipside of vulnerability, or even as one determinant of it (Gallopín, 2006).

3.2.2 Theoretical critiques of resilience

A number of geographers and social scientists contend that issues of power, scale, and equity are not given sufficient attention when considering the resilience of socio-ecological systems (Cote & Nightingale, 2011; Cretney, 2014; Evans, 2011; MacKinnon & Derickson, 2012; Pizzo, 2015; Weichselgartner & Kelman, 2014). They are especially concerned with the ramifications of applying ecological models to society, as well as how resilience as a concept is deployed and by whom. In other words, "resilience of what, to what, and for whom?" (Elmqvist, 2014) As a whole, this emerging critical discourse focuses on three shortcomings: 1) a general lack of clarity with respect to meaning; 2) failure to sufficiently address scalar dimensions and trade-offs; and 3) inherent conservatism and the resulting preservation of the status quo.

The concept of resilience is commonly criticized for being too ambiguous and difficult to operationalize or measure (Matyas & Pelling, 2014; Vale, 2014). As resilience is adapted to a wide array of disciplines and policy sectors, there is concern that it may lose meaning and become another "empty signifier," much like sustainability (Weichselgartner & Kelman, 2015).

Depending on how resilience is operationalized, it can lead to spatial and temporal trade-offs and inequitable benefits, but these issues have not been sufficiently scrutinized (Chelleri et al., 2015). Part of the problem has to do with the transference of an ecological concept (i.e. resilient ecosystems) to social systems, at least initially by scholars not especially familiar with complexities associated with studying how society functions (Brown, 2013). For McKinnon and Derickson (2012), resilience approaches oversimplify issues of spatial scale because they tend to view cities or communities as a "self-organizing" unit, akin to an ecosystem, that must protect itself from external threats. This artificially separates them from wider scales and processes. Conceptualizing cities as predictable or generalizable systems has also been criticized as a theoretical regression (Beilin & Wilkinson, 2015), ignoring decades of work on urban interconnectedness and inequality by urban theorists (see for example Brenner & Schmid (2011), Harvey (1996), and Heynen, Kaika, and Swyngedouw (2006)).

For Joseph (2013) and others, the resilience agenda is inherently conservative and tends to perpetuate an unjust status quo (Cretney, 2014; MacKinnon & Derickson, 2012; Walker & Cooper, 2011; Welsh, 2014). By assuming that complex systems naturally go through adaptive cycles of collapse and reorganization, ecological resilience theory "accepts change somewhat passively," often precluding the consideration of the social causes of crises (Evans (2011, p. 224). The onus is placed on individuals or communities to adapt to inevitable disruptions, rather than addressing the underlying causes of these crises (Wamsler, 2014). For some, this resonates with neoliberal efforts to roll back the responsibilities of the state (Joseph, 2013; MacKinnon & Derickson, 2012; Welsh, 2014). As Evans and Reid (2014, p. 1) write, the resilience agenda is an effort on the part of liberal regimes to create a "catastrophic imaginary that promotes insecurity by design." Similarly, Walker and Cooper (2011) attribute the popularity of resilience theory to its ideological fit with the influential complexity theory-based financial system models of Friedrich Hayek.

For MacKinnon and Derickson (2012), a focus on resilience impedes necessary systemic transformation. Indeed, in analyzing the discourse of major international organizations' resilience-building initiatives, Brown (2012) found that resilience supported business as usual. In response, some leading resilience scholars have attempted to integrate transformation into resilience thinking, in addition to recovery and adaptability (see Olsson, Galaz, & Boonstra, (2014) for a discussion). Nevertheless, Mackinnon and Derickson (2012) argue for replacing resilience with "resourcefulness," which they feel better supports social justice by providing marginalized communities with the capacity to transform society and enact their own desired futures.

While critical social scientists may ultimately disagree on the value of the resilience concept, together they highlight the need to examine the underlying politics of resilience. This includes questioning who sets the resilience agenda, how resilience is conceptualized, at what scales it is applied, and who benefits or loses.

3.3 Enabling a politics of urban resilience

This section introduces an iterative three-phase process to facilitate a politics of urban resilience in which knowledge is co-produced by decision makers and researchers and ideally leads to more usable science (Dilling & Lemos, 2011; Jasanoff, 2004) (Figure 5). Phase 1 involves conceptualizing urban resilience as a boundary object based on a shared definition and understanding of what is included in the 'urban system.' In phase 2, questions related to resilience for whom, what, where, when and why are carefully considered. This forms the basis for testing, modeling, and applying urban resilience in empirical contexts (Phase 3), thereby advancing both knowledge and practice.

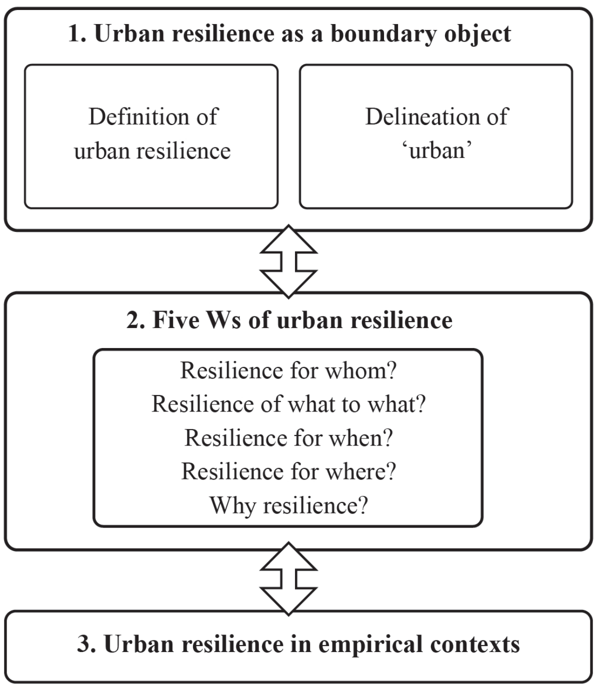

Figure 5 Process for enabling a politics of urban resilience

3.3.1 Urban resilience as a boundary object

The concept of urban resilience serves a valuable function by initiating multidisciplinary dialogue; however, some consensus on both the meaning of 'resilience' and 'urban' provides a stronger basis for collaboration. Thus, in phase 1, an inclusive definition of urban resilience and conceptual schematic of the urban serve as a boundary object, bringing together different stakeholders and disciplines.

A boundary object refers to an object or concept that resonates with different social worlds and as a result, supports scientific collaboration across disciplines (Star & Griesemer, 1989). A boundary object's meaning is somewhat flexible, which allows it to be adapted to the needs of various disciplines and stakeholders. Previous studies have shown that resilience effectively functions as a boundary object or bridging concept (Beichler et al., 2014; Brand & Jax, 2007; Coaffee, 2013). As Vale (2014, p. 198) argues, "the biggest upside to resilience, however, is the opportunity to turn its flexibility to full advantage by taking seriously the actual interconnections among various domains that have embraced the same terminology." While some malleability in the meaning of resilience may foster collaboration, too much ambiguity makes it difficult to operationalize resilience for any specific policy context (Matyas & Pelling, 2014).

Like the broader concept of resilience, urban resilience has become an increasingly popular, but also increasingly vague term (Meerow et al. 2016). This ambiguity hinders effective operationalization, benchmarking and measurement of resilience (Pizzo, 2015). A shared interest in building more resilient cities may bring different disciplines to the table, but conceptual tensions have made consensus on a shared definition elusive (Beichler et al., 2014). Some agreement on a common definition of urban resilience is needed to avoid it becoming an empty signifier (Vale, 2014). Therefore, Meerow et al. (2016) recently proposed the following definition:

> *Urban resilience refers to the ability of an urban system—and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.*

Part of what makes urban resilience so difficult to define is the inherent complexity of cities (Jabareen, 2013). Geographers and urban scholars have long debated what constitutes the 'urban.' Should cities be understood as individual bounded systems or even ecosystems (Pickett et al., 2001), as linked systems of cities (Ernstson et al., 2010), or a complex system of networks (Desouza & Flanery, 2013)? Developing a conceptual model of the urban requires delineating the various political, social, ecological, and technical features of cities as well as complex urban-rural and city-to-city linkages and resource flows. Figure 6 represents Meerow et al.'s (2016) conceptual model of an urban system, which is composed of four interconnected components: 1) governance networks; 2) networked material and energy flows; 3) urban infrastructure and form; and 4) socio-economic dynamics, all of which interact across spatial and temporal scales. A conceptual schematic like this one can help structure meaningful discussions about the complex and multi-scalar components of cities, or what is meant by 'urban' in urban resilience.

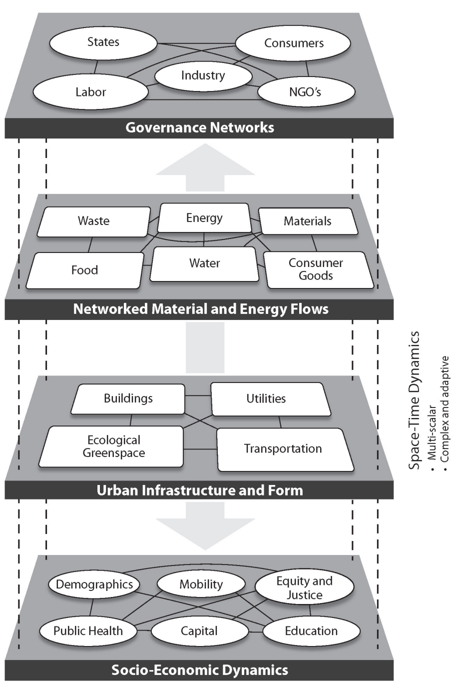

Figure 6 A conceptual schematic of the urban system proposed by Meerow et al. (2016) and inspired by Dicken (2011)

3.3.2 Elaborating the five Ws of urban resilience

Once collaborators have a common interest in, and understanding of, urban resilience, the next phase is to collectively think through questions related to resilience for whom? What? When? Where? And why? (Table 5) These 'five W's' bring the politics of resilience to the forefront by encouraging the explicit recognition of politicized decisions, scalar dimensions, and trade-offs inherent to applying resilience empirically. Who determines the resilience priorities for a city and what are their motivations for doing so? What spatial and temporal scales are included or excluded from the urban system? This section considers these and other questions related to the five Ws and the trade-offs within and between them.

When urban resilience theory is adapted to specific urban contexts, the process and outcome is highly dependent on the system and scales (e.g. temporal, spatial, jurisdictional) being included, and what disturbances or changes the system aims to become resilient to (Cutter et al., 2008; Vale, 2014; Walker & Salt, 2006). Although the resilience literature widely acknowledges that there are likely to be trade-offs in these decisions (Armitage & Johnson, 2006; Bahadur & Tanner, 2014; Fabinyi, 2008; Vale, 2014), as Chelleri et al. (2015, p. 2) note, the "nature and consequences of resilience trade-offs (between and within scales)" are still poorly understood. As the remainder of this section demonstrates, considering potential trade-offs is a crucial step in thinking through each of the five W's (Table 4).

3.3.2.1 Resilience for whom?

Whose vision of a desirable resilient future prevails and who benefits or loses as a result of this particular construct? Urban actors have diverse worldviews and priorities and those with the power to make decisions about how resilience is applied will do so based on their perspective. Adger (2006) and Vale (2014) suggest that they do so based largely on personal short-term interests, rather than for the long-term benefit of the most vulnerable. Who makes the decisions (often at a particular jurisdictional scales) thus shapes whose resilience is prioritized over what time scale (Wagenaar & Wilkinson, 2015).[6]

Table 5 The five Ws of urban resilience

<table>
<tr><th></th><th></th><th>Questions to Consider</th></tr>
<tr><td>Who?</td><td rowspan="5">T
R
A
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F
F
S</td><td>Who determines what is desirable for an urban system?
Whose resilience is prioritized?
Who is included (and excluded) from the urban system?</td></tr>
<tr><td>What?</td><td>What perturbations should the urban system be resilient to?
What networks and sectors are included in the urban system?
Is the focus on generic or specific resilience?</td></tr>
<tr><td>When?</td><td>Is the focus on rapid-onset disturbances or slow-onset changes?
Is the focus on short-term resilience or long-term resilience?
Is the focus on the resilience of present or future generations?</td></tr>
<tr><td>Where?</td><td>Where are the spatial boundaries of the urban system?
Is the resilience of some areas prioritized over others?
Does building resilience in some areas affect resilience elsewhere?</td></tr>
<tr><td>Why?</td><td>What is the goal of building urban resilience?
What are the underlying motivations for building urban resilience?
Is the focus on process or outcome?</td></tr>
</table>

Who is included and excluded from the urban system of focus? Who gets to draw those boundaries? “Who counts as the city?” (Vale, 2014, p. 197) Thinking through questions of resilience for whom entails considering potential trade-offs between stakeholders (Fabinyi, 2008). As Wagenaar and Wilkinson (2013) observed in their case study of Melbourne, planning for resilience is inherently a struggle.

[6] The question of resilience for whom has obvious relevance to non-human actors. As Beilin & Wilkinson (2015, p. 3) write, “We cannot ignore the non-human species encapsulated within the territory of and significantly affected by the ever-expanding urban or its amorphous boundaries.”

3.3.2.2 Resilience of what to what?

Operationalizing resilience requires specifying what will be made resilient to what (Carpenter et al., 2001). Urban policies and interventions vary depending on which disturbance is prioritized (e.g. climate change, natural disasters, terrorism). Enhancing resilience to military attack might require closing off access to important buildings, whereas easier entry could help aid relief efforts post-disaster (Vale, 2014). Which parts of a city's population, infrastructure, or resource flows are going to be made more resilient? This entails revisiting what is included in the urban. Does it include the power plants that provide energy, for instance, if they are located outside the city proper?

A tension often exists between maximizing *specified* resilience to existing threats and *general* capacity to adapt to unanticipated disruptions (Walker & Salt, 2006, p. 121). Wu & Wu (2013) opt for general resilience based on the argument that focusing on specific threats tends to undermine the flexibility and diversity of possible system responses. Research on adaptive capacity, however, has shown that balancing the two is crucial (Eakin, Lemos, & Nelson, 2014). Chelleri and Olazabal (2012, p. 70) illustrate this potential trade-off by noting that an entirely wind-based electricity system might be a positive adaptation to current energy and climate concerns, but a more diverse and flexible energy portfolio (even including some fossil fuels) would increase the ability to adjust to future changes.

3.3.2.3 Resilience for when?

The wind electricity example also draws attention to temporal scale and trade-offs. Is the primary goal to build resilience to short-term disruptions (e.g. hurricanes) or long-term stress (e.g. precipitation changes caused by climate change)? If the focus is on the short-term, then according to Chelleri and Olazabal (2012), the objective is system persistence, whereas a long-term perspective would likely require some degree of transition or transformation. How does building resilience for the current generation impact future ones? Walker and Salt (2006) argue that building long-term general resilience often comes at the expense of short-term efficiency. Another question related to temporal scale is whether resilience interventions focus on anticipating future threats or reacting to past disturbances (Chelleri & Olazabal, 2012; Vale, 2014).

3.3.2.4 Resilience for where?

Cities are inextricably linked to their surrounding regions and globally through commodity, social, economic, political and infrastructure networks (Castells, 2002; da Silva, Kernaghan, & Luque, 2012; Hodson & Marvin, 2010; Seitzinger et al., 2012). The resilience of a city, therefore, necessitates consideration of its relationship to larger networks of flows (Pearson & Pearson, 2014).

SES resilience theory does acknowledge the importance of cross-scalar dynamics (Bahadur & Tanner, 2014; Ernstson et al., 2010). This emphasis is represented in Gunderson and Holling's (2002) influential panarchy model, where "revolt" and "remember" arrows link nested adaptive cycles (Olsson et al., 2014). These arrows indicate that local resilience may be affected by global-scale processes, such as a recession in global financial markets (Armitage & Johnson, 2006). Conversely, local scale transformations can catalyze broader scale change. Nevertheless, in empirical contexts, including urban applications, these scalar dimensions often receive insufficient attention (Chelleri et al., 2015; MacKinnon & Derickson, 2012). As Beilin and Wilkinson (2015, p. 4) note, where the boundary of the urban is delineated "has implications across all levels of management, government and communities." Ideally the city should be conceptualized in terms of urbanization processes that cut across scales. In practice, operationalizing resilience necessitates some limitation of spatial extent, but should at least reflect on the implications of these designations, cross-scalar interactions, and how fostering resilience at one spatial scale affects those at others.

3.3.2.5 Why resilience?

Given the criticism that resilience-based policies are too focused on maintaining the status quo, it becomes crucial to question why urban resilience is being studied or promoted and the ultimate goal of these interventions. Is it to improve adaptive processes generally, achieve a certain outcome, or both? Urban resilience interventions tend to prioritize swift system recovery after a disturbance, but this is not necessarily desired. As Vale (2014, p. 198) writes, "It is all too easy to talk about 'bouncing back to where we were' without asking which 'we' is counted, and without asking whether 'where we were' is a place to which a return is desirable." This connects back to the "who" questions, highlighting the need to understand the political context, decision-making processes, and powerbrokers that define the resilience agenda and to carefully consider underlying motives.

In short, urban plans and interventions must be considered in terms of political context, trade-offs, interconnections, and multiple scales. Thinking through the questions related to who, what, when, where, and why should be followed by empirical research to illuminate how these trade-offs work when resilience is operationalized in a specific context. To illustrate how differences in the five W's shape outcomes, we briefly examine the case of green infrastructure spatial planning.

3.4 Understanding urban resilience in empirical contexts

One strategy cities employ to enhance resilience is to expand green infrastructure, which Benedict and McMahon (2002, p. 12) define as: "An interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations." Based on this definition, green infrastructure includes urban green spaces such as parks, greenways, rain gardens, or green roofs (Wise, 2008). Advocates focus on the multiple social and ecological benefits of green infrastructure, from improved public health to enhanced stormwater retention (Elmqvist et al., 2015; Sussams, Sheate, & Eales, 2015; Tzoulas et al., 2007).

Green infrastructure may be particularly attractive to city officials because it provides a concrete approach for enhancing different aspects of urban resilience (Kearns et al., 2014). Depending on the technology and scale of implementation, green infrastructure can support both short and long-term resilience through its ability to counteract the urban heat island effect, reduce the need for building cooling, reduce storm vulnerability through natural absorption of water, reduce runoff and overflows of untreated stormwater into bodies of water, and even provide a local source of food (Rouse and Bunster-Ossa, 2013). Less clear in the literature are the trade-offs between these benefits and who profits and why (Ernstson, 2013; Hansen & Pauleit, 2014; Lovell & Taylor, 2013).

Like resilience more broadly, planning for multifunctional green infrastructure requires "knowledge that crosses many disciplinary boundaries" (Kearns et al., 2014, p. 55), but getting traditionally siloed departments and agencies to work together is usually difficult (Sussams et al., 2015). Resources for urban green infrastructure (and resilience building generally) are limited, leading to difficult decisions about where to expand it. If managing stormwater is the primary determinant of where to locate new green space, for example, will it also alleviate relative park poverty? These concerns highlight the potential trade-offs between various social and environmental goals and the inherently political nature of green infrastructure planning. Thus, we briefly consider a hypothetical case of green infrastructure planning for the City of Los Angeles (LA), which is the second largest city in the U.S. with a diverse population of 3.8 million living in 468 square miles (U.S. Census, 2010). In recent years, city agencies and nongovernmental organizations have promoted green infrastructure expansion.[7] We present two hypothetical planning scenarios for LA corresponding to two desired resilience benefits, or different responses to questions related to resilience for whom, what, when, where, and why (Table 6). The example shows how these choices would redraw which areas of the city are prioritized and who benefits as a result.

In hypothetical Scenario #1, a municipal department (such as the Los Angeles Department of Public Works) seeks to increase resilience through better stormwater management. In Scenario #2, a non-governmental organization (such as the Trust for Public Land) aims to support community resilience by increasing access to green space. For both scenarios, existing spatial datasets are used to generate indicators for where the particular green infrastructure resilience benefit is needed most. These indicators are then aggregated and compared for each census tract within the city boundary using ArcGIS.

[7] The city has a number of plans and initiatives including the Green Streets program and the Emerald Necklace Forest to Ocean Extended Vision Plan (Goodyear, 2014).

Table 6 Illustrative applications of the 'five W's of urban resilience' to green infrastructure planning

		Scenario 1	Scenario 2
Who?	**TRADEOFFS**	Beneficiaries are city residents living in flood risk zones	Beneficiaries are city residents with most limited access to green space
What?		Specifically focused on stormwater management	Generic community resilience
When?		Focused on current residents and based on current estimates of risk	Both short-term and long-term resilience
Where?		Neighborhoods with the most area in flood hazard zones within the municipal boundaries	Neighborhoods with the lowest average access to green space (parks) within the municipal boundaries
Why?		Goal is an outcome: Flood losses and investments in 'grey' stormwater infrastructure are reduced	Goal is an outcome: increased social justice

3.4.1 Hypothetical scenario #1: Optimizing green infrastructure for stormwater management

The first scenario focuses on the stormwater management benefits of green infrastructure, historically the predominant rationale for its deployment (Newell et al., 2013). The goal is to build resilience through improved stormwater management, and in this case, flood risk maps are used as a spatial indicator for where stormwater is likely to accumulate. Consequently, the chief beneficiaries are residents living in these areas. Priority areas for stormwater management are based on 2008 Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) Flood Insurance Rate Maps (FIRM) for Los Angeles County. High-risk areas (one percent annual chance of flood hazard) and medium-risk areas (0.2 percent annual chance of flood hazard) are merged. The final tract score is a function of the area of this flood hazard layer within (intersecting) the tract.

3.4.2 Hypothetical scenario #2: Optimizing green infrastructure to increase access to green space

Access to green space is associated with many social benefits and increased community resilience, which is why cities like LA may aim to increase social equity with respect to green space access (Tidball & Krasny, 2014; Wolch, Byrne, & Newell, 2014). In this scenario, green infrastructure development is prioritized for neighborhoods that have relative park poverty, as a proxy for access to green space. This scenario thus promotes generic community resilience through more equitable green space distribution. To identify areas of park poverty, we use a GIS dataset containing all the parks in Los Angeles that was generated as part of the 2008 Green Visions Plan (Newell et al., 2008). A quarter-mile buffer is drawn around each park, and this area denoted as accessible park acreage (Wolch, Wilson, & Fehrenbach, 2005). To determine the average amount of accessible park area per person for each census tract, the total accessible park area intersecting each tract is divided by the population living in that tract. The resulting attribute is the basis of the park poverty indicator.

3.4.3 Comparing green infrastructure scenarios

Reflecting on the five Ws (Table 5), the two scenarios generate very different spatial outcomes, providing different benefits to communities in these areas. The motivation (or why question) for the green infrastructure differs, reflecting the interests of the actors setting the agenda. In scenario #1, individuals located in areas of high flood risk are likely to benefit. Scenario #2 would focus green infrastructure development in neighborhoods with smaller park acreage in an effort to address inequalities in access to green space. Concerns related to spatial scale come up in both scenarios. In scenario #1 and #2, the system boundary is the City of LA, thus the residents living within its boundaries would benefit more directly, rather than the larger metropolitan area. Census tracts are the basic unit of analysis, but with an average population of 4000 they are likely heterogeneous, and this variation may not be accurately represented by tract-level data. For example, if there is a large park on one side of a tract, the park poverty score may be low, even if residents on the other side of the tract have no accessible park area.

The scenarios also differ in terms of what is being made resilient to what. The first is aimed at building resilience to a specific challenge (e.g. stormwater management), whereas the second seeks to foster generic community resilience through more equitable distribution of green space. With regard to temporal scale, both are similarly focused on current populations rather to past or future generations. For example, scenario #1 uses current estimates of flood risk, rather than future risk profiles based on long-term climate impacts.

Figure 7 illustrates how different areas of LA would be prioritized for green infrastructure in the two hypothetical scenarios. In both cases, standardized census tract indicator values are divided into 10 quantiles, with a score of 1 representing 'low priority' and 10 'high priority.' The statistically significant negative correlation[8] between the tract values in the two scenarios indicates that spatial trade-offs are involved. If flood risk is the primary determinant, then it may not address other resilience needs. If green infrastructure is only developed in flood hazard zones in LA, environmental justice advocates concerned with park poverty might be less willing to provide support than if it were implemented in their priority areas. One possible solution might be to layer different criteria and identify spatial 'hotspots' (i.e. areas where green infrastructure benefits can be coupled). A wide range of stakeholders could then be asked to weight the importance of the criteria for siting it, and these weights used to develop combined planning scenarios.

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[8] Pearson's correlation coefficient is -0.07, which is significant at $p<0.05$

The scale of analysis (and scale at which planning decisions are made) has implications for what gets prioritized and where. When the scenario scores are aggregated to the LA Council District scale (Figure 8), different trade-off patterns emerge. While a negative relationship still persists between stormwater management and park access, it is no longer statistically significant. When comparing the results of the two scenarios at the scale of the census tract and council district, priority hotspots that appear in the census tract analysis are obscured in the council district analysis.

This brief example provides a basic illustration of how spatial planning based on different resilience benefits, and at different scales, would impact priorities for green infrastructure development. It, therefore, highlights the challenges associated with planning for urban resilience, the likelihood of inherent trade-offs in this process, and the need to critically examine the politics and practices of resilience planning to determine whose priorities are being implemented and at what cost. Every resilience planning or measurement decision is inevitably a political one, with winners and losers, thus resilience needs be operationalized through a collaborative and inclusive process that takes into account varying stakeholder priorities.

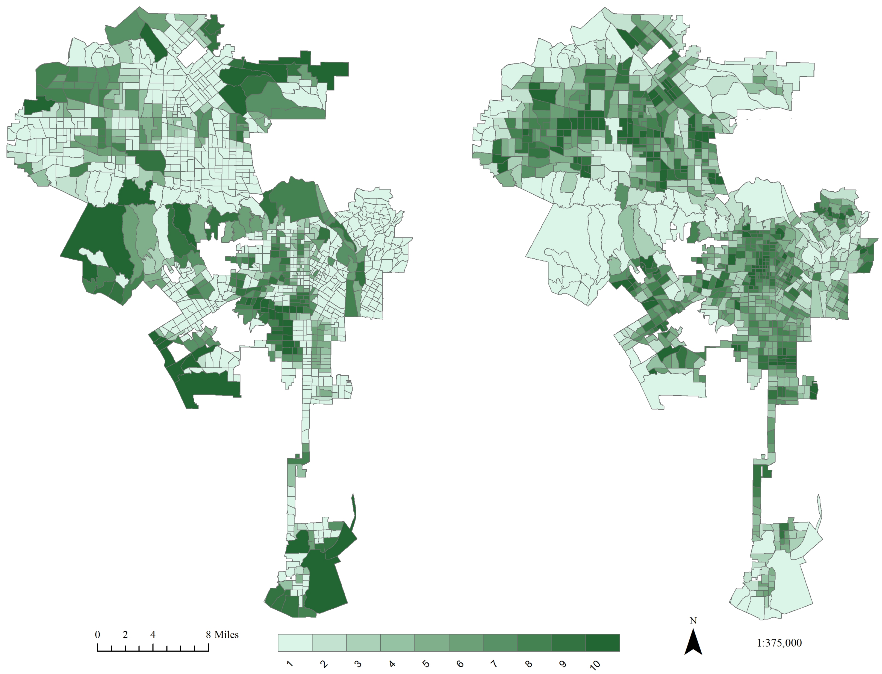

Figure 7 Priority census tracts for green infrastructure development in the City of Los Angeles based stormwater management (left) and access to green space (right)
Note: Maps show standardized census tract scores divided into 10 quantiles. Darker colors indicate higher priority.

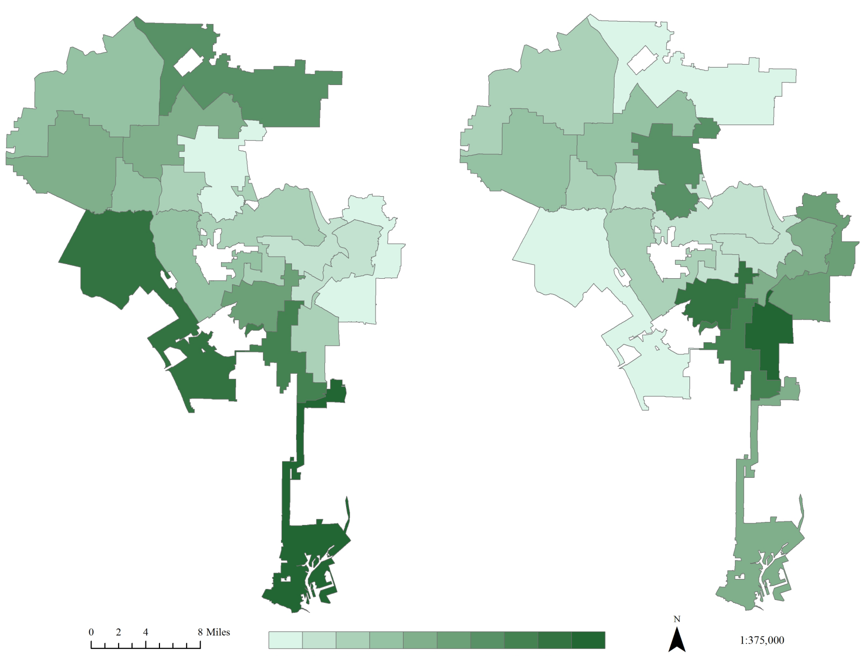

Figure 8 Priority council districts for green infrastructure development in the City of Los Angeles based on stormwater management (left) and access to green space (right)
Note: Standardized tract scores are aggregated at the council district level, and these district scores divided into 10 quantiles. Darker colors indicate higher priority.

3.5 Conclusion

Resilience theory has evolved into an influential global discourse, including for urban research and policy. For some, resilience is eclipsing sustainability, vulnerability, and adaptation as the primary organizing principle for managing the unpredictable and changing futures of socio-ecological systems, including cities. As the popularity of the urban resilience concept grows, it becomes increasingly important to interrogate the ways in which it is used. Social scientists have made significant contributions to this discourse by critically evaluating the term's conceptual ambiguities, conservative tendencies, and underdeveloped usage in social contexts.

The paper introduces a collaborative process for advancing a *politics of urban resilience*, which entails confronting the inherent political and scalar complexities and trade-offs. We have divided this process into three phases: urban resilience as a boundary object, the 5 Ws of urban resilience, and urban resilience in empirical contexts. To highlight trade-offs and policy implications related to the 5 Ws and the politics of urban resilience, we provided two potential scenarios of green infrastructure spatial planning in Los Angeles. This brief example illustrated how prioritizing one resilience benefit of green infrastructure (e.g. stormwater abatement) over another (e.g. alleviating park poverty) could lead to markedly different spatial priorities, with implications for a city's ecology and socio-economic fabric. This suggests a need for future research to scrutinize resilience-building planning decisions and the ways in which different models of decision-making affect outcomes.

Critical human geographers were among the first scholars to interrogate the growing influence of resilience discourse, contributing to a richer understanding of the concept's limitations. This provides a foundation for additional investigations into, for example, issues of power and how disparities might impact even the most collaborative resilience decision-making, which has been understudied in the resilience literature (Olsson et al., 2014). Urban political ecologists could contribute by continuing to ask "questions about who produces what kind of social-ecological configurations for whom" (Heynen, Kaika, & Swyngedouw, 2006, p. 2). The urban resilience literature needs a more nuanced appreciation for what defines the 'city' or 'urban', as well as attentiveness to scalar dimensions. Finally, geographers can continue to provide empirically rich place-based research that advances our understanding of what resilience means and how it is applied in different urban contexts**.**

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Chapter 4 Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit[9]

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

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[9] Published as Meerow, Sara, & Newell, Joshua P. (2017). Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landscape and Urban Planning*, *159*, 62–75. http://doi.org/10.1016/j.landurbplan.2016.10.005

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.

4.1 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 (Meerow, Newell, & Stults, 2016). As with sustainability, planning for resilience is contested and political (Chelleri, Waters, Olazabal, & Minucci, 2015; Davoudi et al., 2012).

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 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 (Newell et al., 2013; Kremer et al., 2016). 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 impacts, 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 4.3 introduces the GISP model methodology and the data sources used to apply it to Detroit. Section 4.4 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 4.5, 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 offer 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.

4.2 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 & 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 and 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, et al., 2010, p. 8).

4.2.1 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) reduced social vulnerability; 4) greater access to green space; and 5) increased landscape connectivity connectivity (Table 7). These ecosystem service benefits serve as the criterion indicators for the GISP model and so are briefly summarized here.

Ambient air pollution annually leads to an estimated 3.7 million premature deaths and is especially acute in urban areas (World Health Organization, 2014). Green infrastructure and vegetation improves air quality by reducing nitrogen dioxide, particulate matter (Pugh, Mackenzie, Whyatt, & Hewitt, 2012) and ozone levels (Taha, 1996). Street trees are also positively correlated with lower child asthma rates (Lovasi, Quinn, Neckerman, Perzanowski, & Rundle, 2008).

By cooling the immediate surrounding through the shading of buildings and other surfaces, vegetation can ameliorate the urban heat island (UHI) effect (Tzoulas et al., 2007). Impervious surfaces in urban areas are 2 °C warmer on average in the summer (Bounoua et al., 2015) and increasing urban tree canopy can reduce air temperatures by 1–3 °C (O'Neill et al., 2009). Health impacts due to UHI are also projected to become more severe with climate change (Stone, 2012).

Green infrastructure can build community resilience by reducing social vulnerability, the incapacity of residents to deal with environmental hazards (Cutter, 1996). The factors that shape vulnerability are complex and difficult to quantify. Studies have, however, linked increased vegetation to a variety of social benefits that would likely influence or interact with social vulnerability including: lower crime rates (Kuo & Sullivan, 2001); increased feelings of social safety (Maas, Spreeuwenberg, et al., 2009); better health (Kardan et al., 2015), especially for women and the elderly (Takano, Nakamura, & Watanabe, 2002; Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003); better mental health (Alcock, White, Wheeler, Fleming, & Depledge, 2014) and reduced stress (Ward Thompson et al., 2012); and increased social capital (Maas, Dillen, Verheij, & Groenewegen, 2009; Rung, Broyles, Mowen, Gustat, & Sothern, 2011).

It is especially problematic, therefore, that low-income and minority communities have less green space per capita, both in terms of access and total area (Heynen, 2006; Wolch, Wilson, & Fehrenbach, 2005). This relative park poverty is an environmental injustice (Jennings, Gaither, & Gragg, 2012; Wolch, Byrne, & Newell, 2014). Strategically siting future green infrastructure could reduce these inequities (Dunn, 2010) provided such efforts do not lead to "green" gentrification and negatively impact the very communities these efforts were designed to assist (Wolch et al., 2014).

Finally, some forms of green infrastructure can benefit the ecological matrix of urban areas. Due to urbanization processes and sprawl, this urban landscape is often highly fragmented, or composed of a series of isolated patches (Ahern, 2011). Reduced habitat connectivity (i.e., fragmentation) usually results in fewer ecosystem services (Mitchell, Bennett, & Gonzalez, 2013). By connecting fragmented patches, green infrastructure can be sited to form contiguous ribbons of urban green space. This connectivity has positive implications, especially for biological diversity (Kong, Yin, Nakagoshi, & Zong, 2010). Landscape ecology focuses on two types of connectivity: 1) structural, or the spatial configuration of habitat patches; and 2) functional, which takes into account the behaviors of various species (Tischendorf & Fahrig, 2000). With regard to planning for structural connectivity, Colding (2007, p. 46) argues for "ecological land-use complementation," or the clustering of urban green space "to increase available habitats for species, to promote landscape complementation/supplementation functions, and to nurture key ecosystem processes essential for the support of biodiversity." But different actors govern green space differently, which makes landscape-scale planning challenging, both politically and institutionally (Ernstson, Barthel, & Andersson, 2010).

4.2.2 The challenges of green infrastructure planning and Detroit

Evidence suggests that from a stormwater abatement perspective green infrastructure can be comparable, and in some instances superior, to gray infrastructure in terms of performance and cost (Jaffe, Zellner, & Minor, 2010; Casal-Campos et al., 2015). But it is the other co-benefits that really "tip the scale" in its favor (Palmer et al., 2015). To date, however, cities and their respective government agencies have not fully accounted for the multiple ecosystem services that green infrastructure provides, including tradeoffs and synergies between these services (Elmqvist et al., 2016; Hansen & Pauleit, 2014; Lovell & Taylor, 2013; Madureira & Andresen, 2013; Snäll, Lehtomäki, Arponen, Elith, & Moilanen, 2015). Part of this is due to the planning silos that persist in cities, making it difficult to bring together different departments and groups (Kambites & Owen, 2006; Thorne et al., 2015). For this reason, Larsen (2015, p. 488) has called for a new "green infrastructure utility" focused on providing multiple ecosystem services. Transcending these barriers is critical as green infrastructure functions are highly local, with a limited "service benefit area" (Hansen & Pauleit, 2014). Where green infrastructure gets sited, therefore, determines who and what reaps these benefits (Authors, 2016). Despite the obvious implications for environmental and social justice and the acknowledgement that spatial planning decisions – particularly those related to sustainability– are invariably based on conflicting criteria and priorities (Campbell, 1996), we lack fundamental knowledge of whether green infrastructure developments are equitably distributed *across* cities (Brink et al., 2016).

Detroit is one city where green infrastructure has emerged as a planning priority, making it an interesting, timely, and appropriate case study city to examine and improve these processes (Schilling & Logan, 2008). For decades, the loss of manufacturing, population decline, weak tax revenue base, and social strife have plagued the city. It has one of the nation's highest rates of property vacancy, with over 40 square miles of vacant residential, commercial, and industrial land (Figure 9). This represents almost one in four of Detroit's properties and totals approximately 100,000 properties—nearly 20% of the city's total land area (Dewar, 2006). The city is also grappling with increasingly intense and frequent precipitation events due to climate change (Karl, Melillo, & Peterson, 2009).

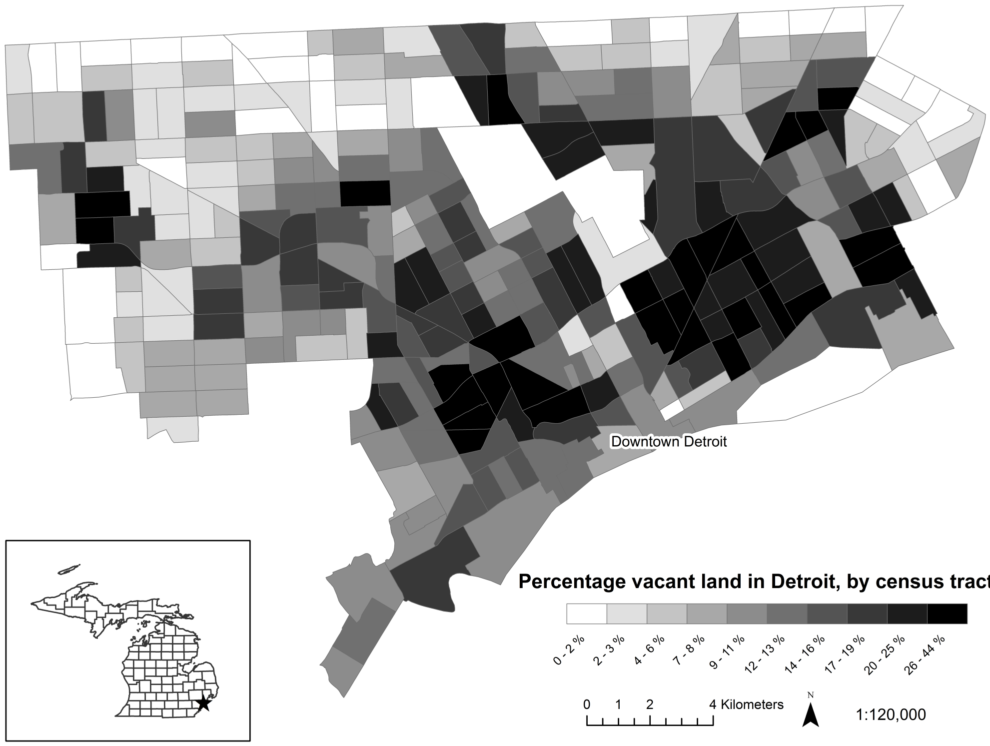

Figure 9 Vacant land in Detroit neighborhoods, as a percent of total census tract area
Note: The map shows the percent of the total area of each 2010 census tract made up of vacant parcels with no structure (Motor City Mapping, 2014).

The abundant underutilized land in Detroit presents opportunities for transformation and urban redevelopment, if appropriate strategies and policies can be put in place (Herrmann et al., 2016). In the late 1990s, green infrastructure emerged as a revitalization strategy for the city, beginning with the transformation of abandoned rail infrastructure into greenways (Gallagher, 2010). Green infrastructure projects are being planned and implemented by city and regional agencies, non-profit organizations (NGO), and private entities. The most significant player thus far is the Detroit Water and Sewerage Department (DWSD), a public utility that provides services to the city and administers a sprawling water-sewage infrastructure to communities across seven counties. Facing increasingly strict EPA water regulations and the need to reduce flows into its combined sewer system, DWSD has invested in bioretention, green streets, and tree planting projects (DWSD, 2015). For similar reasons, the NGO Greening of Detroit is planting trees in many parts of the city, often in partnership with DWSD. To catalyze community redevelopment in particularly hard-hit areas of the city, green infrastructure projects are also being implemented in the Lower East Side of Detroit through the EPA-funded Great Lakes Restoration Initiative (GLRI). Figure 10 presents the locations of these major green infrastructure initiatives. Additionally, private actors are also engaged in greening initiatives. For example, Hantz Woodlands, to the alarm of community groups, purchased a large block of consolidated land parcels in the lower eastside from the city and planted trees ostensibly for future harvest (Safransky, 2014).

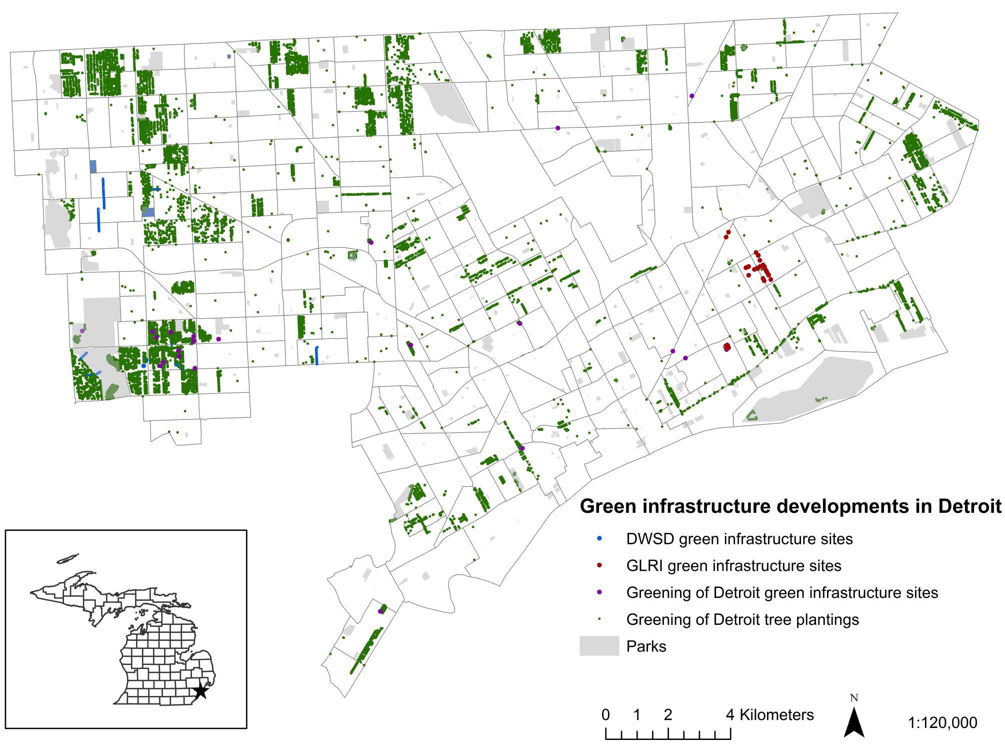

Figure 10 Locations of major green infrastructure projects across the city of Detroit
Note: Data on Detroit Water and Sewerage Department (DWSD) sites from Tetra Tech (2016); Great Lakes Restoration Initiative (GLRI) sites from Detroit Future City (2016); and greening and tree planting data from Greening of Detroit (2016).

But are these projects being planned and sited in locations that enhance multiple aspects of urban sustainability and resilience? Or are they being sited haphazardly, opportunistically, and for the purpose of one benefit, such as stormwater, rather than a suite of potential ecosystem service benefits (e.g., improved air quality, access to green space, habitat connectivity)?

To answer these questions and to identify spatial tradeoffs, synergies, and areas in Detroit where green infrastructure could be strategically sited to maximize *multifunctionality*, we developed an integrated stakeholder-driven modeling approach called the Green Infrastructure Spatial Planning (GISP) model.

4.3 Methods: Green Infrastructure Spatial Planning (GISP) model

The GISP model is GIS-based and uses a spatial multi-criteria evaluation (MCE) framework that incorporates stakeholder priorities so the results serve as collaborative decision-support tools (Jankowski & Nyerges, 2001). GIS-based or spatial MCE models allow stakeholders – defined broadly as "the individuals who affect or are affected by certain decisions and actions" (Freeman 1984 in Prell et al. 2009, p. 515) – to visualize the implications of their preferences and identify tradeoffs in policy goals (Malczewski, 2006). For this reason, MCE has been referred to as an "institution in action" to build support for sustainable and resilient solutions (De Brucker, MacHaris, & Verbeke, 2013, p. 122).

Although multifunctional green infrastructure planning needs to consider stakeholder preferences (Hansen & Pauleit, 2014), relatively few studies use a GIS-based MCE approach to do so. Kremer et al. (2016) apply spatial MCE to evaluate the distribution of ecosystem services across New York City as a means to identify priority areas for green infrastructure. They demonstrate the potential impact of different weighting schemes, but do not use stakeholder-derived weights. Madureira and Andreson (2013) identify "spatial priority areas" for green infrastructure in Porto, Portugal, but based on just two criteria: 1) access to green space and 2) potential to reduce the UHI effect. They also do not incorporate stakeholder input to weight these criteria. Similarly, Norton et al. (2015) identify priority areas within the City of Port Phillip in Melbourne, Australia on the basis of the cooling benefits of green infrastructure. Conine, Xiang, Young, and Whitley (2004) do use stakeholder-derived weights in their GIS analysis to identify potential greenway sites in Concord, North Carolina, but do not consider tradeoffs or benefits of this green infrastructure. Recent work by Hoang et al. (2016) introduces a helpful methodology and tool to examine spatial benefit tradeoffs and synergies of specific green infrastructure interventions designed to manage urban flooding. However, they do not integrate stakeholder weights or use the model to identify priority areas across the entire city. Therefore, the GISP approach advances spatial MCE modeling for green infrastructure by integrating an array of ecosystem services and local stakeholder priorities and by assessing tradeoffs and synergies to facilitate equitable distribution and leverage co-benefits.

4.3.1 Six ecosystem benefit criteria

The six benefit criteria, or ecosystem services, described in section 4.2 serve as the foundation of the GISP model (Table 7). The scale of analysis is the 2010 U.S. census tract, the smallest spatial unit for which data were readily available for all criteria. To make the GISP model generalizable for other cities, we used publicly available pre-processed data, or that readily obtainable from stakeholders. We applied a linear scale transformation ("maximum score") to measurement scales so all criterion scores ranged from zero to one (Malczewski, 1999).

To assess synergy and tradeoff patterns, we used Pearson's bivariate correlations for all census tracts in Detroit (N=296) to test relationships between the criteria scores. Results were cross-checked with Spearman's rank correlations and tradeoff patterns were consistent. Using ESRI's ArcGIS Online and Story Maps applications, we then integrated the individual and combined criteria maps into a web-based interface. The selection rationale, data sources, limitations, and processing steps for the six benefit criteria are as follows:

4.3.1.1 Stormwater

To identify areas prioritized based on stormwater management concerns, we combined two indicators: 1) an estimated runoff coefficient using the Rational Method, originally proposed by Mulvany in 1850 (O'Loughlin, Huber, & Chocat, 1996); and 2) CSO waste water discharges (location and volume). The runoff coefficient was calculated using a modified land use layer based on high-resolution parcel-level land use data (SEMCOG, 2008) and data on vacant (no structure) parcels (Motor City Mapping, 2014). Using the rational method, we estimated a relative runoff coefficient for each census tract by first assigning each land-use category in the land use layer a runoff coefficient (Appendix 4.1, Table 9), and then multiplied these coefficients by the area of that land-use classification within each tract. Obtaining coefficients from the literature (Strom, Nathan, & Woland, 2009), we validated them by consulting a Detroit-based stormwater expert (personal communication, February 5, 2016). For each census tract, we summed the results of each land-use category and then divided it by the total tract area.
For the CSO indicator, we summed the total diluted raw sewage released at all discharge locations (2008–2014) within each census tract. This indicator was then standardized (0-1). Census tracts with no discharge locations received a score of 0. We then added the standardized

scores for both the runoff coefficient and the CSO indicator and rescaled the combined score from 0 to 1.

Table 7 Green Infrastructure Spatial Planning (GISP) model criteria and data sources

Resilience planning priority	Ecosystem service category	Criterion	Spatial attributes (Indicator)	Data sources for Detroit
Managing stormwater	Regulating; provisioning	Stormwater hazard	Average runoff coefficients based on Rational Method and CSO outfall location data	SEMCOG parcel-level land use layer (2008); Motor City Mapping (no structure) parcel layer (2015); Detroit Water & Sewerage waste water discharge event location data (2008–2014) (Data Driven Detroit, 2015)
Reducing social vulnerability	Cultural	Social Vulnerability Index (SoVI)	Combination of indicators shown to correlate with social vulnerability to natural hazards	SoVI data for 2010 created by the Hazards and Vulnerability Research Institute, University of South Carolina (Hazards and Vulnerability Research Institute, 2015)
Increasing access to green space	Cultural	Lack of access to parks	Estimate of tract population without access to parks	Parcels within a 10-minute walk of a park (SEMCOG, 2016); City of Detroit parcels (2015)
Reducing the urban heat island effect	Regulating	Land surface temperature	Average land surface temperature	Estimate of average daytime surface temperatures per census tract from MODIS for June, July, & August 2010 (Burillo et al., 2015)
Improving air quality	Regulating	Severity of air pollution	Particulate matter ($PM_{2.5}$) emissions	High-resolution traffic-related air pollution estimates (Batterman & Ganguly, 2013)
Increasing landscape connectivity	Supporting	Patch Cohesion Index	Physical connectedness of wildlife habitat (forest cover) within spatial unit	Southeast Michigan Council of Governments (SEMCOG) land cover layer (2010)

4.3.1.2 Social vulnerability

Social vulnerability is challenging to measure, with various methods of assessing and mapping it (Cutter et al., 2008; Dunning & Durden, 2013). We used the Social Vulnerability Index (SoVI) created by Cutter and colleagues (2003). Freely available to many states through NOAA and other sources, SoVI is arguably the most well established and widely used methodology (Dunning & Durden, 2013). SoVI is a composite index of 27 socio-economic and demographic variables that research has shown relate to susceptibility to natural hazards, but 11 of the variables (including wealth, age, density of the built environment, housing, and race) account for more than 75 percent of variance between U.S. counties. The SoVI version used in the GISP model compares census tract scores for the 27-variable index across Detroit (Hazards and Vulnerability Research Group, 2015).

4.3.1.3 Access to green space

For access to green space, the available indicator was relative 'park poverty.' Spatial data on all city parcels within a 10-minute walk of a park (SEMCOG, 2016) served as the basis of analysis. To generate this dataset, which entailed calculating all parcels within a half mile of park entry points along the walkable road network (excluding non-walkable features such as highways, highway ramps), SEMCOG used the Pandas for Network Analysis (Pandana) extension in UrbanSim (Waddell, 2002). To calculate the percentage of the total area in each census tract falling outside of the 10-minute walking distance, we compared this SEMCOG dataset with a city-wide parcel layer (City of Detroit, 2015) and census tract information. We then multiplied this percentage by the total tract population (2010 Census), resulting in an estimate of the population without park access for each tract. It does not account for variations in park size or quality, however, which is a limitation. This methodology is similar to that used by Wolch et al. (2005), but differs in that rather than a simple buffer distances along the walkable road network are used.

4.3.1.4 Urban heat island

To map the UHI, the mean daytime land surface temperature for three summer months (June–August 2010) were calculated for each census tract. Burillo, Chester, Chang, & Thau et al. (2015) derived temperatures using Moderate Resolution Imaging Spectrometer (MODIS) sensor data and the Google Earth Engine API. For validation, we compared census tract scores with percent impervious surface in each tract, a proven indicator of the UHI effect (Yuan & Bauer, 2007). They were significantly positively correlated (.53, $p<0.00$).

4.3.1.5 Air quality

A high-resolution spatial air pollution model based on traffic-related emissions, developed by Batterman and Ganguly (2013), was the data source for air quality. We used the model's simulated annual average emissions of particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$) for 2010. We focused on $PM_{2.5}$ because the World Health Organization (2013) has concluded that long-term exposure to $PM_{2.5}$ has a higher mortality risk than PM_{10} (World Health Organization, 2013). As the air quality model uses a 150 square meter grid, for those instances where the grid did not align with census tract boundaries, we used the mean of all intersecting grid cells.

4.3.1.6 Landscape connectivity

The GISP model uses metrics related to the structural connectivity of the landscape, which relates to the impact of habitat structure on biodiversity (Itkonen, Viinikka, Heikinheimo, & Kopperoinen, 2015). We used the Patch Cohesion Index metric in Fragstats, a free software used to measure physical connectedness of habitat patches (McGarigal et al. 2012[10]).

Areas classified as 'forest' in the land cover dataset (2010) served as representative patches based on the assumption that this land cover type would provide habitat for the largest number of species in the Detroit region. Even if green infrastructure development does not all focus on reforestation, Colding's (2007) theory of "ecological land-use complementation" suggests that it would still be beneficial to cluster new vegetation near existing forest patches.

We used Geospatial Modeling Environment (Bayer, 2014) software to convert the forest polygons from vector to raster cells so Fragstats could analyze them individually. This does make the results subject to edge effects, since each tract is analyzed in isolation. Tracts were then analyzed as a batch to generate a Patch Cohesion Index score for each tract.

4.3.2 Local stakeholder priorities

After constructing maps for the six indicators, we held a meeting with 23 expert stakeholders in Detroit representing government agencies, local and national nonprofits, and community development organizations (Appendix 4.2, Table 10). Stakeholders were selected in consultation with local contacts on the basis of their expertise and leadership in green infrastructure and urban development issues in Detroit. At the meeting, these stakeholders

[10] FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

weighted the model criteria based on which green infrastructure benefits they valued most by completing a survey asking them to compare the importance of the six benefit criteria using three methods: rating, ranking, and pair-wise comparisons. Stakeholders also provided feedback on the data sources and criteria used in the model and its broader utility as part of an open discussion at the meeting. We audio recorded the meeting for subsequent review. Stakeholders were also subsequently asked via email to provide anonymous feedback on both the model and meeting. They were also given the opportunity to review a draft of this paper prior to publication.

We used the ESRI Story Maps application to present the individual criteria and aggregated results based on different weights from the stakeholders' ranking and pair-wise comparison survey results. For the latter, we used an Excel-based AHP calculator (Goepel, 2013). We then used weighted linear combination to develop combined maps from the two sets of weights to identify 'hotspots' or priority neighborhoods for green infrastructure expansion. As distribution of scores differed significantly across the criteria, individual criterion scores were first divided into 10 quantiles before applying weights and combining them.

4.3.3 Mapping existing projects in Detroit

To generate a map of major public green infrastructure projects underway or planned in Detroit (Figure 10), we included current projects supported or implemented by 2016 by the DWSD, Greening of Detroit, and the Great Lakes Restoration Initiative (Greening of Detroit, 2016; Detroit Future City, 2016; Tetra Tech, 2016). Although no comprehensive map of all green infrastructure projects for the city exists yet, these projects were identified by city stakeholders as the major public ones. We then calculated the total number of individual locations that intersected with each census tract in the City of Detroit. Some projects are more spatially extensive than others (e.g. parks vs. tree planting), but as we only had data on the locations, we counted them all equally. We then compared these sites with those identified as priority areas for green infrastructure by the GISP model by running Pearson's correlations between the number of sites in each census tract and the GISP model scores (individual criteria and combined and stakeholder-weighted results). We also ran correlations at the census tract level between vacant land and the green infrastructure sites, based on the rationale that vacancy and blight in some neighborhoods may provide an added incentive and opportunity for green infrastructure development.

4.4 Results: Green infrastructure tradeoffs, synergies, and hotspots

Applying the GISP model to the city of Detroit reveals that some areas have a greater need for green infrastructure interventions than other parts of the city, and that these locations differ by ecosystem service. Areas that would be high priority for stormwater abatement, for example, are generally not best suited for maximizing landscape connectivity. Priority locations for other resilience benefits, including addressing stormwater, urban heat island, and air quality problems, appear more synergistic, but a strategic planning process is still needed in order to capitalize on these synergies and manage trade-offs. Unfortunately, such a process seems to be lacking in Detroit, as the locations of current green infrastructure projects across the city do not align with most of the priority areas identified with the GISP model. For example, Detroit stakeholders claimed that reducing social vulnerability was an important benefit of green infrastructure (second only to stormwater abatement), yet projects have not been sited in areas where residents are most vulnerable according to the SoVI. By combining different planning criteria and weighting them according to local stakeholders' priorities, the GISP model could enable planners to identify ‘hotspots’ where green infrastructure has the greatest potential to foster social and ecological resilience.

Tradeoffs between the six resilience benefits considered in the GISP model are evident spatially (Figure 11) and through negative correlations. We see a statistically significant negative relationship between stormwater and landscape connectivity criteria (Figure 12). Thus, restoring the urban ecological fabric by siting green infrastructure near more interconnected forest habitat patches would not place it in ideal locations to abate stormwater, and vice versa. Landscape connectivity is also negatively correlated with UHI and air quality, which is not surprising given that vegetation is thought to contribute to cooler local temperatures and less air pollution (Larsen, 2015). These spatial tradeoffs reveal that *multifunctionality* across all benefits can be an elusive goal and underscores the fact that planning for green infrastructure is a contested and political process, in which tradeoffs have to be understood and negotiated. This is reflective of sustainability and resilience planning more broadly.

The GISP model also reveals potential spatial synergies across the Detroit landscape where green infrastructure can enhance resilience. Positive correlations are statistically significant for stormwater, UHI, and air quality. Thus, even if stormwater concerns drive siting decisions, green infrastructure will also be located in areas that suffer from urban heat island and air quality impacts. Areas of high social vulnerability are also areas that suffer from heat island impacts, which is concerning since vulnerable communities are less able to cope with extreme heat events (O’Neill et al., 2009). Given that UHI and air quality criteria are also positively correlated, public health concerns seem to be co-located, at least in Detroit. Prior research has also shown a negative interaction between poor air quality and mortality due to extreme heat

(Harlan & Ruddell, 2011). This may provide an added incentive to locate green infrastructure in these areas, especially with rising global temperatures.

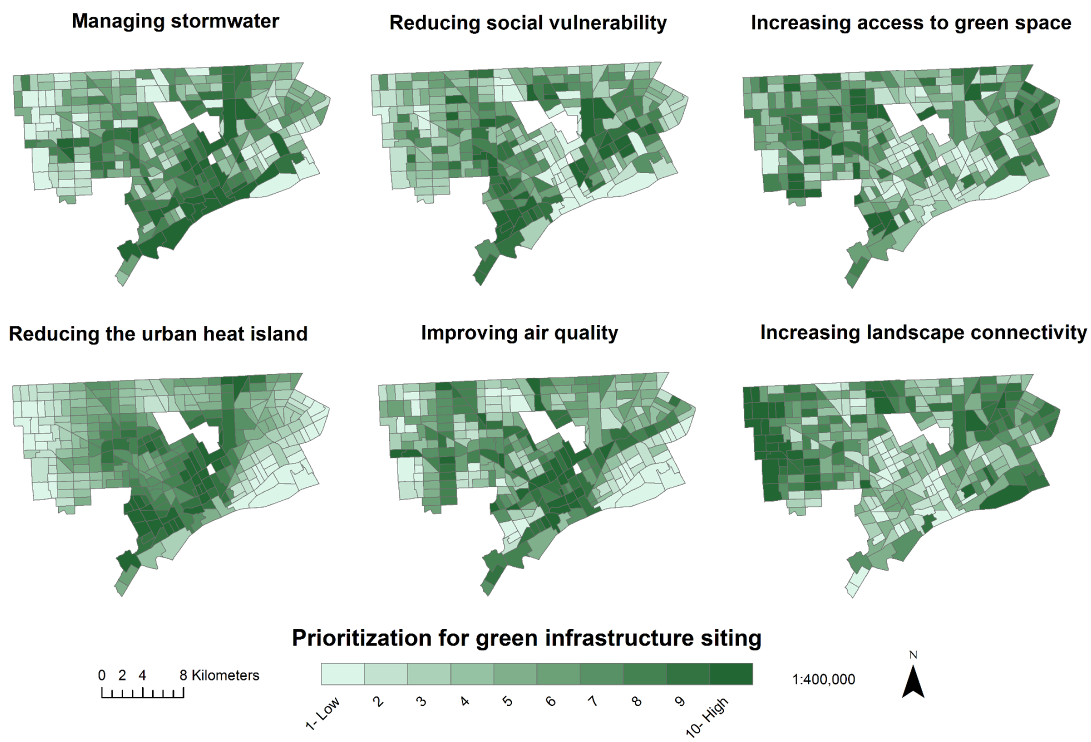

Figure 11 Green Infrastructure Spatial Planning (GISP) model criteria
Note: Each map shows the relative prioritization of census tracts in Detroit for green infrastructure based on a commonly cited green infrastructure benefits

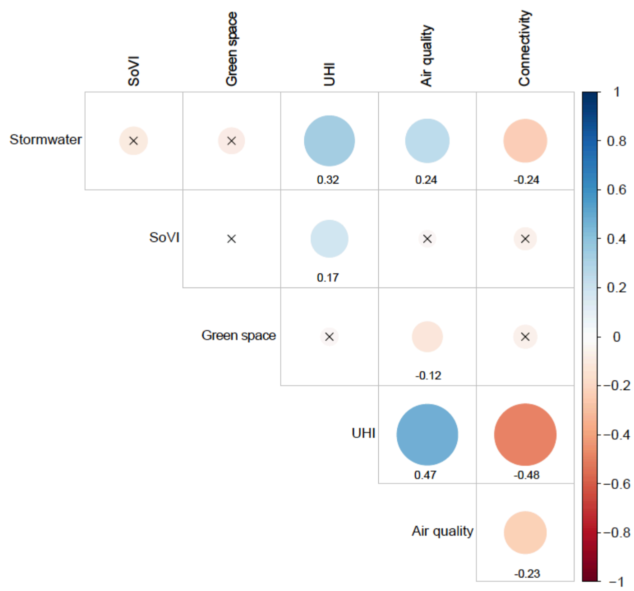

Figure 12 Spatial trade-offs and synergies between GISP model criteria
Note: The larger the diameter and shading of circles depict the Pearson's correlation coefficient for GISP model criteria. A larger circle indicates a stronger negative (dark) or positive (light) relationship. Circles marked with an "X" are not statistically significant.

Table 8 Detroit stakeholder survey results

Method	**1-storm water**	**2-SoVI**	**3-park access**	**4-UHI**	**5-Air quality**	**6-connect-ivity**
Rating						
Order	**1**	**2**	**3**	**6**	**4**	**5**
Mean rating	4.61	4.39	4.18	3.70	4.17	3.78
Standard Deviation	0.66	0.71	0.83	0.91	0.87	1.02
Ranking						
Order	**1**	**2**	**4**	**6**	**3**	**5**
Mean ranking	1.79	3.11	3.53	5.00	3.42	4.16
Standard Deviation	1.18	1.20	1.50	1.20	1.64	1.77
Pair-wise comparisons						
Order	**1**	**3**	**4**	**6**	**2**	**5**

In light of citywide tradeoff and synergy patterns, it is helpful to identify specific high priority 'hotspots' (through the spatial overlay of all six criteria using linear combination) where green infrastructure is most needed in Detroit. As illustrated in Figure 14, these hotspots shift slightly based on whether criteria are weighted equally or stakeholders' priorities are taken into account. However some areas, such as the southwest part of Detroit, do consistently appear as high priority for multifunctional green infrastructure. The Detroit expert stakeholders identified stormwater as the most important priority, based on survey results (Table 8) and the weights derived from them (Figure 13).

Reducing social vulnerability, increasing access to green space, and improving air quality were regarded as the next most important criteria. The ranking among these criteria shifted based on weighting method. The mean rating and ranking values suggest that social vulnerability was slightly higher priority than the other two, but all three are close. The landscape connectivity criterion came out fifth out of the six criteria in terms of importance. UHI amelioration was the lowest priority (ranked 6th in all three survey questions). Although beyond the scope of this study, examining how expert stakeholder priorities compare with Detroit residents' at large would be interesting.

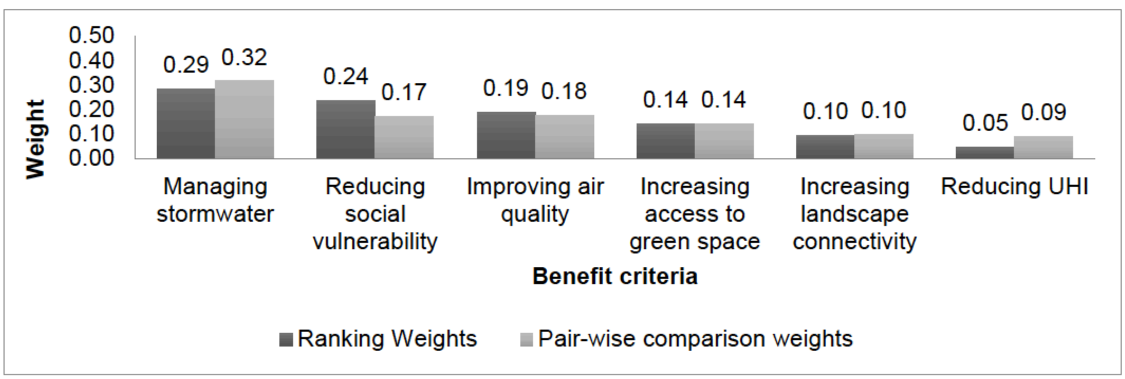

Figure 13 Stakeholder priorities for green infrastructure in Detroit, by benefit category

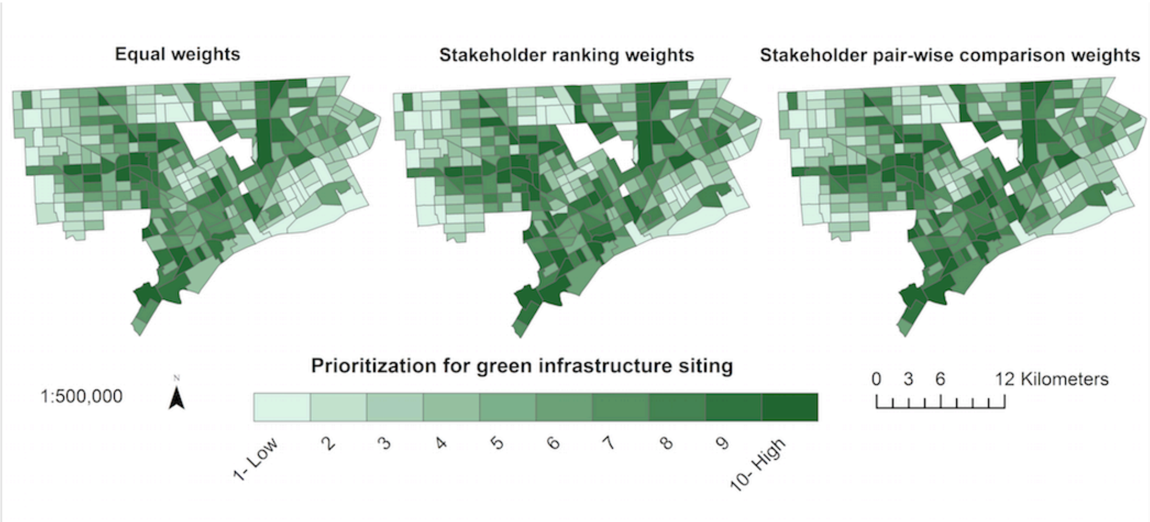

Figure 14 Combined criteria using different weighting methods

4.4.1 Assessment of green infrastructure project siting in Detroit

So how do current and planned green infrastructure projects in Detroit align with the siting hotspots identified by the GISP modeling? Figure 2 shows green infrastructure sites across the city, with projects by DWSD, Greening of Detroit, and the Great Lakes Restoration Initiative represented. Statistical analysis (Figure 7) reveals that across the city, at a census tract scale, these sites are reducing park poverty (significant positive correlation), but not being sited in geographic areas that would be high priority for stormwater, UHI, social vulnerability, air quality, or habitat connectivity (all negatively correlated, stormwater and UHI significantly so). Even when Detroit stakeholders' priorities are used to weight and combine criteria, the results are still significantly negatively correlated with current green infrastructure sites (Figure 8).

Large areas of vacant land in Detroit make it hypothetically easier to implement new green infrastructure and blight removal provides an added incentive. Therefore, one would expect these green infrastructure sites to be situated in areas of the city with especially high vacancy rates (Figure 9), but analysis, at least at the census tract scale, indicates that this is not the case (Figure 15). In fact, there is a negative correlation between vacant land area percentages and green infrastructure locations (Figure 16). Why this is so remains unclear and is an area for future research. DWSD's green infrastructure program is specifically designed to reduce runoff to the combined sewer system in the Upper Rouge River Tributary area, so it is logical that projects are clustered in that area. To account for this focus, we also ran correlations for just the census tracts in this region. The directions of the relationships do not change, and in most cases they actually have a stronger statistical significance (Figure 16). This suggests that even within this priority stormwater area, there is a missed opportunity for city planners to leverage green infrastructure co-benefits.

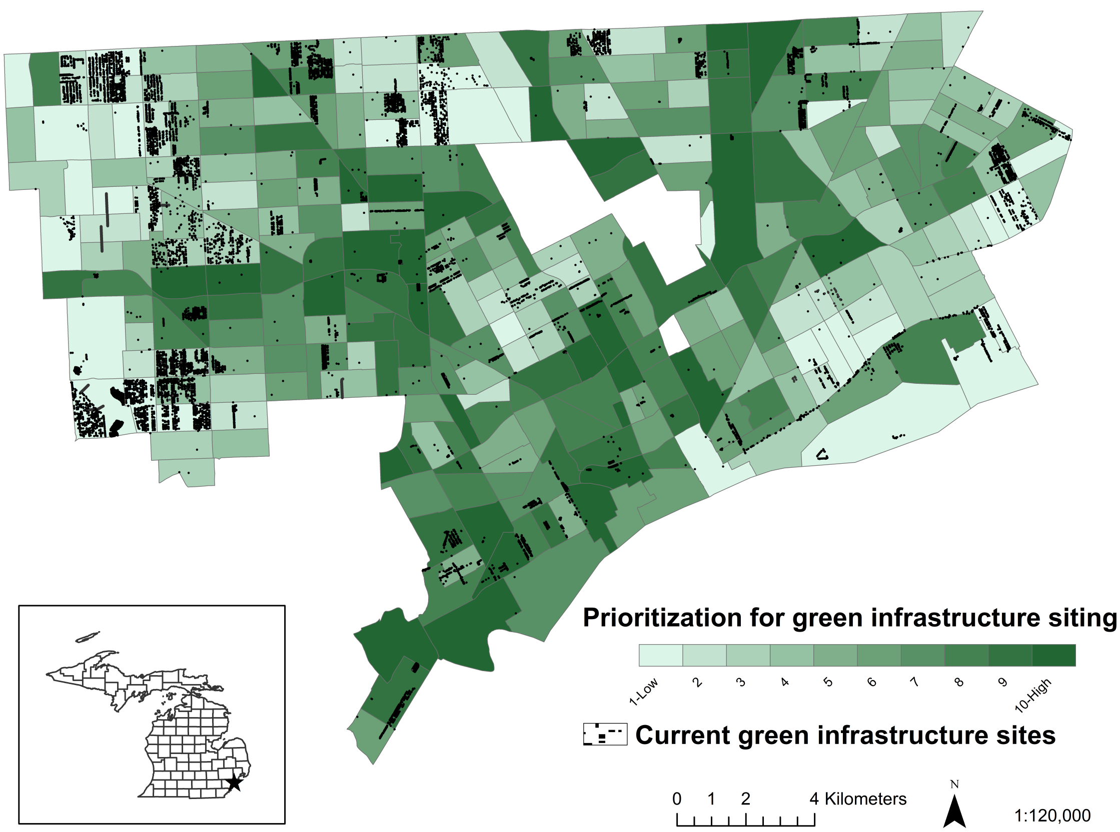

Figure 15 Overlay of current green infrastructure project locations, city parks, and GISP model combined criteria scores using stakeholder pairwise comparison weights

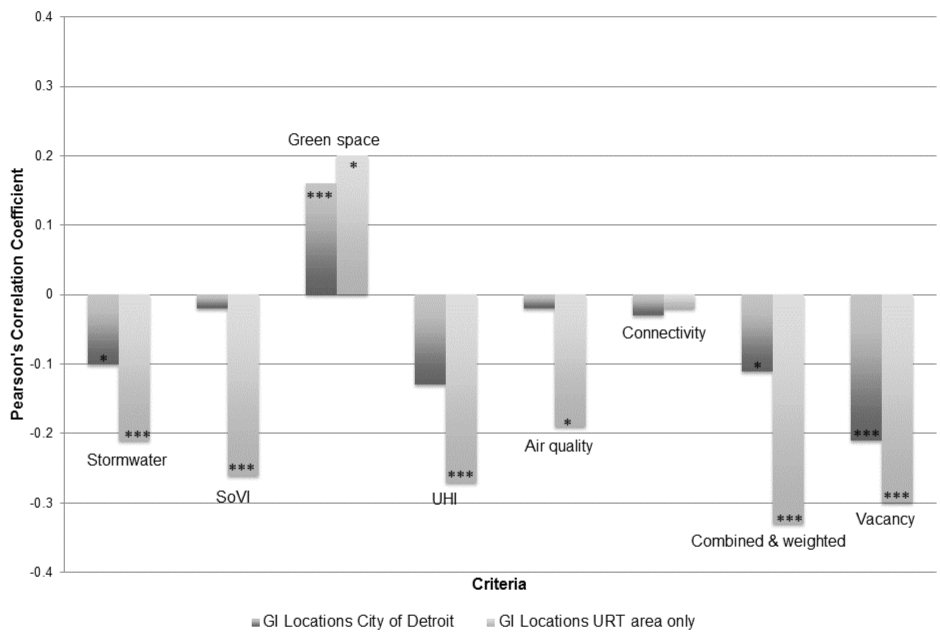

Figure 16 Pearson's correlation coefficients for Detroit green infrastructure locations and GISP model criteria and vacancy rates
Note: "*" indicates correlations are statistically significant at $p < 0.1$; "***" indicates significant at $p < 0.05$

4.5 Discussion

The results of the GISP model suggest that current green infrastructure projects in Detroit are not being strategically planned to maximize multiple ecosystem service benefits. As this study has illustrated, there will be spatial tradeoffs and synergies among and between these benefits. To make the green infrastructure planning process more effective, these tradeoffs and synergies need to be understood, contested, and negotiated, especially since siting it has significant implications for resource use, equity, and health across time and space. Indeed, if it were being planned more holistically to support social-ecological resilience in Detroit, the locations of the projects would be quite different. A more strategic and integrated process could help to ensure that multiple ecosystem services are provided to areas of the city that need them most.

The GISP model provides a flexible tool to facilitate this process by operationalizing a green infrastructure approach that "seeks to steer spatial planning towards integrated land use governance, wherein multifunctional ecosystem services potential are realized through enhancing positive synergies between abiotic, biotic and social systems." (Lennon & Scott, 2014, p. 574) This is not an entirely new or radical goal. Indeed, the underlying principles of multifunctional landscapes and the societal benefits of green space can be traced back to the 19th century, with the work of Frederick Law Olmsted and Ebenezer Howard (Eisenman, 2013; Mell, 2008). Over the last decade, however, a broader consensus on the meaning and value of multifunctional green infrastructure has emerged (Mell, 2016). Lennon and Scott (2014, p. 570) argue that the recent popularity of green infrastructure is part of a larger shift from planning for "sustainable development" and city competitiveness to planning to create "resilient places" and ecosystem services. This shift is driven in part by a growing concern with climate change impacts. Green infrastructure has "positioned itself as a 'go-to' approach in contemporary landscape planning, as it holistically addresses climate change, social development, and economic valuation simultaneously" (Mell, 2016, p. 5). Planning for multiple benefits requires breaking down traditional silos in cities, and this may be challenging, but a shared interest in promoting 'resilience' may be one way to get stakeholders from different departments or agencies into the same room. Resilience can serve a valuable function in this way, as a uniting concept or so-called "boundary object" (Brand & Jax, 2007; Meerow et al., 2016).

While the GISP model is useful as a way to operationalize a multifunctional resilience-based approach to spatial planning, it should not be considered a land suitability analysis, since it does not look at specific parcels nor does it consider land use, cost, or other constraints on green infrastructure development. In addition, the GISP model is not decision support for choosing specific green infrastructure technologies, since numerous additional factors would need to be considered. For example, filtration technologies would only be appropriate for areas where groundwater is not contaminated.

Rather, the model is best suited for identifying areas to focus on for green infrastructure development as part of a city's master or vision plan, to be followed up with finer-scale analysis. The GISP model, especially when presented in an easy-to-use web-based Story Map format (Figure 17), is valuable as a planning tool for considering tradeoffs and benefits. As a representative of the Detroit City Planning Commission noted in the meeting, "As a planner for the city I think this would be very useful both from a macro level as we are looking at a master plan and from a neighborhood redevelopment and planning level."

We considered six ecosystem services criteria, but the modeling approach allows for additional criteria. For future iterations of the model, stakeholders, for example, suggested including data on flooding, asthma deaths (air quality indicator), soil type and historical hydrological network (stormwater indicator), and additional land cover types, such as open space, wetlands, etc., and data on canopy quality (landscape connectivity indicator). Incorporating additional criteria hinges in part on data availability, which also poses a challenge with respect to the scale of analysis considered. Our unit of analysis was the census tract, for which there is a wealth of socio-economic and demographic data. However, each tract represents an average of 4000 residents, so there can be significant variability within them that is not captured in the model. Additionally, they are unrelated to the scales at which governance or planning occurs. Research is currently underway that quantifies both the services and potential 'disservices' (e.g. water use in arid climates and increased pests and allergens; Lo & Balbus, 2015; Pataki et al., 2011) associated with green infrastructure. As the results from these studies emerge they can be incorporated into the GISP model and the benefit criteria adjusted accordingly.

Finally, the GISP model can be applied as a spatial planning approach for a broad swath of cities. Comparing modeling results and stakeholder priorities across different cities will build generalizable knowledge about ecosystem service tradeoff and synergy patterns, how green infrastructure is sited, and how stakeholders perceive the importance of its various benefits.

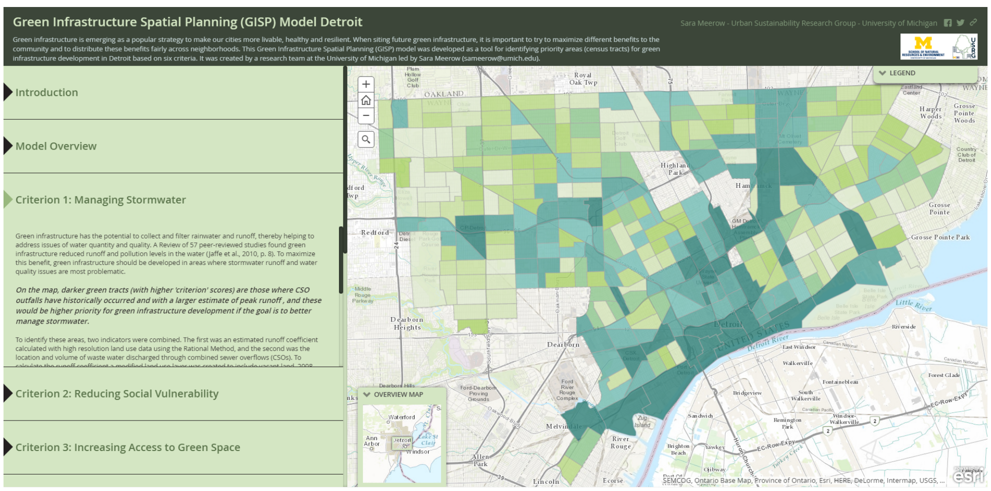

Figure 17 Screenshot of the stormwater GISP model criterion in the web-based Story Map (www.gispmodel.com)

4.6 Conclusion

A growing number of scholars, organizations, and cities like Detroit are promoting green infrastructure as an alternative to traditional gray stormwater infrastructure, as a way to provide multiple ecosystem services to residents, and as a strategy for enhancing urban sustainability and resilience. A primary rationale for expanding green infrastructure is *multifunctionality*, yet most studies and green infrastructure plans to-date, including those in Detroit, focus only on one or a few of the benefits and do not examine tradeoffs or synergies. This represents a missed opportunity to enhance social-ecological resilience and equity.

This paper has introduced a generalizable spatial planning approach that integrates six commonly cited benefits of green infrastructure (addressing stormwater, social vulnerability, park poverty, UHI, air pollution, and landscape connectivity problems) into a GIS-based MCE model. Priority areas for the six criteria are individually mapped, and then combined, taking into account local stakeholders' planning priorities. This approach can assist local communities, planners, and agencies in identifying 'hotspots', assessing potential spatial tradeoffs, and ultimately enabling these decision-makers to create green infrastructure plans that incorporate a wider range of socio-economic and environmental benefits and local resilience priorities.

We used the GISP model to examine ongoing green infrastructure developments in the City of Detroit. The results revealed important tradeoffs (e.g. between stormwater and connectivity criteria) and synergies (e.g. stormwater, UHI, and air quality) in priority areas, illustrating why a strategic spatial planning process is needed in order to maximize ecosystem service benefits. Our findings suggest that this process could be improved in Detroit. The locations of current green infrastructure projects do not match the modeled priority areas. Detroit stakeholders identified reducing social vulnerability as an important benefit, but our analysis suggests that projects are not being sited in areas with the most vulnerable populations or even the highest vacancy rates.

The GISP modeling approach shows promise both as an aid to facilitate more strategic siting decisions in applied settings and as a research instrument to examine synergies and tradeoffs in green infrastructure benefits. Initially developed using six criteria for Detroit, the modeling approach can be adopted for the spatial planning of other ecosystem services in a wide-range of cities.

Appendix 4.1

Table 9 Rational Method coefficients[1]

Land use classification	Coefficient
Commercial	0.6
Governmental	0.6
Industrial	0.8
Multi Family Residential	0.65
Single Family Residential	0.4
Parks and Open Space	0.2
Transportation, Communication, and Utilities	0.85
Airport	0.85
Water	0
Vacant, No Structure	0.3

[1]Adapted from Strom et al., (2009)

Appendix 4.2

Table 10 Detroit expert stakeholder meeting participants, January 2016

Name of organization	**Type**
1. Alliance for the Great Lakes	Local nonprofit
2. Brightmoor Alliance	Community development organization
3. City of Detroit General Services Department	Municipal government
4. Detroit City Planning Commission	Municipal government
5. Detroit Economic Growth Corporation	Local nonprofit
6. Detroit Economic Growth Corporation	Local nonprofit
7. Detroit River Conservancy	Local nonprofit
8. Detroit Water and Sewage Department	Municipal government
9. Detroit Water and Sewage Department	Municipal government
10. Detroit Workers for Environmental Justice	Local nonprofit
11. Eastside Community Network	Community development organization
12. Grandmont Rosedale Development Corporation	Community development organization
13. Greening of Detroit	Local nonprofit
14. Michigan Department of Environmental Quality	State government
15. Michigan Department of Environmental Quality	State government
16. Midtown Detroit, Inc.	Community development organization
17. Southeast Michigan Council of Governments	Regional planning organization
18. Southwest Detroit Environmental Vision	Local nonprofit
19. Tetra Tech, Inc.	Local consulting company
20. The Erb Family Foundation	Charitable foundation
21. The Nature Conservancy	International nonprofit
22. Urban Neighborhoods Initiative	Local nonprofit
23. United States Forest Service	Federal government

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Chapter 5 A Green Infrastructure Spatial Planning model for evaluating ecosystem service tradeoffs and synergies in three coastal megacities

Abstract: A growing number of cities are expanding green infrastructure to foster resilience. While these nature-based solutions are often promoted on the basis of their multifunctionality, in practice, most studies and plans focus on a single benefit, such as stormwater management. This represents a missed opportunity to strategically site green infrastructure to leverage social and ecological co-benefits. To address this gap, this paper presents the Green Infrastructure Spatial Planning (GISP) model as a tool for identifying and comparing spatial tradeoffs and synergistic 'hotspots' for multiple benefits in three diverse coastal megacities: New York City, Los Angeles (United States), and Manila (Philippines). Spatial multi-criteria evaluation is used to examine how strategic areas for green infrastructure development across the cities change depending on which benefit is prioritized. Preliminary GIS layers corresponding to six planning priorities (managing stormwater, reducing social vulnerability, increasing access to green space, improving air quality, reducing the urban heat island effect, and increasing landscape connectivity) are mapped using existing datasets and spatial tradeoffs assessed. Criteria are weighted to reflect local stakeholders' priorities as determined through surveys and stakeholder meetings, and the combined results visualized. While additional model improvements are clearly needed, preliminary results empirically illustrate the complexities of planning green infrastructure and urban resilience more generally.

5.1 Introduction

Coastal megacities concentrate risks and opportunities for resilience. On the one hand, these densely populated urban areas are highly vulnerable to disasters and climate impacts including sea-level rise, storm surge, and heat waves (Klein, Nicholls, & Thomalla, 2003). Megacities are responsible for a large share of global consumption, energy use, and carbon emissions (Duren & Miller, 2012). Urbanization in coastal areas also negatively impacts the local environment in many ways, for example through subsidence, erosion, pollution, habitat fragmentation, and a general loss of ecosystem services (Blackburn & Pelling, 2014). On the other hand, large cities may also be part of the solution, since they can present certain efficiencies and economies of scale (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007). For example, the average New York City resident produces less than a third of the carbon emissions of the average American (Grove, 2009).

There are numerous proposed strategies for mitigating the negative impacts of urbanization and enhancing urban resilience. One increasingly popular stategy is green infrastructure (Beatley & Newman, 2013; Jim, Yo, & Byrne, 2015; Scott, Collier, Foley, & Lennon, 2013). Like the concept of resilience itself, definitions of green infrastructure vary (Wright, 2011), but it generally refers to urban green spaces such as parks, greenways, rain gardens, or green roofs (Wise, 2008). A growing number of researchers, government agencies, and organizations are actively promoting green infrastructure, and individual municipalities such as New York City have budgeted billions of dollars to implement green infrastructure plans (Kremer et al., 2016).

Green infrastructure is generally advocated on the basis of its multiple social, ecological, and technical benefits, from improved public health to stormwater abatement (Austin, 2014;

Rouse & Bunster-Ossa, 2013; Wise, 2008). These are often classified as provisioning, regulating, supporting, and cultural services using the popular "ecosystem services" framework (Ahern, 2007; Andersson et al., 2014; Elmqvist, Gomez-Baggethun, & Langemeyer, 2016). Environmental benefits from green infrastructure include carbon sequestration, greenhouse gas emission reductions, wildlife habitat, groundwater replenishment, alleviation of the urban heat island, and pollutant filtration. Green infrastructure also serves an important technical function by reducing the need for grey infrastructure (e.g. sewers, water treatment, and electricity to power wastewater treatment facilities) and by reducing the likelihood of combined sewer overflows (CSO). Social benefits result not only from increased property values, cost savings, and reduced risk of flooding and water pollution from CSOs, but also psychological benefits of increased access to green space, health benefits from more outdoor recreation, and better air quality (Tzoulas et al., 2007).

In most cases these benefits are localized, which means that the spatial planning and distribution of green infrastructure has important environmental and social justice implications (Hansen and Pauleit 2014: 520). There is thus a clear need to critically examine where green infrastructure is being developed and who benefits as a result. Moreover, while green infrastructure may be promoted on the basis of its multifunctionality, it is often planned, implemented, and researched from the perspective of a single benefit. More specifically, green infrastructure projects seem to be largely stormwater driven (Newell et al., 2013). This is problematic for two primary reasons. First, if there truly are synergistic benefits, focusing on only one benefit will undervalue green infrastructure vis-à-vis other approaches. Conversely, if decisions about where to site green infrastructure are made on the basis of just one function, and it turns out that there are trade-offs between the different benefits, the green infrastructure project may not be as beneficial as expected. Generally, very little research has examined the tradeoffs between green infrastructure benefits or who profits from them and why (Ernstson, 2013; Hansen & Pauleit, 2014; Lovell & Taylor, 2013). Integrated planning models that holistically evaluate environmental and social trade-offs and synergies are lacking.

To address this research gap, Meerow and Newell (2017) developed the Green Infrastructure Spatial Planning (GISP) model. The GISP model provides a general approach for mapping priority areas (or 'hotspots') where green infrastructure can be strategically placed so as to maximize ecosystem service benefits, and to assess spatial tradeoffs. The model combines GIS-based multi-criteria evaluation and stakeholder-derived weights. The six criteria, which represent commonly cited benefits of green infrastructure include: 1) managing stormwater; 2) reducing social vulnerability; 3) increasing access to green space or reducing park poverty; 4) reducing the urban heat island; 5) improving air quality; and 6) increasing landscape or habitat connectivity. These are combined and weighted based on local expert stakeholders' planning priorities, as determined through a survey administered during a workshop. The GISP model was initially applied in Detroit, Michigan, demonstrating the value of the approach and interesting synergy and tradeoff patterns. But as a post-industrial "shrinking" city with extensive vacant land, Detroit's situation is not representative of many cities (Schilling & Logan, 2008). Megacities worldwide are growing and have very limited open space. This paper 1) demonstrates the broader applicability of the GISP model, 2) compares spatial synergy and tradeoff patterns, and 3) compares green infrastructure planning priorities in three diverse megacities: New York City (NYC), Los Angeles (LA), and Metropolitan Manila (Manila).

These three cities were selected based on several criteria. First, they can all be classified as coastal megacities, meaning they are the center of an urban agglomeration with a population over ten million and located within a 50 meter elevation and 100 kilometer distance of mean high water (Blackburn & Pelling, 2014). Second, the cities are all vulnerable to multiple natural hazards (Sundermann, Schelske, & Hausmann, 2013; UN DESA, 2011). Third, the cities vary in terms of the scope of their green infrastructure planning. NYC is several years into the implementation of a comprehensive green infrastructure master plan (Kremer et al., 2016). LA has several ambitious plans and programs, but all in the early stages of development. Metro Manila has no comprehensive plan, but does have localized initiatives. An important motivation for including Manila in the study is to test the utility of the model outside of the U.S., in a relatively data scarce environment, and a less industrialized country.

Next, I will outline the methodology used to develop the GISP models for the three cities, including the mapping of individual model criteria, evaluation of synergy and tradeoff patterns, and stakeholder weighting. In section 5.3 I will present the results. In the fourth and final section I will discuss the implications of these findings, important model limitations, and recommendations for future improvement.

5.2 Methodology

The six criteria in the GISP model each reflect a commonly cited resilience benefit of green infrastructure, and the spatial attributes indicate an area's relative need for these benefits. For a more extensive literature review justifying the methodology and the choice of these six benefits see Meerow and Newell (2017). I use much the same modeling approach as I did in Detroit to develop the GISP models for the three megacities, but changed some of the specific spatial indicators because of data availability. Wherever possible, similar datasets were used for the three cities, but especially for Manila, this was not always possible. This represents an important limitation of the study, and will be further discussed in section 5.4.

5.2.1 Mapping criteria

For each of the six criteria in each city, indicators are aggregated at the smallest spatial unit for which data was readily available. For NYC and LA that is the 2010 census tract, and for Manila it is the *barangay* or village (the smallest local government unit and scale at which census data is aggregated). Official census boundaries were clipped to include only land areas (excluding buffers extending into the ocean). Since some indicators consider population, tracts with a population of zero in 2010 (e.g. parks, water features) were excluded from analysis. The model is constructed from the best readily available spatial datasets that I could acquire, which were selected in consultation with local experts. Data for each criterion was processed and mapped separately; with a linear scale transformation ("maximum score") applied to measurement scales so that all criterion scores were standardized to range from zero to one (Malczewski, 1999). The selection rationale for each indicator, the data sources, processing steps, and limitations are outlined below and summarized in Table 11.

5.2.2 Managing stormwater

To identify priority areas for green infrastructure based on stormwater management, rough estimates of percent impervious surface were calculated for each spatial unit in each city. Impervious surfaces such as buildings, roads, and pavement prevent water from infiltrating into the ground, and are therefore more likely to produce runoff that collects pollutants, strains sewer infrastructure, and potentially causes flooding (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005).

Table 11 GISP model criteria and data sources for three megacities

Resilience planning priority	Criterion	Spatial attributes (Indicator)	Los Angeles	NYC	Manila
Managing stormwater	Stormwater hazard	Estimate of runoff production based on percent impervious surface	Percent of area classified as low, medium, or highly developed in land cover data from NOAA (2010).	Percent of area classified as buildings, road/railroad, & paved surfaces in Urban Ecological covertype Map (ECM) (O'Neil-Dunne et al., 2014).	Percent of area classified as built up in land cover data from NAMRIA (2010)
Reducing social vulnerability	Social Vulnerability Index (SoVI)	Combination of indicators associated with social vulnerability to natural hazards	SoVI data for 2010 created by the Hazards and Vulnerability Research Institute (2015)	SoVI data for 2010 created by the Hazards and Vulnerability Research Institute (2015)	SoVI data for 2010 calculated for cities in Manila by See and Porio (2015)
Increasing access to green space	Lack of access to parks	Park access indicator	Population weighted distance to nearest park from buildings within tract based on Open Street Map (Logan et al., in review)	Population weighted distance to nearest park from buildings within tract based on Open Street Map (Logan et al., in review)	Percent of area classified as public open spaces and environmentally sensitive areas in land use data from NAMRIA (2003)
Reducing the urban heat island effect	Land surface temperature	Average land surface temperature for three months	Estimate of average nighttime surface temperatures per census tract from MODIS for June, July, & August, 2010 (Burillo et al., 2015)	Estimate of average nighttime surface temperatures per census tract from MODIS for June, July, & August, 2010 (Burillo et al., 2015)	Estimate of average daytime surface temperatures from MODIS for December, January, & February, 2010 (Burillo et al., 2015)
Improving air quality	Severity of air pollution	Estimated severity of air pollution	Combined and standardized total cancer risk & noncancer respiratory risk from National Air Toxics Assessment (EPA 2011)	Combined and standardized total cancer risk & noncancer respiratory risk from National Air Toxics Assessment (EPA 2011)	Percent of total area within 200 m of a major (> 4 lane) road. (University of Philippines School of Urban and Regional Planning, 2013)
Increasing landscape connectivity	Physical connectedness of wildlife habitat (vegetated cover) within spatial unit	Patch cohesion Index (Fragstats)	Physical connectedness of tree canopy (LA Regional Imagery Acquisition Consortium (LAR-IAC), 2011)	Physical connectedness vegetated areas (excluding built-up and water areas) based on ECM (O'Neil-Dunne et al., 2014).	Physical connectedness of wildlife habitat (excluding built-up and water areas) using land cover data from NAMRIA (2010)

There are many ways of measuring imperviousness, but here I focus on land cover classifications derived from satellite imagery data (Table 11) that is widely available for cities. For example, in NYC I calculated the percent of the total tract area classified as "buildings," "road/railroad," or "other paved surface" in the high resolution Ecological Covertype Map (ECM) (O'Neil-Dunne, MacFaden, Forgione, & Lu, 2014). Of course this is only a very rough estimate of impervious cover, and does not consider where the water would be likely to flow based on topography. It also does not take into account other stormwater management priorities, for example in NYC, large areas of the city have a combined sewer system, and the current green infrastructure program is focused on these priority catchment areas. The resolution of the different land cover datasets also differs for the cities. NYC's combines LiDAR at 0.7 meters and orthoimagery at 0.15 meters, whereas Manila's combines Landsat, AVNIR, and SPOT5 data, all of which are at a coarser resolution.

5.2.3 Reducing social vulnerability

Green infrastructure has been linked to numerous social and community benefits, thus it may be strategic to site new developments in disadvantaged, or more socially vulnerable communities. There are many possible indicators for social vulnerability, arguably the most well-established being the Social Vulnerability Index (SoVI) (Cutter et al., 2003; Cutter & Finch, 2008). The original SoVI is made up of demographic and socio-economic variables from the U.S. Census and American Community Survey that are associated with vulnerability to natural hazards. For LA and NYC, the SoVIs were calculated specifically for the cities by researchers at the Hazards and Vulnerability Research Institute using 27 variables from 2010 at a census tract scale. For NYC the final index consisted of 7 factors that accounted for approximately 70% of the variance, and LA's had six factors accounting for 68% of the variance. Manila was more problematic. No SoVI has been calculated at the barangay level, but See and Porio (2015) have created a SoVI based on 2010 census data for each of the 16 cities and one municipality that make up Manila. Unfortunately these results had to be downscaled to the barangay (all barangays were given their city's value), which undoubtedly obscures variation within the municipalities. This may be especially true in the Philippines, given the country's high income inequality (UN-Habitat, 2013).

5.2.4 Increasing access to green space

Many studies have shown that green spaces are not evenly distributed across cities, which is problematic given their many benefits (Heynen, Perkins, & Roy, 2006; Wolch et al., 2005). New investments in green infrastructure could be sited in communities with less access to green space to address this inequity. To identify these areas in New York and Los Angeles, I used an indicator representing the population weighted mean distance to the nearest park for all buildings within a census tract (Logan et al., in review). Logan et al.'s model uses open source data from OpenStreetMap (OSM) and the Open Source Routing Machine (OSRM; http://project-osrm.org/) to calculate the walking distance between every building (using the city's building footprint data) and the nearest park (OSM). The total census tract population (in the case of LA) and census block (in the case of NYC) population is divided evenly among the buildings in that block for this preliminary model. This indicator is calculated by multiplying every building's assigned 'population' and park distance, summing these values for the tract, and dividing this by the total tract population. It was not possible to use this methodology for Manila as no building footprint dataset could be identified. Instead I calculated the percentage of each barangay's area classified as "public open spaces and environmentally sensitive areas" in land use data from the National Mapping and Resource Information Authority (NAMRIA, 2003). This indicator is significantly different from that used in NYC and LA, since it is not weighted by population, and given the current rate of development; it is also very possible that land uses in many areas of the city have changed since 2003.

5.2.5 Reducing the urban heat island effect

Vegetation can help to cool the local environment, thereby helping to mitigate the urban heat island effect (UHI) (O'Neill et al., 2009). To map the UHI in each city I used 2010 land surface temperature data calculated by Burillo et al (2015) using the Google Earth Engine API from the Moderate Resolution Imaging Spectrometer (MODIS) sensor. For NYC and LA, I used the mean nighttime surface temperature for the three summer months of June-August. For NYC, there were 30 tracts with missing data, which were filled in using areal interpolation. Temperatures were aggregated for the original census tracts before they were clipped to land features, thus some water areas may have been included, especially in NYC. For Manila I averaged daytime data from December-February, 2010 because these were the most recent months with the least missing data. Nevertheless, nearly 29% of barangays were missing, and areal interpolation had to be used to estimate values for missing barangays.

5.2.6 Improving air quality

Vegetation can reduce air pollution, such as particulate matter and ozone (Pugh, Mackenzie, Whyatt, & Hewitt, 2012). To identify high priority areas for air quality improvement in NYC and LA I used the US EPA's 2011 National Air Toxics Assessment (NATA). The EPA produces this “screening-level” model of cancer and non-cancer respiratory risks to human health from outdoor air toxics at a census-tract scale, which are designed for identifying “geographic patterns and ranges of risk” (US Environmental Protection Agency, 2015). While there are many limitations to this data, it has the important benefit of being freely available for the entire United States. To calculate the final indicator, I combined the total cancer risk and total non-cancer respiratory risk estimates for each tract, standardizing each one from 0 to 1, then averaging the results, and rescaling those from 0 to 1. Unfortunately, no barangay-level air quality model could be identified for Manila. Transportation-related emissions are among the most harmful to public health, and concentrations of air pollutants are higher closer to major roadways (Design for Health, 2007). Therefore, I used proximity to major roads as a proxy for air pollution hotspots. I calculated a buffer of 200 meters (the threshold used by the US Department of Transportation for “proximity to major roadways”) around all roads with more than four lanes, and then calculated the percentage of each barangays total area within the buffer.

5.2.7 Increasing landscape connectivity

Vegetation and green spaces provide refuge and resources for many species, but as land is developed and paved over in urban areas, remaining habitat patches become increasingly fragmented. Ecological research generally suggests that reduced connectivity (and increased fragmentation) results in fewer ecosystem services (Mitchell, Bennett, & Gonzalez, 2013). A possible solution is to try and connect and expand the remaining green spaces, and research suggests such networks can provide valuable habitat for animals (Kong, Yin, Nakagoshi, & Zong, 2010). Landscape ecologists have developed many different ways of measuring both structural and functional connectivity (Calabrese & Fagan, 2004). Fragstats is a popular, free, and easy to use software program for doing various connectivity calculations (McGarigal, Cushman, & Ene, 2012). Within Fragstats[11], the Patch Cohesion Index metric was selected for the GISP model because it provides a measure of the physical connectedness of 'habitat patches' across a landscape. I calculated the Patch Cohesion Index for vegetated land cover for each spatial unit in each city, assuming that these areas would provide habitat to a wide range of species. This does make the results subject to edge effects, since each tract is analyzed in isolation. In NYC I used the high-resolution Ecological Covertype map (O'Neil-Dunne et al., 2014) and combined areas classified as "forested wetland," "freshwater wetlands," "maintained lawn and shrubs," "maritime forest," "other tree canopy," "tidal wetlands," "upland forest," and "upland grass and shrubs" into the habitat patches. In LA I used tree canopy areas as the habitat patches (LAR-IAC, 2011), and because so much of Manila's land cover dataset (NAMRIA, 2010) was classified as "built up" I included all areas categorized as "mangrove forest," "open forest," "broadleaved," "cultivated annual and perennial crops," "barren land, grassland, marshland" and "wooded land (shrubs, wooded grassland)" as habitat patches.

5.2.8 Determining stakeholder priorities and criteria weights

In addition to mapping the six criteria, I conducted fieldwork in each of the three cities and co-organized expert stakeholder meetings (LA in February 2016, Manila in August 2016, and NYC in January 2017) that brought together key local decision-makers for green infrastructure planning. At all three events I introduced the model and I also asked participants (Appendix 5.1) to complete a survey comparing the relative importance of the six model criteria and green

[11] FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

infrastructure benefits using three different methods: rating, ranking, and pair-wise comparisons. In LA and Manila I had participants fill out the survey during the meeting, in NYC due to time constraints a link to the online survey was provided with the invitation and attendees were asked to fill it out before the event. The surveys were collected before respondents saw the model results, to avoid influencing their decisions. I also asked some experts that were not present at the meetings to fill out the survey online. Particularly for the online surveys, a large number of people who were sent an invitation to the survey did not complete it, thus overall response rates were quite low. Additional surveys had to be excluded from analysis because they were clearly incorrectly filled out or incomplete. The survey is thus clearly not representative. It was merely meant to gather a wide a range of expert opinions in each city. The results from the ranking and pairwise comparison survey questions were aggregated to produce weights. Pairwise comparison analysis was done using Excel-based AHP calculator (Goepel, 2013); rating question weights were calculated using the rank sum (Malczewski, 1999). I then used weighted linear combination to develop combined 'hotspot' maps for green infrastructure expansion in each city using the two sets of stakeholder-derived weights and equal weights.

5.3 Results

Developing the GISP model for three diverse megacities highlights the complexities of planning green infrastructure to maximize multiple resilience benefits. Priority areas for green infrastructure expansion clearly differ depending on decision criteria. Some spatial tradeoff and synergy patterns are consistent across the three cities, while others differ. Local priorities also seem to vary between the three cities, confirming the need for stakeholder consultation and customized weighting schemes.

The six preliminary individual criterion maps for each of the cities are shown in Figures 19-21. In each case, the darker shaded spatial units represent areas that are higher priority for green infrastructure development based on the model. It is clear that spatial priorities vary across the criteria. I examine these tradeoff and synergy relationships quantitatively by running Pearson's bivariate correlations between the criteria in each city (Figure 21).

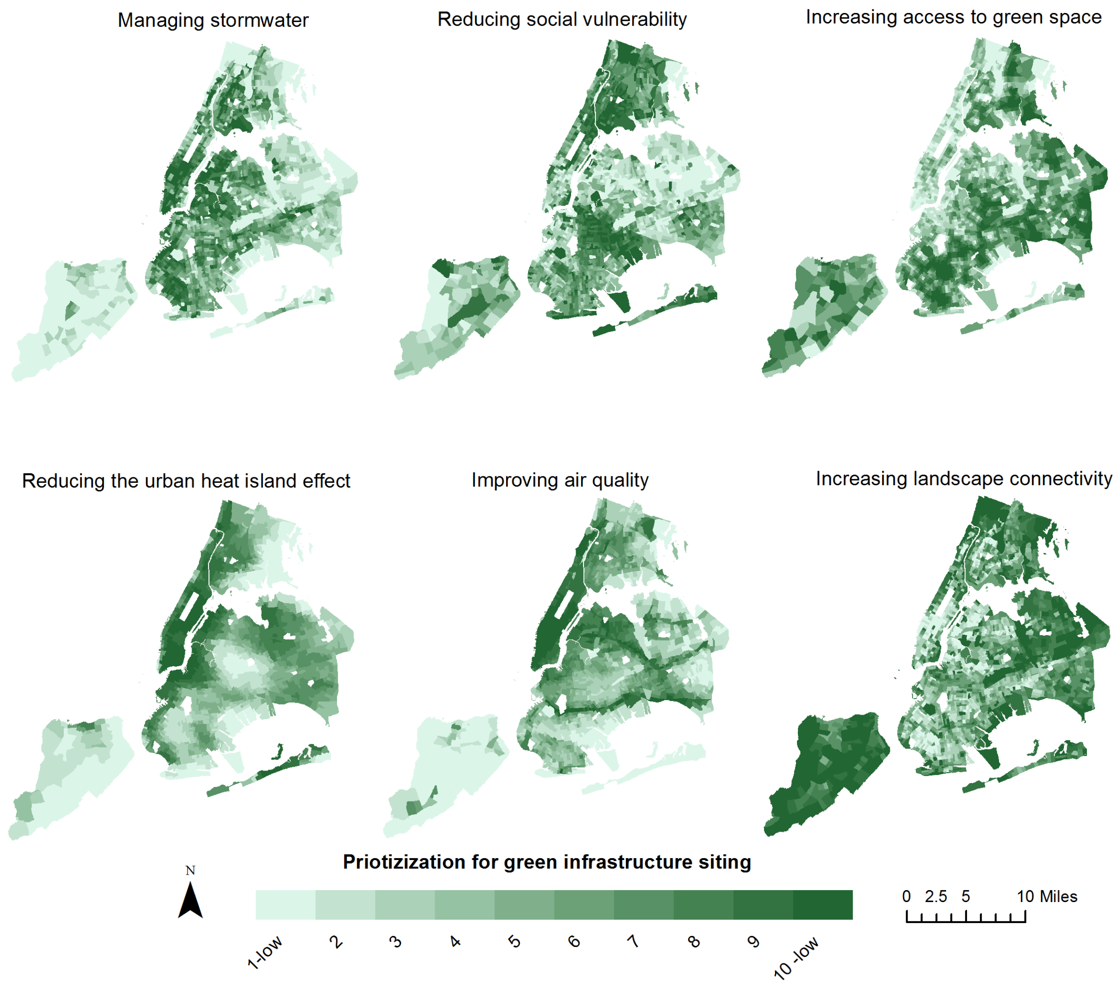

Figure 18 New York Green Infrastructure Spatial Planning (GISP) model criteria
*Note***:** Each map shows the relative prioritization of census tracts in New York for green infrastructure based on a commonly cited green infrastructure benefits.

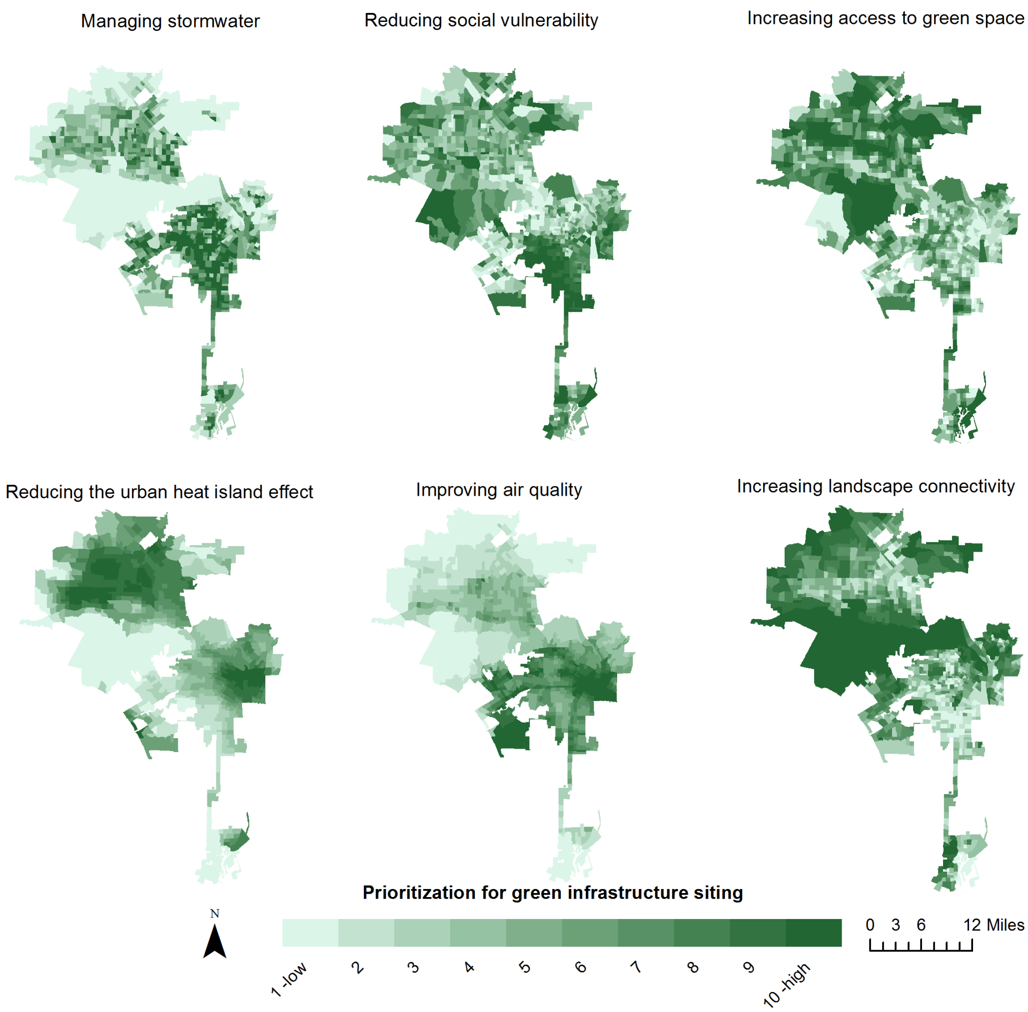

Figure 19 Los Angeles Green Infrastructure Spatial Planning (GISP) model criteria
*Note***:** Each map shows the relative prioritization of census tracts in Los Angeles for green infrastructure based on a commonly cited green infrastructure benefits.

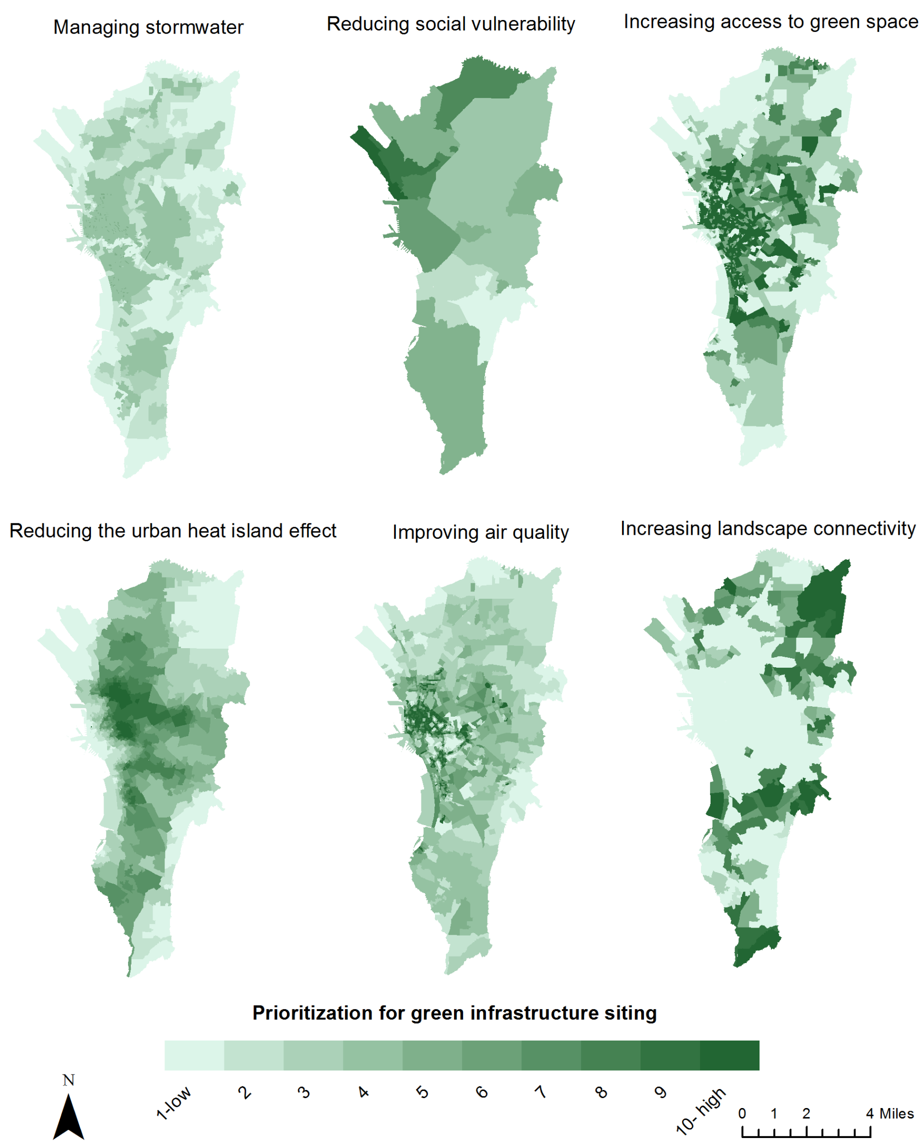

Figure 20 Manila Green Infrastructure Spatial Planning (GISP) model criteria
Note: Each map shows the relative prioritization of barangays in Manila for green infrastructure based on a commonly cited green infrastructure benefits.

Figure 21 Spatial trade-offs and synergies between GISP model criteria
Note: The larger the diameter and shading of circles depict the Pearson's correlation coefficient for GISP model criteria. A larger circle indicates a stronger negative (dark) or positive (light) relationship. Circles marked with an "X" are not statistically significant.

5.3.1 Analyzing spatial synergies and tradeoffs

I examine correlations between criterion scores to identify potential spatial tradeoffs and synergies between planning priorities. A positive correlation indicates a potential synergy, whereas a negative relationship indicates a spatial tradeoff. Certain correlation patterns are consistent across the three cities. First, I find a positive correlation, and thus a synergy, between the stormwater, air quality, and UHI criteria. There also appears to be a tradeoff between these three criteria and the connectivity criterion. This is not surprising since those areas with more "connected" vegetated areas should have less impervious areas, reduced air pollution levels, and be cooler. In fact, if I found the opposite this would call into question these supposed benefits of vegetation or suggest a problem with the data or indicators. For example, percent impervious surface is often used as an indicator of UHI, so we would expect the stormwater criterion and UHI criterion to be correlated (Yuan & Bauer, 2007).

Other relationships are not consistent across the cities. Stormwater and social vulnerability are significantly positively correlated in LA and Manila, but not in NYC. We see a synergy between stormwater and park area in Manila, but not in NYC or LA. In fact, in LA there appears to be a spatial tradeoff between these criteria. This is likely a product of the different way in which park access was measured in Manila, just using the percentage of public open space and not weighting it by population. In both NYC and LA there seems to be a tradeoff between access to green space and air quality. In NYC I also find evidence for a tradeoff between access to green space and UHI. This may be due to the fact that much of densely populated Manhattan is built around Central Park, putting most residents there in close proximity to green space. While there is some evidence of a synergy between SoVI and UHI in NYC, we see a negative correlation in LA. More in depth research is needed to understand these differences.

Overall, the results suggest that it may be possible to site green infrastructure in high priority areas for stormwater management, air quality, and UHI simultaneously. Trying to also prioritize socially vulnerable neighborhoods, those with less access to parks, or expanding and connecting existing habitat may be more problematic. The fact that these tradeoffs exist suggests that decision-makers should evaluate local priorities as part of a strategic planning process.

5.3.2 Local priorities and mapping green infrastructure hotspots

Expert stakeholders in the three cities appear to have different priorities with respect to the benefits of green infrastructure. The aggregated survey results for the importance of the model criteria for each city are presented in Table 12. The criteria are ranked in importance based on the results of the rating, ranking and pair-wise comparison questions. Interestingly, the ordering is only completely consistent across all three questions for LA, and this is the city with the fewest respondents. Nevertheless, there still seems to be a coherent prioritization pattern in

NYC and Manila. This becomes clear when one looks more closely at the means (for rating higher is more important and for ranking lower is more important) and weights (higher is more important) generated from the pair-wise comparison question. For example, in NYC, managing stormwater is identified as much more important than the other criteria, which are all quite close together. In Manila, the stormwater and air quality benefits appear to be regarded as almost equally high priority.

Table 12 Local stakeholder survey results

City	New York (N=18)			Los Angeles (N=6)			Manila (N=19)		
Rating									
	Rank order	**Mean**	**Standard deviation**	**Rank order**	**Mean**	**Standard deviation**	**Rank order**	**Mean**	**Standard deviation**
Stormwater	1	4.72	0.46	2	4.50	0.55	2	4.53	0.84
Sovi	6	3.78	1.40	1	4.83	0.41	3	4.21	0.92
Green space	4	3.94	1.11	3	4.00	0.63	4	4.11	0.74
UHI	3	4.11	0.90	4	3.83	0.41	5	4.05	0.91
Air quality	2	4.17	0.71	5	3.67	1.03	1	4.58	0.51
Connectivity	4	3.94	1.11	6	3.50	1.05	5	4.05	1.08
Ranking									
	Rank order	**Mean**	**Standard deviation**	**Rank order**	**Mean**	**Standard deviation**	**Rank order**	**Mean**	**Standard deviation**
Stormwater	1	1.56	1.10	2	1.67	0.82	1	2.55	1.75
Sovi	3	3.50	2.01	1	1.50	0.55	5	4.00	1.41
Green space	2	3.39	1.54	3	3.67	0.82	3	3.82	1.54
UHI	4	3.72	1.23	4	4.17	1.47	4	3.45	2.02
Air quality	5	4.22	0.94	5	4.50	1.05	2	2.45	1.13
Connectivity	6	4.56	1.65	6	5.50	0.84	6	4.60	1.51
Pair-wise comparisons									
	Rank order	**Weight**		**Rank order**	**Weight**		**Rank order**	**Weight**	
Stormwater	1	0.342		2	0.277		1	0.227	
Sovi	6	0.102		1	0.337		4	0.168	
Green space	3	0.128		3	0.125		3	0.169	
UHI	2	0.191		4	0.099		5	0.120	
Air quality	4	0.119		5	0.097		2	0.211	
Connectivity	5	0.117		6	0.064		6	0.105	

Consistent with other studies (Meerow & Newell, 2017; Newell et al., 2013), stormwater was considered either the most or second most important benefit in all three cities. The other benefits varied considerably. This may be because green infrastructure has been specifically promoted by influential institutions like the US EPA as a stormwater management approach (US EPA, 2017). NYC's green infrastructure plan, for example, lays out very specific goals related to improving water quality and managing runoff, while the other desired "sustainability benefits" are not as well defined (PLANYC, 2010, p. 2). Reducing social vulnerability was deemed most important in LA, but fairly low in NYC and Manila. Air quality benefits were seen as very important in Manila, but not necessarily so in NYC or LA. Increasing landscape connectivity was generally seen as one of the least important criteria, perhaps suggesting that stakeholders are more interested in social benefits than more indirect ecological services of green infrastructure.

Figure 22 below shows how these aggregated survey results translate to criteria weights, and Figures 23-25 show how combined criteria hotspots for green infrastructure in each of the cities change slightly depending on whether and if so which stakeholder weights are used.

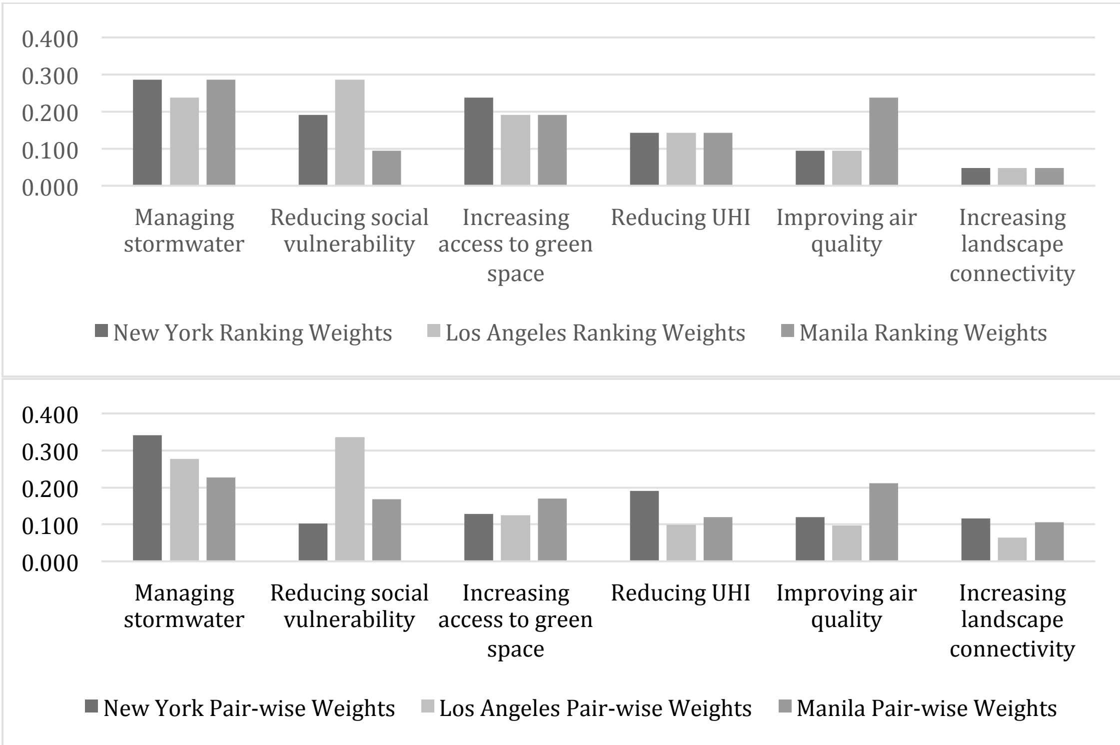

Figure 22 Criteria weights based on stakeholder ranking (top) and pair-wise comparison (bottom) survey responses

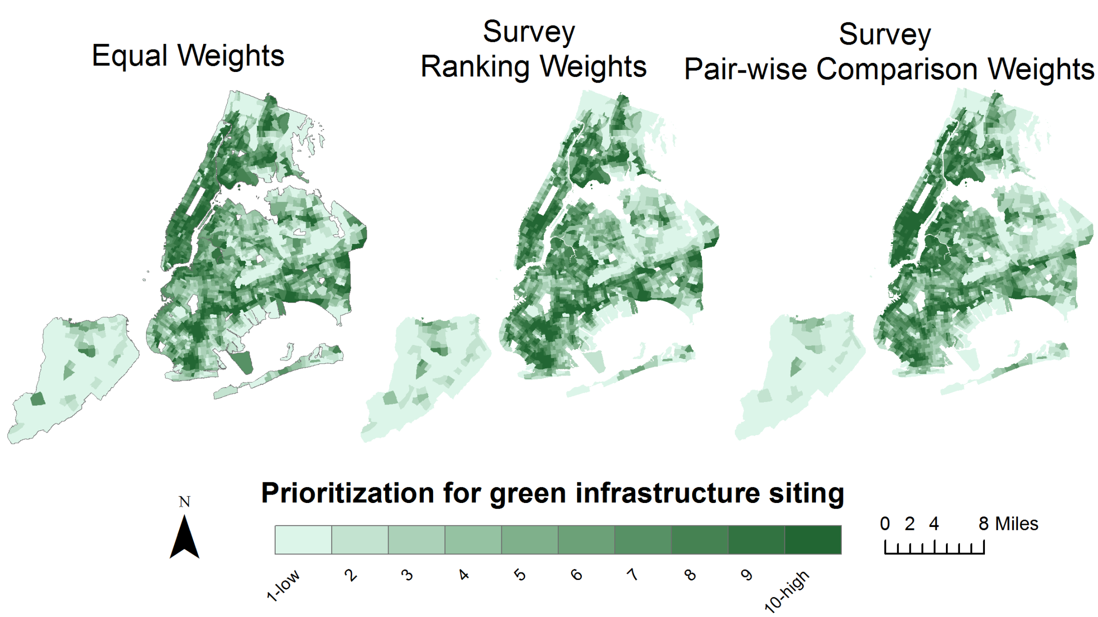

Figure 23 New York combined criteria using different weighting methods

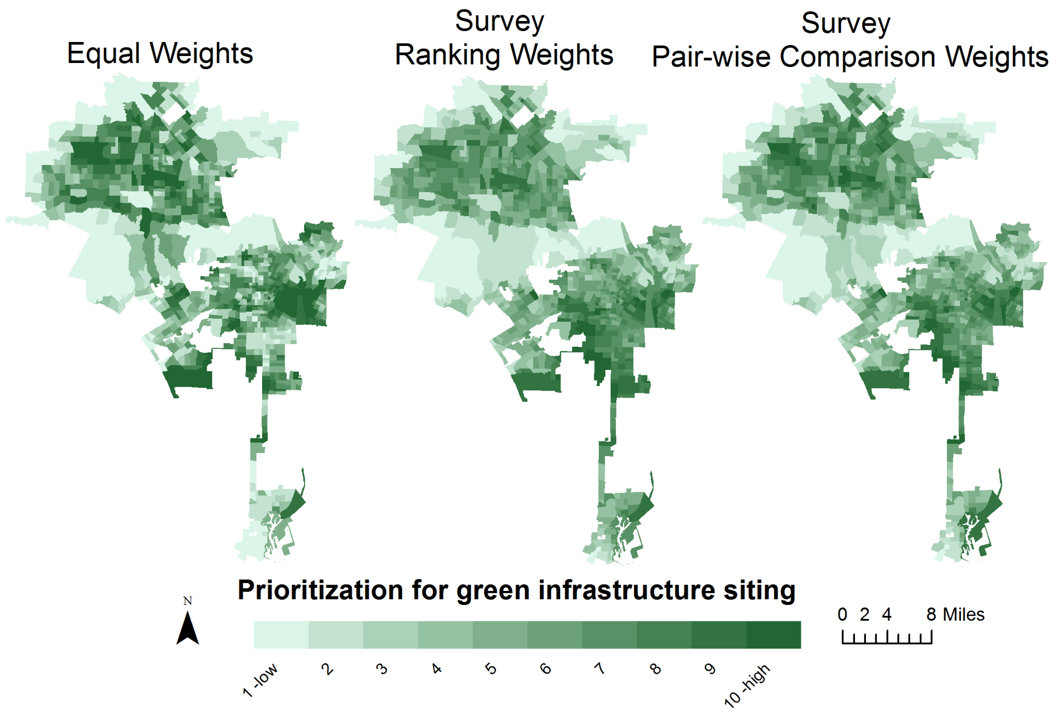

Figure 24 Los Angeles combined criteria using different weighting methods

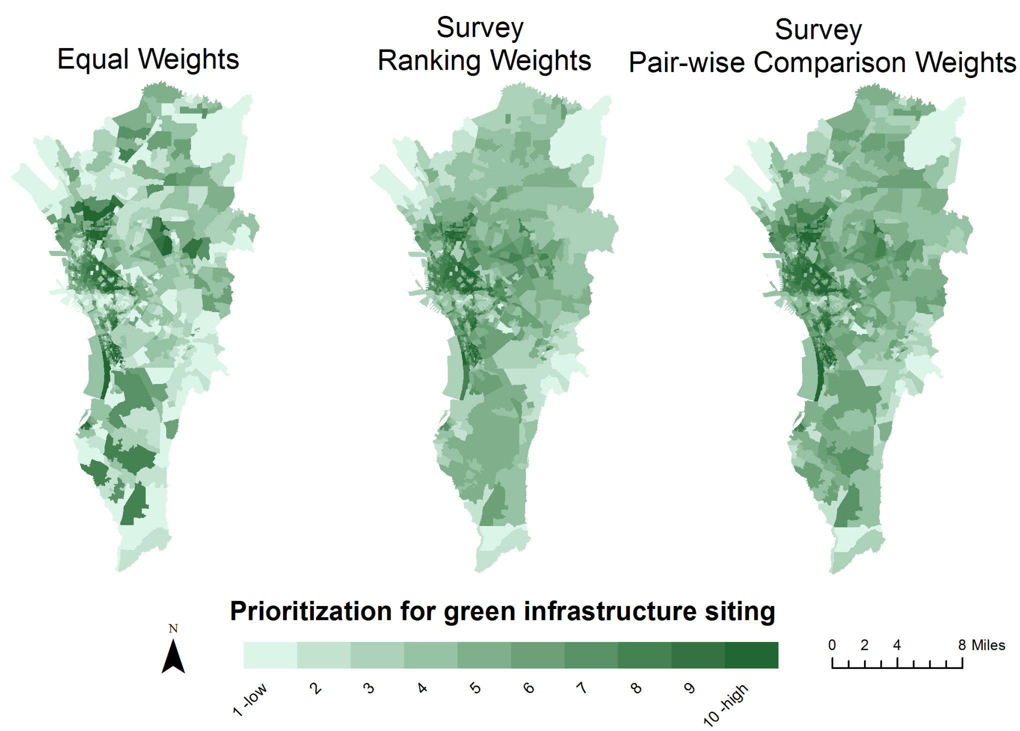

Figure 25 Manila combined criteria using different weighting methods

5.4 Discussion and conclusion

NYC, LA, and Manila represent three very different coastal megacities. Yet in all three cities there are ongoing efforts to expand green infrastructure and urban vegetation to enhance sustainability and resilience. This is part of a broader trend, as a growing number of scholars, organizations, and governments are advocating the multiple benefits of green infrastructure. The GISP model was developed as a city-wide approach for strategically planning green infrastructure investments based on local priorities and where multiple benefits are needed most (Meerow & Newell, 2017). It also helps to reveal spatial tradeoff and synergy patterns between benefit priorities, complicating assumptions of multifunctionality, and highlighting the political and scalar complexities of planning for resilience (Meerow & Newell, 2016).

This preliminary effort to apply the GISP model to these three cities revealed a number of interesting findings. First, it showed that it is possible to develop the model for very different cities, although it was much more problematic to acquire data at a sufficiently fine scale for Manila, and the results should be interpreted with caution. Second, despite the fact that different data sources were used for the cities, there were several consistent synergy and tradeoff patterns. I identified spatial synergies between stormwater, UHI, and air quality benefit criteria, and a tradeoff between these criteria and increasing landscape connectivity. The same was also true in the initial Detroit model (Meerow & Newell, 2017). This is promising, because it suggests that even if stormwater continues to be a major focus of green infrastructure investments, and if areas with high imperviousness are prioritized, developments may also help to address UHI problems and air pollution. In contrast, planning focused on stormwater would not necessarily capture areas of relative park poverty, for example, although increasing access to green space was seen as a somewhat important goal in all three cities. Third, survey results suggest that expert stakeholders see certain green infrastructure benefits as more important in some cities than others. Comparisons should be made with caution, however, since the number and institutional affiliation of survey respondents is very different in the three cities (Appendix 5.1, Table 13).

While the stakeholders I interviewed and surveyed for this study did see practical value in the GISP modeling approach, it has a number of important limitations. First, the model is obviously constrained by data availability. It proved extremely difficult to find comparable datasets for all three cities, and Manila was a particular challenge. For example, the access to green space and air quality indicators used for Manila are very different than those used for LA and NYC. This limits the comparative claims that can be made about tradeoff and synergy patterns across the three cities. The model's accuracy depends on the underlying datasets, which are likely imperfect. I also acquired data from a wide variety of sources, which makes it difficult to validate its accuracy. Ultimately, there is a tradeoff between using indicators based on data that is widely available and easily replicated versus data that is highly customized and has been ground-truthed. The models and results presented in this chapter should be seen as a preliminary assessment, and model layers will be updated in the future as I acquire better datasets.

The unit of analysis (the census tract and barangay) also limit the model's utility. While census tracts are commonly used in studies (such as social vulnerability indices), each tract represents an average of 4000 residents, so there is likely variability within them. Additionally, census tracts are unrelated to the scales at which governance or planning occurs. Barangays do represent the smallest local government unit in the Philippines, but their population varies even more than US census tracts —the largest in Manila has nearly 250,000 residents (Philippine Statistics Authority, 2016). Model results could be used as an initial step in developing a city-wide green infrastructure vision plan or identifying areas for more detailed suitability assessments. These finer scale analyses would identify specific parcels within modeled priority areas for green infrastructure development based on land use, cost, or other constraints.

Despite these important limitations, the GISP model has the potential to inform more strategic green infrastructure spatial planning in these three cities to enhance both social and ecological resilience. NYC and LA already have ambitious plans to expand green infrastructure with explicit multifunctionality aims, and Manila is rapidly developing and is looking for ways to do so in a way that greener and more resilient. Moreover, the modeling approach could be applied to the many other cities worldwide that are investing in multifunctional green space.

Appendix 5.1

Table 13 Affiliations of individuals completing weighting survey

NYC	**LA**	**Manila**
NYC Parks (4)	Council for Watershed health (2)	Makati City, Planning and Technical Services Division
US EPA (2)	Heal the Bay	Malabon City, CENRO
NYC DEP	The Nature Conservancy	Quezon City, Department of Building
Douglas Manor Association	The Mayor's Office	Valenzuela City, Engineering Office, Infrastructure Division
New York Restoration Project	LA Department of Public Works BoS stormwater (City of Los Angeles Stormwater Program)	Mandaluyong City
The New School		San Juan City, CENRO
The Nature Conservancy		Makati City, Urban Development Department
Mid-Atlantic Regional Seed Bank		Pasig City, CENRE
Waterfront Alliance		Panghulo, Obando, Bulacan
BPCP		Manila Observatory
Whitney Museum of American Art		Quezon City, City Planning and Development Office
Hudson River Foundation		Ayala Land, Inc
Bronx & Harlem River Urban Waters Ambassador		Concep, Inc.
Unaffiliated water & sustainability professional		Philippine Institute of Environmental Planners
		Makati City, Department of Environmental Services (2)
		Makati City (4)

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Chapter 6 Comparing conceptualizations of urban climate resilience in theory and practice[12]

Abstract: In the face of climate change, scholars and policymakers are increasingly concerned with fostering "urban resilience". This paper seeks to contribute to a better understanding of synergies and differences in how academics and local decision-makers think about resilience in the context of climate change. We compare definitions and characteristics of urban climate resilience in the academic literature with a survey of 134 local government representatives from across the U.S. Our analysis shows discrepancies in how academics and practitioners define and characterize urban climate resilience, most notably in their focus on either "bouncing back" or "bouncing forward" after a disturbance. Practitioners have diverse understandings of the concept, but tend to favor potentially problematic "bouncing back" or engineering-based definitions of resilience. While local government respondents confirm the importance of all 16 resilience characteristics we identified in the academic literature, coding practitioners' free response definitions reveals that they rarely mention qualities commonly associated with resilience in the scholarly literature such as diversity, flexibility, and redundancy. These inconsistencies need to be resolved to ensure both the usability of climate resilience research and the effectiveness of resilience policy.

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[12] Published as Meerow S and Stults M (2016) Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice. *Sustainability* 8(701): 1–16. doi:10.3390/su8070701

6.1 Introduction

There is a critical relationship between cities and climate change. On the one hand, urban areas are major contributors to climate change, being responsible for the majority of global energy consumption and greenhouse gas emissions. On the other hand, densely populated urban areas are particularly vulnerable to climate change impacts including sea-level rise, storm surge, heat waves, droughts, and shifting diseases, with vulnerable populations in cities likely to be disproportionately impacted (Hunt & Watkiss, 2010; Klein et al., 2003). Moreover, due to the heat island effect, urban areas are already experiencing amplified warming effects (Stone, 2012), which are likely to continue as the climate warms (Intergovernmental Panel on Climate Change Working Group 2, 2012). In short, climate change is likely to exacerbate existing urban problems and vulnerabilities, placing additional pressure on already strained municipal capacities (Adger, Huq, Brown, Conway, & Hulme, 2003; Tyler & Moench, 2012).

Confronted with these challenges, cities cannot simply sustain the status quo (Jabareen, 2015). This realization has led academics and policymakers to look for new ways to frame development and operations in a manner that helps cities build the capacities needed to effectively and efficiently prepare for climate change impacts (Wamsler, Brink, & Rivera, 2013). Increasingly, these conversations are turning to the concept of resilience (Leichenko, 2011). This 'resilience turn' in urban policy is evident in both the academic literature (Figure 26) and in major policy initiatives like the Rockefeller Foundation's '100 Resilient Cities'.

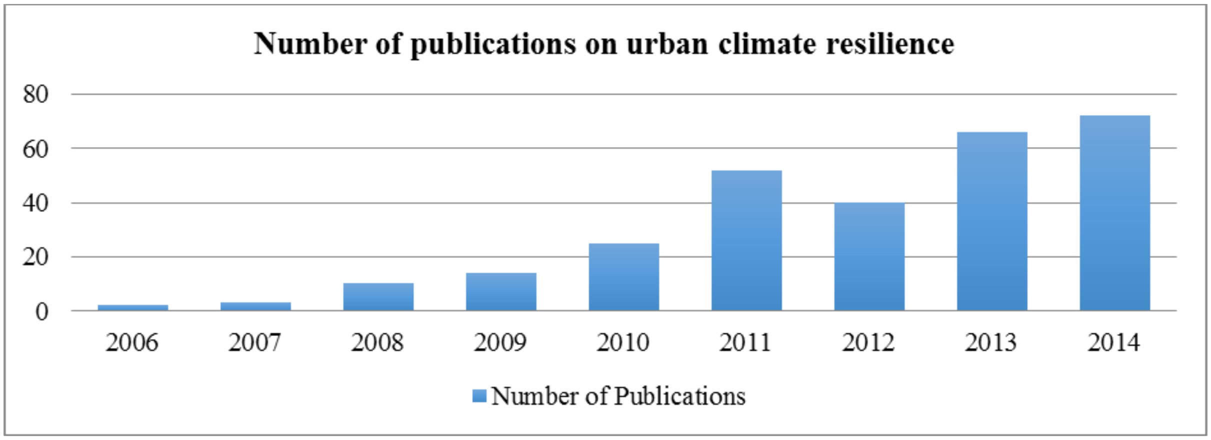

Figure 26 The rise of resilience in climate change research: graph shows the number of citations in Web of Science for each year with the terms "urban resilience" and "climate change" in the title, keywords, or abstract

The concept of resilience is not new. It has a long history of use in engineering, psychology, and ecology (Teigão dos Santos & Partidário, 2011). The urban climate change literature draws heavily on ecological resilience theory originally developed by Holling (Holling, 1973). In his conceptualization, resilience refers to an ecosystem's ability to "persist" in the face of a disturbance or change, but this persistence does not mean that the system remains static (Holling, 1973). Holling and colleagues used this dynamic ecological resilience concept as the foundation for broader theories of change for social-ecological systems (Gunderson & Holling, 2002).

The explosion in popularity of the term "resilience" has been accompanied by an equally remarkable proliferation of definitions of resilience. Some argue that the concept's very popularity is owed at least in part to the fact that the meaning of resilience is "infinitely malleable" (Turner, 2014). Yet scholars have expressed concern that as resilience becomes ubiquitous, the term may lose any real meaning or cause confusion (Cote & Nightingale, 2011). In this regard, resilience may be comparable to other increasingly ambiguous yet fashionable concepts like sustainability (Lhomme, Serre, Diab, & Laganier, 2013). Undoubtedly, one of the strengths of resilience theory is its applicability across disciplines and ability to serve as a boundary object (Star & Griesemer, 1989). This malleability can be a barrier to interdisciplinary collaboration, however, if every discipline has its own idea of what resilience means (Brand & Jax, 2007). The absence of an accepted definition has not stopped researchers from proposing various process- and outcome-focused system characteristics that supposedly enhance climate resilience (Leichenko, 2011). But the lack of a unified understanding of resilience has made it difficult to operationalize the concept or to develop metrics for resilient systems (Leichenko, 2011; Lhomme et al., 2013).

Prior studies have reviewed the academic literature on urban resilience (Jabareen, 2015; Leichenko, 2011; Meerow et al., 2016), but it is unclear how scholarly definitions and characteristics compare with those of practitioners. In this paper we attempt to address this gap and advance our knowledge of how climate resilience is understood in both theory and practice. We compare definitions and characteristics of urban climate resilience from a recent review of the academic literature and a survey of local government practitioners from across the U.S. Our analysis reveals some important inconsistencies in how the scholarly literature defines and characterizes urban climate resilience as opposed how practitioners view the topic, particularly as it relates to recovering and 'bouncing back' versus transformation and 'bouncing forward'. In addition, practitioner survey responses show a much wider range of interpretations of what resilience means in practice than what is widely discussed in the scholarly literature. Collectively, the practitioners seem to favor 'bouncing back' or engineering definitions of resilience, which we argue could be problematic. Survey results also suggest that practitioners see all sixteen characteristics of resilient systems identified in the literature as important, but we find considerable variation in the extent to which practitioners include these characteristics in their own definitions of urban resilience. Ultimately, understanding these synergies and differences in how academics and practitioners are thinking about resilience in the context of urban climate adaptation can lay the foundation for more usable resilience research, which is crucial given the scope of the urban climate change challenge.

6.2 Materials and Methods

To examine how practitioners and academics conceptualize resilience, we combined an extensive literature review with the results of a 2014 survey of U.S. local government practitioners. For the literature review, we drew from a broader review of the urban resilience literature (Meerow et al., 2016), which looked at 172 articles from 1973-2013 with the terms "urban resilience" and "resilient cities" in the title, abstract, or keywords in order to identify how resilience was conceptualized across the literature. We reviewed these articles, as well as the studies they frequently cited, to identify a list of potential characteristics of resilient urban systems. We then developed a survey instrument to gauge how urban climate change resilience is defined and characterized by practitioners and how this compares to definitions and characteristics in the literature. It should be acknowledged that since urban resilience research and practice is rapidly evolving, new definitions have likely emerged since the research was completed.

The survey of local practitioners was conducted as part of a larger project funded by The Kresge Foundation to assess the range of climate adaptation resources and services available to support local climate adaptation (for more information see Nordgren, Stults, & Meerow, 2016). The online survey was developed and administered by the researchers in collaboration with three nonprofit organizations: ICLEI-Local Governments for Sustainability USA (ICLEI), the Urban Sustainability Directors Network (USDN) and the National League of Cities (NLC). The survey instrument, which was built using Qualtrics software, was reviewed by members of the Kresge

Foundation, the project's expert advisory committee, and survey experts at the University of Michigan's Institute for Social Research. The survey was also piloted with students at the University of Michigan and local government staff members from three communities around the U.S. The final survey was distributed by ICLEI, NLC, and USDN through their membership lists, and ran from March 27, 2014 and until May 6, 2014.

We are unable to calculate exactly how many individuals received the survey, since membership in the three organizations administering the survey overlap. However, we estimate that around 1,200 individuals working for local governments received the survey. 446 began taking the survey and 291 completed more than three-quarters of the questions. 134 completed the final two questions on resilience that are pertinent to this analysis. Importantly, the survey sample is not representative of the population of cities in the U.S., since communities elect to be members of each of these three organizations. Nevertheless, the survey as a whole did succeed in capturing a wide range of communities: respondents represented 41 states and were well distributed in terms of local jurisdiction size and geographic features. Respondents' roles in their communities also varied with the largest group (30 percent) working in the energy or environment field (i.e. energy, environmental services, parks, or sustainability staff), followed by 24 percent that serve as elected officials, and 12 percent that work in local government administration.

The survey included a total of 24 questions, but for the purposes of this study, we were primarily interested in the two questions that focus on conceptualizations of resilience. The first of these was a free response question asking respondents, "What do you think it would mean for your local jurisdiction to be resilient to climate change?" A total of 134 respondents provided a response to this question. The second question asked, "In your opinion, how important are each of the following characteristics in making your local jurisdiction more resilient" and then asked respondents to rate the importance of 16 different characteristics on a five-point scale (1-unimportant, 2-slightly important, 3-important, 4-very important, 5-critical). 199 respondents filled out this question. The characteristics (Table 16) were drawn from and defined based on the literature review and chosen because of their common association with resilience. Respondents were also given the opportunity to fill in and rate a self-determined "other" characteristic.

We coded all responses to the question where respondents were asked to define resilience (question one), looking for the presence of the 16 resilience-based characteristics identified in the literature. We also coded the definitions for whether they focused on "bouncing back" or "bouncing forwards," explained in section 6.3.1. All responses were coded independently by two researchers (inter-coder agreement was 94.27%[13]), after which the discrepancies were discussed and reconciled.

6.3 Results: Definitions of a climate resilient city

Definitions of urban climate resilience in the scholarly literature differ, but they do have some commonalities. All definitions identified in our analysis (Table 14) are broad, defining resilience in terms of a generic capacity to deal with climate impacts and disturbances. One key distinguishing factor is the extent to which the definitions incorporate change, as opposed to resistance or recovery. This tension is also evident in the definitions provided in the survey by practitioners. Overall, we find much more variation in the practitioners' definitions of resilience than what exists in the scholarly literature (Table 15).

[13] The inter-coder reliability percentage includes all instances where both researchers agreed on either the absence or presence of the characteristics in the definition.

6.3.1 'Bouncing back' or 'bouncing forward'?

The academic literature makes a major distinction between "engineering resilience," which is about resisting change and returning to a prior state of equilibrium following a disturbance, and "ecological resilience," which focuses on maintaining key functions while accepting that it is not always possible or desirable to return to previous conditions (Holling, 1996; Meerow & Newell, 2015). This division is also framed as 'bouncing back' versus 'bouncing forward' (Shaw & Maythorne, 2012). Prominent resilience scholars, such as the leaders of the international *Resilience Alliance,* advocate for the latter conceptualization. They argue that the concept of resilience, particularly ecological resilience, is better suited for complex systems that must adapt to change and uncertainty. Cities are certainly complex and dynamic systems (Batty, 2008), and indeed, Meerow's et al. (Meerow et al., 2016) review found that the majority of urban resilience definitions are more closely aligned with ecological resilience. Despite this recognition, engineering resilience continues to persist in many fields, including disaster management, economics, and public policy discourses (Davoudi et al., 2012).

That said, there still seems to be some disagreement within the urban climate resilience literature as to whether resilience is about resisting impacts and change or embracing them. Looking at the definitions identified in the literature (Table 14), Henstra's (Henstra, 2012) seems more aligned with engineering resilience since it emphasizes the capacity to "withstand" and "recover." In contrast, Brown et al. (Brown, Dayal, & Rumbaitis Del Rio, 2012) include reorganization and even "transformational change" as part of resilience, which is more consistent with the concept associated with ecological resilience.

This divide is also evident in the different definitions of resilience provided by survey respondents, with engineering, equilibrium perspectives predominating. According to our coding, 35 definitions suggested that resilience was about bouncing back, 15 indicated that it could be about improving and bouncing forward, and 7 indicated that both could be important. In the remaining definitions it was impossible to determine the respondent's position. Five respondents specifically mentioned "bouncing back," another emphasized a "return to normalcy," two others equated resilience to stability, and several highlighted minimal disruption or "community changes" as being key to a resilient urban system.

Table 14 Definitions of urban climate resilience from the academic literature[14]

Authors	Definition
Brown et al. (2012)	"The capacity of an individual, community or institution to dynamically and effectively respond to shifting climate circumstances while continuing to function at an acceptable level. This definition includes the ability to resist or withstand impacts, as well as the ability to recover and re-organize in order to establish the necessary functionality to prevent catastrophic failure at a minimum and the ability to thrive at best. Resilience is thus a spectrum, ranging from avoidance of breakdown to a state where transformational change is possible."
Henstra (2012)	"A climate-resilient city . . . has the capacity to withstand climate change stresses, to respond effectively to climate-related hazards, and to recover quickly from residual negative impacts" (p. 178).
Leichenko (2011)	"The ability of a city or urban system to withstand a wide array of shocks and stresses" (p. 164)
Lu and Stead (2013)	"the ability of a city to absorb disturbance while maintaining its functions and structures" (p. 200).
Thornbush et al. (2013)	"a general quality of the city's social, economic, and natural systems to be sufficiently future-proof" (p. 2).
Tyler and Moench (2012)	"In the case of urban climate adaptation, an approach based on resilience encourages practitioners to consider innovation and change to aid recovery from stresses and shocks that may or may not be predictable...three generalizable elements of urban resilience: systems, agents and institutions." (p. 312)
Wamsler et al. (2013)	"A disaster resilient city can be understood as a city that has managed . . . to: (a) reduce or avoid current and future hazards; (b) reduce current and future susceptibility to hazards; (c) establish functioning mechanisms and structures for disaster response; and (d) establish functioning mechanisms and structures for disaster recovery" (p. 71).
Wardekker et al., (2010)	"A resilience approach makes the system less prone to disturbances, enables quick and flexible responses, and is better capable of dealing with surprises than traditional predictive approaches...a 'bottom–up' way of thinking about adaptation that aims to promote a system's capability of coping with disturbances and surprises" (p. 988)

[14] Definitions taken from review conducted by Meerow et al. (2016)

6.3.2 Unpacking practitioners' definitions of urban resilience

Of the 15 that provided definitions related to bouncing forward or improving, two explicitly mentioned the ability to "bounce forward" and several others saw resilience not just in terms of persisting under changing climate conditions, but actually adapting, improving and thriving. These definitions are more closely aligned with resilience as defined in the social-ecological systems literature.

One of the most striking results of the survey was the variation in the responses practitioners provided when asked what resilience would mean in their local jurisdiction (Table 15). While academics see resilience as omnipresent (Brown, 2013), several practitioners claimed not to know what it means, others noted that it was not acknowledged in their community, and one even dismissed it as "meaningless jargon." In contrast, other respondents called resilience "critical" and "absolutely imperative." Some definitions focused on very specific threats or sectors, like "heavy rain," "hurricanes," or "public transportation," whereas in other cases resilience was more generic, such as "improvement in quality of life." In fact, livability or quality of life was mentioned in almost 10 percent of responses. For more than 20 percent of respondents, resilience had an economic component, whether in terms of general economic prosperity or specifically in terms of reducing the cost of climate impacts. Other common themes (found in at least 5 percent of responses) were health, education and learning, sustainability, self-sufficiency, advanced planning, and the importance of assisting vulnerable populations.

Table 15 Illustrative[15] definitions of urban climate resilience from local practitioner survey

"To be able to bounce back -- with seemingly little or no negative effect - from heavy rains and flooding. To have our city infrastructure built and ready to take on heavy rains and drastically fluctuating temperatures, with little or no impact."
"Achieving the goal of climate change resilience will mean the city can reduce the sensitivity of vulnerable communities to extreme weather events while increasing their capacity to bounce back from such an event. In the long term, this is made possible when city departments will work together to develop a City Climate Resiliency Plan with specific goals & actions. This will have to include the coordination and communication with regional partners."
"Have the ability to bounce forward from climate change impacts to create a more sustainable community."
"Our community could become one that reflects a quality of life that includes the well-being of human and other species. It means a commitment to collaboration, learning new skills and recognition that we are far better together."
"To not suffer economic damage every time a severe weather event hits our city. That we are able to lessen the costs of repairs and shrink the time needed to make those repairs. And to help our residents recover more quickly or suffer less impact from storms."
"It would mean that we are better prepared to respond to the extreme weather events & their consequences that will occur as a result of climate change in all areas of municipal infrastructure & operations, including but not limited to water/wastewater/stormwater, emergency management, public health, public works, urban forestry, parks & recreation, & facility management. It would also mean we are incorporating reasonably foreseeable weather scenarios into our planning & budgeting processes. It would also mean we are better prepared to help our citizens respond to the impacts of climate change, especially those least able to take action on their own, e.g. low-income households, the elderly, the young, those with respiratory & other health problems."
"Be more attractive to certain kinds of businesses. Hopefully prevent poor decisions on location of development for the future."
"We don't even know what you mean by resiliency - sounds like meaningless jargon to us. We have real issues to pursue like public safety and economic development - things that matter now to our residents. Even given unlikely worse case scenarios, our need to react is limited, and not cost effective at this time."

6.4 Results: Characteristics of a climate resilient city

In our review of the academic literature we identified 16 characteristics of urban systems and processes that supposedly foster resilience (Table 16). Hypothesized characteristics of resilient processes include: inclusivity, transparency, and equity in stakeholder engagement approaches (Berke, Cooper, Salvesen, Spurlock, & Rausch, 2011; Leichenko, 2011; Knieling & Filho, 2013) as well as processes that are flexible, forward looking, and iterative (Benson & Stone, 2013; Nelson, Adger, & Brown, 2007; Tyler & Moench, 2012; Walker et al., 2002). Resilience processes are also valued for being knowledge or information driven, meaning that they integrate traditional as well as scientific knowledge into their frameworks and approaches and provide equitable access to information for all parties interested (Dilling & Lemos, 2011; Kawakami,

[15] These eight definitions were chosen from the 101 different responses provided by survey respondents to highlight their variation, and do not represent all conceptualizations.

Aton, Cram, Lai, & Porima, 2007; Vogel, Moser, Kasperson, & Dabelko, 2007). Research in the climate, urban, and resilience fields has postulated that there may be general characteristics of resilience as well as generic/general forms of adaptive capacity that promote resilient systems (Adger & Vincent, 2005; Huq, 2005; Lemos, Eakin, Nelson, Engle, & Johns, 2013; Pearson, Pearce, & Kingham, 2013; Walker & Westley, 2011). Examples of general resilience characteristics include: diversity, iterative/feedback mechanisms, transparency, collaboration and integration, social-ecological integration (also coined environmental focus), efficiency, and adaptive capacity enhancement (Anderies, Folke, Walker, & Ostrom, 2013; Folke et al., 2010; Walker & Westley, 2011). There is also a series of characteristics that are believed to be important for assessing specific resilience to unique climate impacts. Examples include redundancy in the case of drought, robustness in the case of hurricanes and extreme winds, and decentralization in the case of flooding (Adger et al., 2011; Fu & Tang, 2013; McDaniels, Chang, Cole, Mikawoz, & Longstaff, 2008).

When asked to rate the importance of these 16 characteristics (Table 3), survey respondents collectively indicated that they were all important. The mean score for all 16 was high (Figure 27), with very few respondents indicating that any of the characteristics were "1-unimportant" or only "2-slightly important" (Figure 28). Additionally, only 5 respondents listed an "other" characteristic, which could suggest that they were satisfied with the list. There is, however, some variation in the perceived importance of the characteristics. For example, *robustness* had the highest average rating, over 4 (very important), and the largest number of respondents who rated it 5 (critical). In contrast, *decentralization* had the lowest average ranking, although the mean score is still above 3 "important."

Table 16 Sixteen resilience characteristics from the literature

Characteristic	Definition	Illustrative[16] Sources
Robustness	Ensuring municipal-wide infrastructure and organizations can withstand external shocks and quickly return to the previous operational state	(Godschalk, 2003; Rose, 2007)
Redundancy	Having back-up systems, infrastructure, institutions, and agents	(Ahern, 2011; Brown et al., 2012; Campanella, 2006; Desouza & Flanery, 2013; Godschalk, 2003; Wardekker, de Jong, Knoop, & van der Sluijs, 2010; Wilkinson, 2011)
Diversity	Ensuring a diverse economy, infrastructure, and resource base (e.g. not relying on single mode of operation, solution, or agent/institution)	(Ahern, 2011; Desouza & Flanery, 2013; Godschalk, 2003; Liao, 2012; Lu & Stead, 2013; Tyler & Moench, 2012; Wilkinson, 2011)
Integration	Making sure that plans and actions are integrated across multiple departments and external organizations	(Coaffee, 2013; Eraydin, 2013; Tyler & Moench, 2012)
Inclusivity	Ensuring that all residents have access to municipal infrastructure and services, including providing an opportunity for all people to participate in decision-making processes	(Eraydin, 2013; Tanner, Mitchell, Polack, & Guenther, 2009; Tyler & Moench, 2012)
Equity	Ensuring that the benefits and impacts associated with actions are felt equitably throughout the municipality	(Bahadur, Ibrahim, & Tanner, 2010; Godschalk, 2003)
Iterative Process	Creating a process whereby feedback and lessons learned are continually used to inform future actions	(Brown et al., 2012; Tyler & Moench, 2012)
Decentralization	Decentralizing services, resources, and governance (e.g., solar or wind energy; stronger local governance)	(Ahern, 2011; Chelleri, 2012; Tanner et al., 2009)
Feedback	Building mechanisms so that information is rapidly fed back to decision-makers or system operators	(Ahern, 2011; Wilkinson, 2011)
Environmental	Protecting natural systems and assets	(Brown et al., 2012; Godschalk, 2003)
Transparency	Ensuring that all municipal processes and operations are open and transparent	(Tanner et al., 2009; Tyler & Moench, 2012)
Flexibility	Making municipal operations and plans flexible and open to change when needed	(Ahern, 2011; Bahadur et al., 2010; Tanner et al., 2009)
Forward-Thinking	Integrating information about future conditions (i.e., population, economy, weather) into community planning and decision-making	(Tyler & Moench, 2012; Wardekker et al., 2010)
Adaptive Capacity	Ensuring that all residents have the capacity to adapt to climate change	(Eraydin et al., 2013; Wardekker et al., 2010)
Predictable	Ensuring that systems are designed to fail in predictable, safe ways	(Ahern, 2011; Tyler & Moench, 2012)
Efficiency	Enhancing the efficiency of government and external operations	(Godschalk, 2003; Rose, 2007)

[16] References are meant to be illustrative, and do not represent an exhaustive list of studies that mention these characteristics.

A review of survey respondents' collective rating of the 16 characteristics (Figure 27) combined with those included in their free responses (Figure 29) suggest some differences in what practitioners and the scholarly literature view as resilience. For example, some of the most commonly cited characteristics in the academic literature, such as *diversity, redundancy, flexibility, decentralization, and adaptive capacity*, were not among the highest rated by local government respondents. Conversely, practitioners emphasized the importance of *robustness*, yet there is debate in the literature about the universal desirability of this attribute. There were other characteristics commonly mentioned in the literature that practitioners simply did not focus on, including being *predictable* or safe-to-fail, *iterative*, having good systems for *feedback*, and *transparency*. Where scholars and local government respondents did seem to agree was on the importance of supporting *environmental* systems, *equity*, and *integration*.

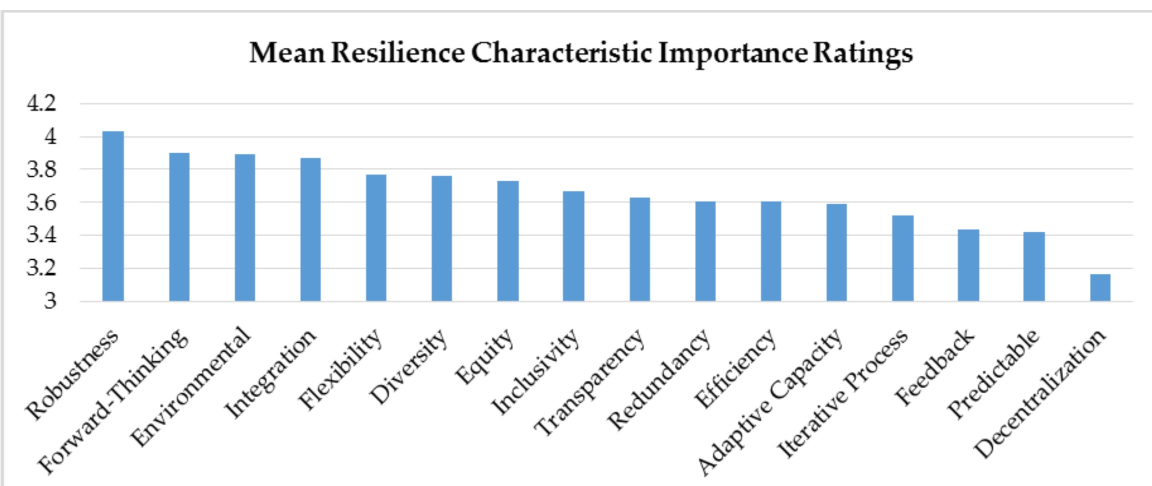

Figure 27 Mean resilience characteristic importance rating

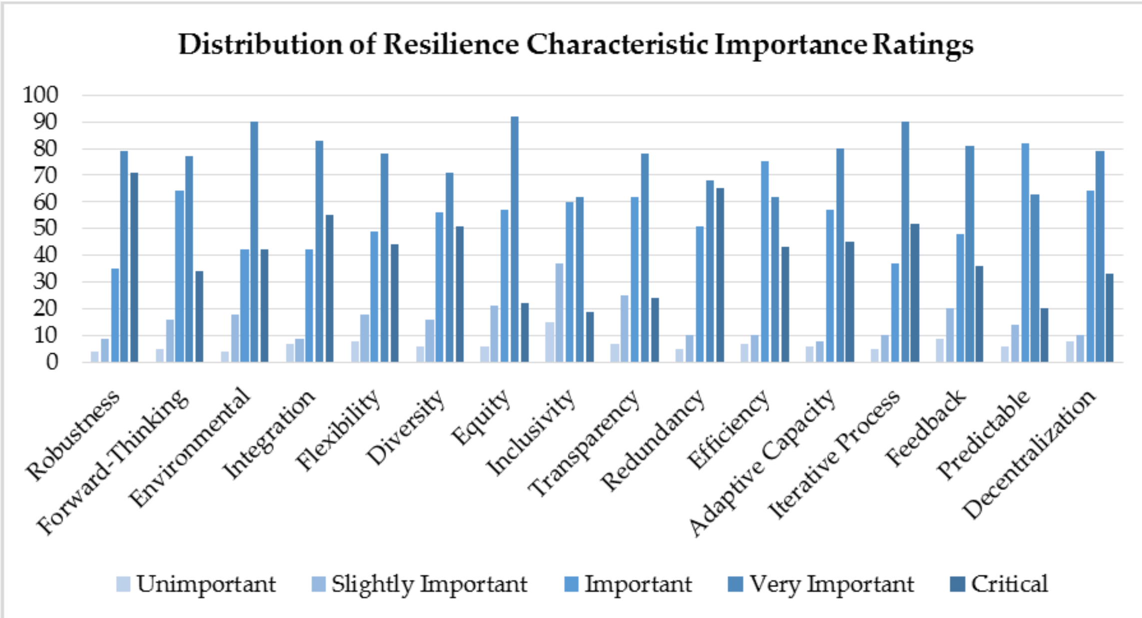

Figure 28 Distribution of resilience characteristic importance ratings

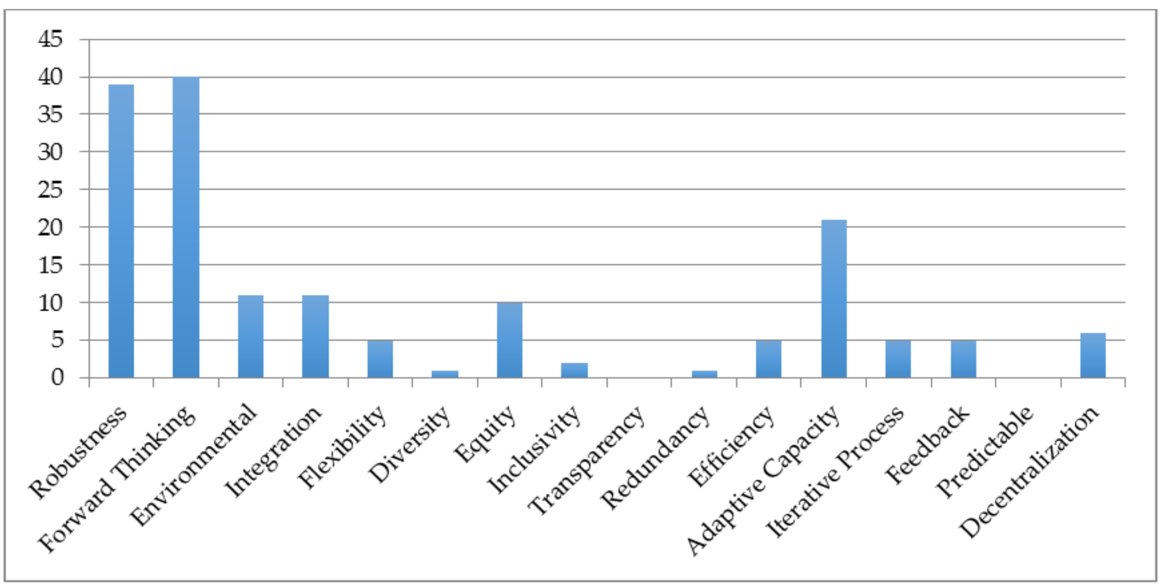

Figure 29 Number of practitioner definitions referencing resilience characteristics based on coding

6.5 Tensions between resilience characteristics in theory and practice

In the urban resilience literature, *robustness* is about a system's ability to resist change or disturbance: it is essentially about "strength" (Lu & Stead, 2013). In the survey, the characteristic *robustness* was defined as "ensuring municipal-wide infrastructure and organizations can withstand external shocks and quickly return to the previous operational state." *Robustness* is very similar to the notion of engineering resilience. If *robustness* is seen as a desirable characteristic of a system, it implies a wish to maintain the status quo. This is not controversial when thinking about certain scales or engineered systems; no one wants a building to collapse in a hurricane. But there are many other more problematic, but nonetheless robust, aspects of modern cities (i.e. inequality or the reliance on fossil fuels). Many critics of resilience discourse and policy argue that resilience, particularly when applied to social systems, is inherently conservative and often employed to prevent positive transformations (Brown, 2012; MacKinnon & Derickson, 2012). In response to these criticisms, some resilience scholars have incorporated transformation into their conceptualizations of resilience (Olsson et al., 2014). In academic theory, the trend seems to be away from static, engineering resilience with its emphasis on robust systems towards these more flexible and adaptive forms of resilience. However, the high importance ascribed to *robustness*, as well as the numerous references in the definitions to 'bouncing back,' suggest that it persists as a dominant line of thinking in 'on-the-ground' urban resilience activities.

According to the local practitioners surveyed, the characteristic *forward-thinking* was second only to *robustness* in terms of average importance. For the purposes of the survey, *forward-thinking* was defined as "Integrating information about future conditions (i.e., population, economy, weather) into community planning and decision-making." In the definitions written by practitioners, almost one in ten specifically mentioned the future, and nearly 15 percent of responses suggested the need for advanced planning. For example, one respondent defined resilience as "No surprises for changing landscape. Advanced planning to make us better prepared." Another wrote "… as change occurs, it has been anticipated and planned for such that no or minimal disruption occurs."

While the academic literature also emphasizes preparing for future changes, some resilience scholars caution against too much emphasis on prediction or the use of single scenarios to understand future threats. Instead, focus is placed on techniques such as scenario planning (Jabareen, 2015) and the selection of actions that will perform well under a wide array of potential future conditions (known as robust actions in the scholarly literature; Quay, 2010). This assessment did not evaluate the types of tools or techniques that local practitioners are using as part of their advanced planning, but it is important to provide practitioners with appropriate tools and the support needed to effectively utilize them.

Another area of discrepancy relates to the relative importance of *adaptive capacity*. In the urban climate resilience literature, building resilience is often equated with enhancing *adaptive capacity* (Leichenko, 2011). However, survey respondents did not rate *adaptive capacity* among the most important characteristics. Furthermore, the term *adaptive capacity* was not explicitly used in any respondents' definitions; however, 21 respondents did allude to it.

In the academic literature, *flexibility* is one of the most commonly cited resilience characteristics (Leichenko, 2011). *Flexibility* means that a system can function under different circumstances and absorb change (Tyler & Moench, 2012). In the survey, *flexibility* was defined as "making municipal operations and plans flexible and open to change when needed." Unfortunately, efficient adaptation and *robustness* against certain threats may come at the expense of the *flexibility* to deal with unexpected future changes (Nelson, Adger, & Brown, 2007). If practitioners are primarily focused on *robustness*, as the survey results suggest, urban systems may not be sufficiently flexible to deal with unexpected climate impacts or other stressors. There were two respondents who explicitly called out *flexibility*: one noted that moving towards climate resilience would mean “increasing flexibility” and another noted resilient jurisdictions should “exhibit nimble behavior.” Overall, however, *flexibility* was not highlighted in the practitioners’ definition of resilience. This seems logical given that local institutional structures and decision-making processes are rigid, making the creation of flexible, adaptive systems capable of integrating emerging information and changing, as needed, a challenge. Going forward, devising solutions to build more flexible systems will likely remain an important area of research.

Like *flexibility*, *diversity* is frequently cited in the literature as a key characteristic of resilience. This relates back to ecological theory, which suggests that biodiversity enhances the ability of an ecosystem to withstand change (Ahern, 2011). Looking specifically at the urban climate change context, Tyler and Moench (Tyler & Moench, 2012) differentiate between “spatial diversity,” meaning system components are widely distributed to reduce the likelihood that the whole system is impacted by a single disruption, and “functional diversity," where there are multiple avenues for meeting critical needs. *Diversity* can also be applied to governance systems, with the idea that polycentric systems that engage a wide array of stakeholders are more resilient (Leichenko, 2011). For the purposes of the survey, *diversity* was defined more broadly as “Ensuring a diverse economy, infrastructure, and resource base (e.g. not relying on single mode of operation, solution, or agent/institution).” Given the emphasis on *diversity* in the resilience literature, it was surprising that more respondents did not rate it as important, and only one explicitly mentioned *diversity* in their definition.

Related to the concept of spatial diversity, scholars have argued that decentralized systems are more resilient than centralized ones because when something disrupts a central unit, the entire system is jeopardized, whereas in a decentralized system it only impacts a small portion. In the literature, arguments are made for *decentralization* in both physical systems (like electricity generation) and governance (Bahadur & Tanner, 2014; Nelson et al., 2007). Admittedly, some resilience scholars caution that decentralized governance may not be universally preferable (Cote & Nightingale, 2011; Lebel et al., 2006). Survey respondents clearly rated *decentralization*, defined in terms of "decentralizing services, resources, and governance e.g., solar or wind energy; stronger local governance", as less critical for resilience than all the other 15 criteria. Similarly, none of their definitions mentioned *decentralization*.

For most resilience scholars, a certain level of functional *redundancy* is thought to enhance resilience; the argument being that when you have units with overlapping functions, if one falters, it can be easily substituted (Wardekker et al., 2010). The definition provided for *redundancy* in the survey was "having back-up systems, infrastructure, institutions, and agents". Like *diversity*, *redundancy* is a characteristic that can be applied to both technical systems, like electricity infrastructure, and social networks. Only one respondent mentioned *redundancy* in their definition, and then only in the context of "water and power systems."

This mismatch between theory and practice on *redundancy* could stem from the fact that *redundancy* has a somewhat negative connotation, and supporting it may seem to conflict with cost or even eco- efficiency (Brown et al., 2012; Godschalk, 2003). In fact, scholars have cautioned that *efficiency* may be at odds with *redundancy* (Walker & Salt, 2006) and that "efficiency, as traditionally conceived, does not necessarily promote resilience" (Zhu & Ruth, 2013). Yet *efficiency* still tends to have a positive connotation in popular discourse, and is sometimes cited in the literature as a characteristic of resilient urban systems (Lu & Stead, 2013).

Some urban resilience scholars such as Ahern (Ahern, 2011) have argued that resilient systems should be "safe-to-fail" as opposed to "fail-safe." In the survey, this was represented by the characteristic *predictable*, defined as "ensuring that systems are designed to fail in predictable, safe ways." Looking specifically at urban climate resilience, Tyler and Moench define "safe failure" as "the ability to absorb sudden shocks (including those that exceed design thresholds) or the cumulative effects of slow-onset stress in ways that avoid catastrophic failure. Safe failure also refers to the interdependence of various systems, which support each other; failures in one structure or linkage being unlikely to result in cascading impacts across other systems." Practitioners did not seem to consider this characteristic to be important, and "predictability" or "safe-to-fail" was not mentioned in any of the resilience definitions. In fact, one respondent even commented "why would anyone design a system to fail," indicating the mismatch between what theoretically is conceived of as being important to resilient systems and what is achievable in practice.

According to the literature, efforts to build resilience should be conducted iteratively, providing opportunities for participants to take stock of what has been learned and apply that knowledge to the next step (Brown et al., 2012; Tyler & Moench, 2012). As defined in the survey, an *iterative process* is "one whereby feedback and lessons learned are continually used to inform future actions." This characteristic emphasizes the importance of learning, which "includes not only the mobilization and sharing of knowledge but also such factors as basic literacy and access to education. These kinds of factors have been identified empirically as contributing to community resilience to disasters." (Tyler & Moench, 2012, p. 315). Iterative learning is also an important part of the popular adaptive management approach, which is closely tied to resilience theory (Bahadur et al., 2010). While the *iterative process* characteristic was not rated as important, on average, as other characteristics, the terms "understanding," "education," or "learning" did appear in almost 10 percent of respondents' definitions. For example, one respondent wrote that resilience means "a commitment to…learning new skills," another "an educated community," and still others noted that residents need to be educated on climate change.

Implementing tight *feedbacks* – or as defined in the survey: "building mechanisms so that information is rapidly fed back to decision-makers or system operators" – can support the iterative process, learning, and ultimately, the resilience of urban systems (Walker & Salt, 2006; Wilkinson, 2011). As previously noted, a number of practitioners referred to education or learning in their conceptualizations of resilience, but none of them mentioned *feedback* directly. On average, respondents also rated this characteristic relatively low in importance.

Transparency and *inclusivity* are also both process- or governance-related characteristics. The meaning of *transparency* as described in the survey is "ensuring that all municipal processes and operations are open and transparent." Survey respondents were prompted to think of *inclusivity* as "Ensuring that all residents have access to municipal infrastructure and services, including providing an opportunity for all people to participate in decision-making processes." While *transparency* and *inclusivity* are not as commonly associated with resilience theory as other characteristics such as *diversity* and *flexibility*, both are mentioned in the literature as being important for continued engagement and good governance. For example, Tanner et al. (Tanner et al., 2009, p. 22) note that a "delivery of climate resilient urban development relies on a municipal system that maintains a relationship of accountability to its citizens, and is open in terms of financial management, information on the use of funds and adherence to legal and administrative policies." Researchers also emphasize the importance of inclusive, participatory decision-making processes that engage those groups most heavily impacted (Tyler & Moench, 2012). This emphasis was not mirrored in practitioners' definitions of resilience; neither *transparency* nor *inclusivity* were mentioned in any of the survey responses.

6.6 Synergies between theory and practice

While we do see a number of inconsistencies and unresolved issues with respect to resilience characteristics in the academic literature and amongst the surveyed practitioners, there are some promising areas of agreement. Within the urban climate change literature, the concept of resilience is most often traced back to the field of ecology, and therefore the maintenance of ecosystems and the relationship between humans and the environment are often central to definitions of resilience. The survey results reveal that practitioners also consider being *environmental*, defined as "protecting natural systems and assets," as quite important for resilience. It was, on average, the third highest rated characteristic. Moreover, several respondents specifically mentioned "ecosystem health," "ecosystem integrity," "ecosystem services," "natural resources," and "biodiversity" in their definitions of resilience.

While resilience theory is often praised for its focus on the interconnections between social and ecological systems, a common critique leveled against resilience theory generally, and urban climate resilience more specifically, is that it fails to address issues of equity (Friend & Moench, 2013; Schrock, Bassett, & Green, 2015). These scholars critically ask 'resilience for whom?' and argue that because resilience theory traditionally uses a systems approach, it ignores inequalities and trade-offs within the system boundaries (Vale, 2014). It is therefore interesting that practitioners rated the importance of *equity*, defined in terms of "ensuring that the benefits and impacts associated with actions are felt equitably throughout the municipality," fairly high. While the word *equity* was not used in any of the respondents' definitions, a number of them did specifically mention assisting vulnerable or less powerful groups within their communities. For example, one respondent wrote that resilience "would also mean we are better prepared to help our citizens respond to the impacts of climate change, especially those least able to take action on their own, e.g. low-income households, the elderly, the young, those with respiratory & other health problems." Another respondent noted, "our priority is to build resilience in our institutions, systems, infrastructure, and communities [that] must protect the poor, elderly, young and ill against hazards and shocks."

The characteristic *integration*, as defined in the survey, requires "making sure that plans and actions are integrated across multiple departments and external organizations." Jabareen (Jabareen, 2013, 2015) argues that dealing with the uncertainties and complexities of climate change necessitates an "integrative approach," one that fosters collaboration across a multitude of public and private stakeholders, agencies, and organizations. Additionally, adaptation planning may be more effective if it is integrated into other local plans, with plans at the state or federal level, or combined with efforts of surrounding municipalities (Henstra, 2012; Muller, 2007). A number of the survey respondents specifically mentioned *integration* in their definitions. For example, one noted that resilience suggests an approach "to foster integrative - cross sector, cross discipline – solutions." Another definition did not use the term *integration* but noted that to be resilient they would need to "include climate adaptation in all of our future planning functions - capital plans, resource allocation, stormwater, etc." Similarly, another respondent highlighted the importance of "regular communications between all sectors and with and among the community."

Overall, scholars and practitioners seem to agree on the importance of supporting ecological systems, equity, and integrated planning for urban resilience, so there is some common ground for collaboration or knowledge exchange. However, there are a number of other theorized characteristics that practitioners see as relatively less important, or that have been called into question by other scholars. In particular, practitioners' emphasis on *robustness*, which is associated with an engineering or 'bounce back' conceptualization of resilience, may be problematic.

6.7 Conclusions

It is clear from our comparative analysis of the literature on urban climate resilience and the results of a survey of U.S. local government respondents that academics and practitioners define and characterize urban climate resilience differently (Table 17). Although the practitioners generally confirmed the importance of the 16 resilience characteristics commonly discussed in the academic literature (and did not suggest many others), when prompted to define resilience, they did not incorporate most of these characteristics into their definitions. Furthermore, the characteristics that were rated most important on average did not necessarily match those that are cited most frequently in the practitioners' definitions of resilience or those frequently discussed in the academic literature. For example, *diversity, flexibility*, and *redundancy* are considered fundamental to resilience in the scholarly literature, yet they are rarely mentioned in practitioners' definitions. Conversely, *robustness*, which is more controversial in the resilience literature, was rated as the most important characteristic in the survey. Another interesting difference relates to how many practitioners still use a more engineering, or 'bounce back' conceptualization of resilience as compared to the scholarly literature, which seemed to be moving towards a 'bouncing forward' conceptualization. This is consistent with the findings of other studies (Davoudi et al., 2012), and bolsters criticisms that resilience policy and discourse is overly focused on maintaining the status quo and therefore inherently conservative (Cretney, 2014; Joseph, 2013; Mackinnon & Derickson, n.d.). This is particularly disheartening for those who would like to see transformative urban change.

Table 17 Key differences in how academics and practitioners conceptualize urban resilience

	Academic literature	Local government practitioners
Resilience as 'bouncing forward' vs. 'bouncing back'	Majority 'bouncing forward'	Majority 'bouncing back'
Definition consistency	Some differences, but share a broad focus on coping with climate and disturbances	Huge variation in meaning, perceived importance, scope, and specificity
Commonly cited characteristics	Diversity, flexibility, redundancy, adaptive capacity, integration, inclusivity, equity, iterative process, decentralization, feedback, environmental, transparency, forward-thinking, predictable	Robustness, forward-thinking, environmental, integration, equity
Less frequently cited or contested characteristics	Robustness, efficiency	Decentralization, predictable, redundancy, feedback, iterative process, transparency

These findings highlight several avenues for future research. First, it would be interesting to survey urban climate resilience scholars and ask them to rate the importance of the sixteen characteristics, to allow for more direct comparison between the survey results and the thinking of leading resilience scholars. It would also be useful to conduct a more representative sample of local practitioners in the U.S. and to survey practitioners in other countries to see how their definitions and characteristic ratings compare. This latter point seems logical since many of the academics whose work we reviewed are not from the U.S. Given the recent explosion in resilience research and policy, it would also be useful to rerun the survey and update the literature review to see whether understandings of resilience have changed in the last couple years. Moving beyond this study, there is a clear need to explore why scholars and practitioners have different conceptualizations of resilience and to empirically examine and test resilience characteristics in different urban contexts to see what types of activities are being implemented at the local level to build more resilient communities and how these activities relate to what is known about fostering resilience.

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Chapter 7 Double exposure, infrastructure planning, and urban climate resilience in coastal megacities: A case study of Manila

Abstract: Coastal megacities pose a particular challenge for climate change adaptation and resilience planning. These dense concentrations of population, economic activity, and consumption—the majority of which are in the Global South—are often extremely vulnerable to climate change impacts such as sea level rise and extreme weather. This paper unpacks these complexities through a case study of Metropolitan Manila, the capital of the Philippines, which represents an example of 'double exposure' to climate change impacts and globalization and associated neoliberal urbanism. The city is experiencing tremendous population and economic growth, yet Manila is plagued by frequent natural disasters, congestion, inadequate infrastructure, poverty, and income inequality. The need for metro-wide planning and infrastructure transformations to address these problems is widely recognized, but governance challenges are a major barrier. Drawing on fieldwork, interviews, and other primary and secondary sources, I argue that climate change and globalization, in combination with Manila's historical and physical context, critically shape metro-wide infrastructure planning. Focusing on electricity and green infrastructure, I find that the largely decentralized and privatized urban governance regime is perpetuating a fragmented and unequal city, which may undermine urban climate resilience. This study extends the double exposure framework to examine how global processes interact with contextual factors to critically shape urban infrastructure planning, and how the resulting system conforms to theorized characteristics of urban climate resilience. In

doing so, I help to connect emerging literatures on double exposure, urban infrastructure planning, and urban climate resilience.

7.1 Introduction

From 1970 to 2015, the number of megacities with populations over 10 million increased from two to 29 (UN DESA, 2011). This rapid urbanization strains urban infrastructure and introduces other environmental and socio-economic problems (Seto et al., 2010). Climate change puts additional pressure on municipal capacities, as cities are both major drivers of greenhouse gas emissions and vulnerable to climate change impacts. Most megacities are located along coasts, exposing them to sea-level rise and more intense storms (Klein et al., 2003). Scholars and policymakers increasingly focus on finding ways to address this "urban climate challenge," often framed as the need to build urban resilience (Johnson et al., 2016).

The resilience of today's megacities is dependent on an intricately connected network of critical infrastructure that provides shelter, energy, water, waste, and transportation services (Vespignani, 2010). Enhancing resilience through improved 'hard' infrastructure, such as the power grid, or 'soft' green infrastructure requires proactive, coordinated planning and considerable investment (Ahern, 2007; Tanner et al., 2009). This is particularly challenging for megacities in the Global South, which are already struggling to provide basic infrastructure for growing populations (Hunt and Watkiss, 2010). Income inequality and large informal settlements further complicate resilience planning, since certain segments of the population disproportionately suffer from climate impacts (Adger, 2006).

Similar patterns of inequality between and within cities are attributed to economic globalization and associated neoliberal reforms (Peck, Theodore, & Brenner, 2009). Neoliberal ideology—characterized by market-oriented development, a reduced role for national government, deregulation, privatization, and often decentralization—has become deeply entrenched in cities across the globe (Leitner et al., 2007; Robinson, 2011). Urban areas play a central role in facilitating globalization while also being shaped by it (Sassen, 1991). Cities are centers for market-based economic growth and urban policies are driven by efforts to compete in the global economy and to be seen as an attractive 'global city' (Peck and Tickell, 2002; Shatkin, 2005). Many scholars argue that the results of globalization and neoliberal restructuring are highly uneven and often destructive (Brenner and Theodore, 2002; Harvey, 2005).

To complicate matters, ongoing processes of globalization and neoliberalization are coinciding with climate change, and their impacts intersect to reinforce patterns of inequality and vulnerability, and undermine social-ecological resilience. O'Brien and Leichenko (2000) brought attention to these combined effects through the "double exposure" framework, which has since been expanded and widely adopted (e.g. Burton and Peoples, 2014; Grineski et al., 2013; Jeffers, 2013; Silva et al., 2010).

This paper contributes to this burgeoning literature by examining how double exposure specifically shapes urban infrastructure planning in rapidly developing megacities, and how this planning, in turn, might impact urban climate resilience. No other studies could be identified that use the framework specifically to examine urban infrastructure planning. It is important to fill this gap since cities cannot function—let alone cope with climate change impacts—without robust infrastructure systems. I use the National Capital Region (NCR) of the Philippines, Metropolitan Manila (hereafter referred to as Manila), as a case study, drawing on fieldwork, interviews, and other primary and secondary sources. Manila is an interesting case because it exemplifies both climate vulnerability and neoliberal urban governance. The city also embodies many of the social, ecological, economic, and political challenges that rapidly developing megacities face, with a growing population of over 14 million (World Bank, 2013).

Urban governance in Manila epitomizes many of the tenets of neoliberal urbanism, including a strong focus on private sector-led development, market-oriented policies, and decentralization (Ortega, 2016b; Shatkin, 2008). Simultaneously, Manila ranks among the world's most vulnerable cities to climate change and other natural hazards (Maplecroft, 2013). The city is already struggling to cope with disasters, and devastating floods occur regularly. For example, in 2009, tropical storm Ketsana, (called Typhoon Ondoy in the Philippines) left more than 80 percent of the city flooded and displaced nearly 300,000 residents (World Bank et al., 2010). In a recent study of 50 world cities, Manila ranked as the fourth least resilient city (above Cairo, Jakarta, and Dhaka; Grosvenor, 2014). I argue that Manila's resilience challenges can only be understood in the context of its double exposure to climate change and globalization. This is not to suggest that contextual factors such as the Philippines' history do not matter, but rather to show how global processes may intensify them. This paper expands this line of argumentation, with a particular focus on urban electricity and green infrastructure planning.

This research combines existing literature and findings from fieldwork in Manila in June-July 2013, May-June 2015, and August 2016. I conducted 38 semi-structured individual and group interviews (see Appendix 7.1, Table 20 for a list of organizations) and two workshops on green infrastructure with mostly local government officials (Appendix 7.2, Table 21). Interviewees represented a diverse array of 'expert' perspectives on urban and infrastructure planning and included high-level officials from national, regional and local government, international and local non-governmental organizations, the private sector, and multiple universities. I focused on these key decision-makers because I was primarily interested in understanding metropolitan infrastructure governance processes. However, this does introduce an important limitation and potential bias to the results—many of these individuals are part of the nation's elite and their perspectives and resilience priorities may differ for those of other citizens.

I used a snowball sampling method to identify interviewees, facilitated by working with a local university contact. I asked interviewees similar open-ended questions about urban infrastructure governance, resilience, and electricity and green infrastructure. Most interviews lasted approximately one hour and were audio recorded and transcribed. I initially took an inductive "open-coding" approach to analyzing the interview transcripts and notes, reading them and noting down common themes and concepts that interviewees themselves used (*in vivo)* (Patton, 2002). For example, I noted that many respondents brought up Manila's highly decentralized urban governance system, and created a code on *decentralization*. Then in repeated readings, I used a more deductive approach, grouping specific quotes under these initial categories and then connecting them with the existing literature on Manila, and ultimately, the theoretical framework.

In the next section, I outline the theoretical framework, which is followed by the Manila case study. First, I discuss how Manila is exposed to climate change and globalization and how these global processes interact with the city's contextual environment. Second, I examine how these contextualized processes interact and are shaping urban infrastructure planning—focusing particularly on electricity and green infrastructure. Third, I assess how infrastructure planning may be affecting the city's climate resilience by examining theorized characteristics of urban resilience. I conclude by discussing broader implications and potential avenues for future research.

7.2 Theoretical framework: Double exposure, megacity infrastructure planning, and resilience

The double exposure framework provides a novel perspective for understanding how the dual processes of global environmental change and globalization interact to shape inequalities and, ultimately, resilience. The framework was developed to show that connections between globalization and environmental change were often underestimated, and to highlight common intersections, combined effects on adaptive capacity, and feedbacks (O'Brien and Leichenko, 2000). It has been applied to different scales and systems, from California's Central Valley (Leichenko et al., 2010) to decision-making in Ireland's coastal cities (Jeffers, 2013). I extend the framework to urban infrastructure planning in the context of climate change in Manila. The double exposure framework consists of five components: 1) processes of global change; 2) exposure; 3) contextual environment; 4) responses; and 5) outcomes (Figure 30). These are briefly explained and applied to the context of megacity infrastructure planning below.

A *process of global change* refers to major transformations occurring concurrently around the world, namely globalization and global environmental change. Here I focus on 1) climate change and 2) globalization and associated neoliberal urbanism (Figure 30). The impacts of these processes are referred to as *exposure*, and the study's unit of analysis (here Manila) is the *exposure frame.* Exposure is mediated by the local context, or *contextual environment*, including myriad "social, economic, biophysical, technological, institutional, political, and cultural" factors (Leichenko and O'Brien, 2008: 35). As the case of Manila will demonstrate, the importance of these elements cannot be overstated. Of course megacities are not isolated units, but rather highly interconnected with regional, national, and global networks and larger economic, political, and ecological systems, all of which can impact the contextual environment. These contextual factors shape *responses* to exposure to processes of global change. Responses refer to decisions and actions that individuals and institutions take because of exposure to global change processes. Here, I focus on metro-wide infrastructure planning occurring in Manila in response to climate change, globalization, and contextual factors.

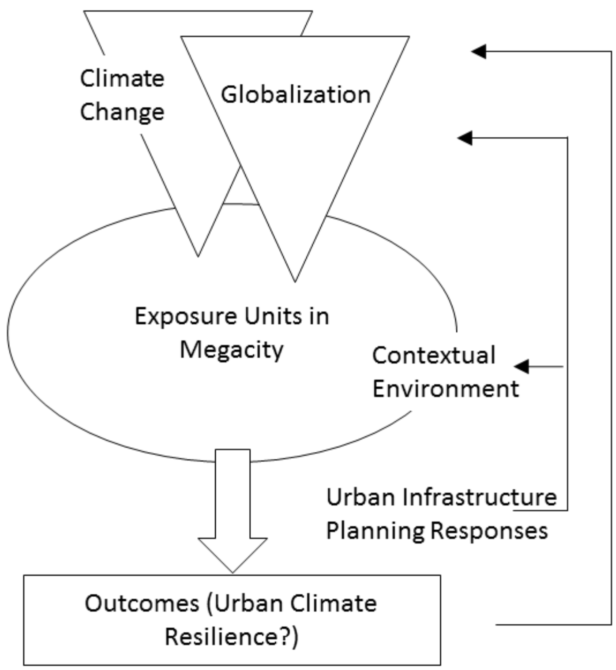

Figure 30 The double exposure framework applied to megacity infrastructure planning[17]

These *responses*, in turn, lead to different *outcomes* for individuals, groups, and the city as a whole. In particular, I am interested in how these outcomes relate to the city's resilience, or its ability to cope with climate impacts. Infrastructure planning responses and outcomes can also lead to *feedbacks* that alter the contextual environment and affect exposure (Figure 30). According to Leichenko and O'Brien (2008, page 83), the outcomes of globalization and climate

[17] Adapted from Leichenko and O'Brien, 2008, page 39

change are frequently undesirable, with a tendency to "increase the vulnerability of some individuals and groups while decreasing resilience of urban systems to future change." Double exposure thus often leads to increased inequality. For example, the negative impacts of environmental change frequently affect people and areas hardest hit by globalization, and conversely those that are positively affected by climate change are often also likely to accrue the benefits of globalization.

7.2.1 Urban infrastructure planning

Urban infrastructure traditionally referred to the networked energy, water, waste, and transportation systems that are central to both environmental problems and solutions, and thus the urban climate challenge (Monstadt, 2009). Built infrastructure systems account for a large share of global greenhouse gas emissions. Simultaneously, the network's robustness affects a city's ability to cope with climate change (Kamal-Chaoui, 2008). Consequently, plans and policies to develop built infrastructure can and should be seen as adaptation efforts (Broto and Bulkeley, 2013). Urban infrastructure is also interesting because it represents the material manifestation of urban politics. As Luque-Ayala and Silver (2016, page xiii) note, "urban electrical networks not only ferry electrons: their geographical reach, terms of access and forms of ownership reflect prevailing distributions of economic and political power."

Scholars have highlighted a global shift in recent decades—coinciding with the rise in neoliberalism—from a standardized, centralized, and more government-led modernist infrastructure ideal to more uneven, decentralized, and privatized infrastructure networks (Graham, 2000). Graham and Marvin (2001) termed this increasing fragmentation and polarization "splintering urbanism." But Kooy and Bakker (2008) and Balbo (1993) argue that cities of the Global South have always been fragmented, often as a legacy of colonialism. Scholars agree that urban infrastructure systems remain highly vulnerable, yet vital to economic development and social justice (Monstadt, 2009).

Electricity infrastructure plays a critical role in mitigation and adaptation. Power systems are vulnerable to extreme weather and changing climates (International Energy Agency, 2015), and because electricity is crucial for many other infrastructure systems, when there are power outages or fuel shortages, the entire industrialized economy comes to a standstill (Molyneaux et al., 2012). Electricity system resilience is particularly essential for coastal megacities, since they are often regional economic hubs, and any disruption will have a wider impact (Wenzel et al., 2007). Moreover, mitigating the worst impacts of climate change will necessitate transitioning to low-carbon power systems, since in 2010 electricity and heat production accounted for 25 percent of global greenhouse gas emissions (IPCC, 2014).

I expand traditional definitions of urban infrastructure to include nature-based green infrastructure, such as street trees, gardens, and parks. These vegetated spaces are increasingly seen as a form of infrastructure similar to water or electricity networks (Schäffler and Swilling, 2013). Green infrastructure is advocated for its multiple social and environmental benefits including stormwater management, wildlife habitat, mitigation of the urban heat island effect and air pollution, and improved mental and physical health, among others (Tzoulas et al., 2007). It is also promoted as a strategy for enhancing climate resilience (Foster et al., 2011; Gill et al., 2007). Consequently, cities are incorporating green infrastructure into resilience planning (Kearns et al., 2014). Who is benefiting from these efforts is less clear as vegetation is often disproportionately clustered in wealthier areas and benefits are localized (Heynen et al., 2006).

Even when green infrastructure is expanded in disadvantaged communities, concerns arise about eco-gentrification (Wolch et al., 2014).

7.2.2. Urban resilience

Leichenko and O'Brien (2008) state that double exposure is likely to increase urban vulnerabilities and reduce resilience. Yet, what that means is debatable since there are different conceptualizations of urban resilience (Davoudi et al., 2012; Pizzo, 2015; Vale, 2014). In an effort to address some of these key conceptual tensions, Meerow et al. (2016, page 39) proposed the definition, "the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity." Thus, a city's resilience crucially shapes its capacity to cope with climate impacts. Meerow and colleagues also note that resilience is unlikely to be evenly distributed across a city. This is why it is crucial to ask 'urban resilience for whom?' (Vale, 2014; Ibid.). Despite its growing popularity, urban climate resilience is a relatively nascent research area (Brown et al., 2012). There is still no consensus on how to assess urban resilience, but there are a number of characteristics related to urban systems and planning processes that are widely cited in the literature as contributing to resilience, such as diversity, flexibility, redundancy, and inclusiveness (Leichenko, 2011; Tyler and Moench, 2012). I review these characteristics in more detail in the fourth section of this paper, and then use them to examine the resilience implications of physical infrastructure networks and their governance in Manila.

7.3 Processes of global change and the contextual environment in Manila

Manila is one of the world's cities most vulnerable to natural disasters and climate change impacts, and it has embraced globalization and many aspects of neoliberal urbanism. This section describes these processes and how they are crucially mediated by the local context.

7.3.1 Exposure to environmental change

Manila is precariously built in the southwestern part of the Philippines' largest island, Luzon, on an isthmus with Manila Bay in the west, Laguna de Bay lake in the east, and mountains (including active volcanoes) to the north (Manasan and Mercado, 1999; Roberts, 2011; Figure 31). About 69% of Manila is built on areas of higher elevation (e.g. Marikina Valley), but the rest of the city is prone to flooding, including areas along the coast and around the Pasig and Marikina River systems (Magno-Ballesteros, 2000). The Philippines is also in the Ring of Fire, and the West Valley Fault—which snakes through some of the densest areas of Manila—could trigger a major earthquake at any time (Boquet, 2015). Typhoons are a regular occurrence, and in 2009 Ondoy caused flood waters to reach seven meters in some parts of the city, displacing approximately 300,000 residents (World Bank et al., 2010). According to a United Nations report, Manila is the only megacity where the risk of three or more natural hazards is in the top three deciles (UN DESA, 2011).

Climate change will likely exacerbate these risks. Anticipated impacts include increasingly frequent and intense extreme weather events and sea level rise, with more of the population at risk of flooding. Models show that without major planning, the area exposed to flooding from a 100-year storm is likely to increase by 18.2% by 2050 (World Bank et al., 2010). Manila's poorest residents are frequently the hardest hit by flooding and other climate impacts (Israel and Briones, 2014; Porio, 2011). Approximately four million people (one third of

Manila's population) live in informal settlements scattered across the city, many of which are located in extremely vulnerable areas such as river banks or under bridges (Boquet, 2015). Not only are these populations more exposed to environmental hazards, but they also have fewer resources to recover and are more likely to be bankrupted as a result of a flood or storm (Zoleta-Nantes, 2002). Continued urban migration and high birth rates in the Philippines suggest the number of urban poor living in Manila will only increase.

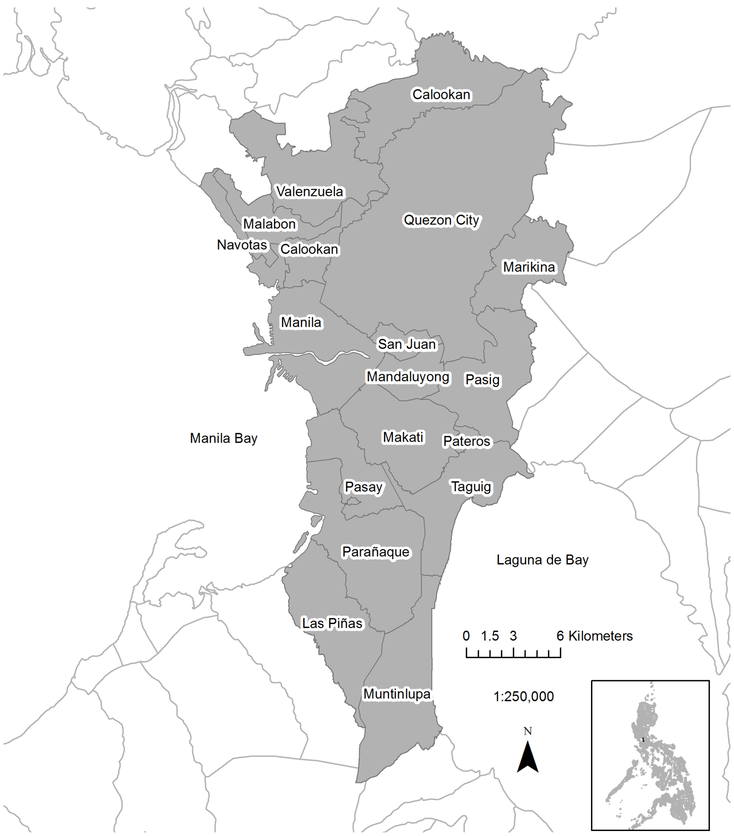

Figure 31 Map of Metropolitan Manila
Note: Data from PhilGIS, 2011

7.3.2 Exposure to globalization

Manila is a 'global city,' inextricably connected to globalized systems of material production and consumption (Connell, 1999). It is home to a growing number of business processing outsourcing (BPO) companies, international corporations and regional headquarters, such as the Asian Development Bank. Investments and remittances from the Philippines' estimated 2.4 million overseas workers are a major source of GDP growth and development for the city (Philippine Statistics Authority, 2016; Raquiza, 2017). Urban development in Manila is also shaped by efforts to attract foreign investment, by (arguably post-colonial) aspirations to be seen as a modern global city, and by the influence of transnational organizations such as the World Bank, International Monetary Fund (IMF), and World Trade Organization (WTO) (Ortega, 2012, 2016a; Tyner, 2006).

Exposure and responses to globalization can only be understood in the historical context of the Philippines (For a more detailed history see Connell (1999), Garrido (2013), Roberts (2011), Michel (2010), or Ortega (2016a, 2016b)). Urban governance has shifted with the country's various regimes, yet throughout most of its history, Manila's development has been shaped primarily by the private sector (particularly a set of elite land-owning families), lacked centralized urban planning, and been highly uneven (Magno-Ballesteros, 2000; Michel, 2010).

The country was a Spanish colony from the 16th century until the United States annexed it in 1898 after its victory in the Spanish American War (in opposition to the Philippines declaration of independence that same year). During the period of American rule, Daniel Burnham developed a master plan for Manila based on 'City Beautiful' principles, including large public parks and buildings (Roberts, 2011). This grand plan was never fully implemented, nor were efforts to establish a metropolitan organization successful, in part because of opposition from elite land-owning families (Magno-Ballesteros, 2000). The Philippines remained under U.S. influence until World War II, when the city was occupied by the Japanese and heavily bombed (Choi, 2016). The US granted full independence to the Philippines in 1946. From the 1950s to the 1970s, metro planning was quite decentralized, deregulated, and development occurred mostly "piecemeal" at the subdivision scale (Connell, 1999; Magno-Ballesteros, 2000: 13). It was in this period that the Ayala Corporation developed the exclusive master-planned Makati City, introducing a new model of private sector-led city development that has been replicated across Manila (Garrido, 2013).

Ferdinand Marcos was elected president in 1965, and declared martial law in 1972, initiating more than a decade of authoritarian rule. The Marcos years were plagued by corruption and cronyism that undermined development and enhanced inequality (Magno-Ballesteros, 2000). Rising national debt in the early 1980s led the World Bank to push for trade liberalization policies in the Philippines, which endured after Marcos' departure (Bello et al., 2004). During the Marcos era the government played an exceptionally strong role in coordinating Manila's development, and key urban planning regulations were established (Garrido, 2013; Magno-Ballesteros, 2000). These included the creation of the first coordinating body for the metro region in 1975, the Metro Manila Commission (MMC). Imelda Marcos, Ferdinand's wife, chaired the MMC and served as Mayor of Metro Manila. With the country under martial law, the MMC was granted considerable powers, including the ability to collect taxes and pass ordinances (Manasan and Mercado, 1999). The MMC enacted zoning restrictions and developed an ambitious master plan for Manila, although this too was never fully enacted, again in part because of resistance from local landowners and business elites (Magno-Ballesteros, 2000). The Marcos government also took on a greater role in infrastructure development. The government-owned National Power Corporation, for example, was established to control the electricity system, including planning, generation, and transmission (Sharma et al., 2004).

The Marcos regime was overthrown in 1986, ushering in an era characterized by a "neoliberal vision in national development policy," the consequence of which "has been the adoption of an urban framework that, perhaps more than that of any other country, exemplifies the ideal outlined in the World Bank's vision of the 'new policy agenda'" (Shatkin, 2004: 2479). In recent decades, urban development has become increasingly focused on globalization, market-oriented development, privatization, and decentralization (Michel, 2010). This evolution is partially a product of external influence and policies of global organizations such as the World Bank, but also a reaction to the centralized power and corruption of the Marcos dictatorship (Michel, 2010; Mouton, 2015). Ortega (2016b, page 12) argues that after the EDSA Revolution democratic freedom became associated with free-market capitalism, and "this conflation of democracy, freedom, and global competitiveness served as the basis for an emerging national-neoliberal ideologue."

The new constitution implemented after the EDSA Revolution devolved significant powers to local governments through the Local Government Code of 1991 (Porio, 2012; Shatkin, 2004). The MMC was replaced by a weaker Metro Manila Authority (MMA) through Executive Order 392 (Manasan and Mercado, 1999). The different municipalities within Manila took advantage of this weakness and developed independently and competed to attract global capital (Shatkin, 2004). Private developers have used this to their advantage (Roderos, 2013). Where the metropolitan or national government has intervened—for example to develop transportation connections between commercial business districts—it often seems to have been with the goal of making Manila more competitive and attracting investment (Michel, 2010; Shatkin, 2005). In the post-Marcos era, decentralization has been coupled with a focus on market-based policy and extensive privatization of public infrastructure and services, including the national airline, bank, mining company, and Manila's water distribution utility (Mouton, 2015).

The need for more metro-wide coordination became increasingly clear, and the MMA was replaced by the Metropolitan Manila Development Authority (MMDA) in 1995. Michel (2010) argues that one of the government's primary motivations for creating the MMDA was to make Manila more attractive to foreign capital, as reflected in the MMDA's vision statement, "Towards a world-class metropolis." The MMDA is charged with coordinating metro-wide transportation, flooding and sewage and development, environmental, and land use planning. In practice it is, as one prominent architect in Manila put it, "a development authority without any authority" (Interview 18, May 2015). The MMDA is not led by an elected official and is not able to pass legislation or levy taxes; these powers were given to individual municipalities (Magno-Ballesteros, 2000). Other metro-wide services and funding come from somewhat siloed national government agencies (Mercado and Paez, 2005).

Finally, the important role that overseas workers play in Manila's urban development and global connections needs to be acknowledged. The city serves as the hub for supporting infrastructure (e.g. remittance processing, placement agencies) and travel (Tyner, 2006). Moreover, many new real estate developments in Manila and in its suburban fringes are designed as investments for those working overseas or receiving remittances (Ortega, 2016a).

7.3.3 Double exposure and the contextual environment

To summarize, Manila is highly exposed to climate change and globalization and associated neoliberalization. Manila's contextual environment has amplified the magnitude of this exposure. With respect to climate change, some of these contextual elements include the city's physical geography, rapid urbanization, large numbers of informal settlers, and high rates of poverty and inequality. While neoliberalism is a global phenomenon, its entrenchment in the Philippines is part of a longer trend of private sector-led development and relatively weak, decentralized urban planning, which can be linked to the country's historical legacy of colonialism and dictatorship (Connell, 1999; Garrido, 2013; Michel, 2010; Ortega, 2012). In the next section, I discuss how infrastructure planning has been affected by exposure to these processes, and some of the ways in which they intersect.

7.4 Urban infrastructure planning responses

Metro-wide infrastructure planning for Manila is shaped by global processes and contextual factors, with two of its defining features being decentralization and privatization/deregulation. These, in turn, are leading to highly uneven infrastructure development, consistent in many ways with notions of "splintering urbanism" (Graham and Marvin, 2001; Shatkin, 2008).

Individual municipalities have the authority to develop land use plans, regulations, and taxes within their jurisdictions (Magno-Ballesteros, 2000). Some local governments are more proactive than others, and disparities in their financial standing and capacities exacerbate differences. The MMDA lacks the power or legitimacy needed to force the interconnected cities of Manila to coordinate. According to several interviewees, despite the myriad problems with the Marcos regime, metropolitan coordination at least was better under the MMC (Interview 24, 26, 36, June 2015). As one architect described the transition:

> *"Imelda Marcos was the first lady and the first governor and she was more efficient than anyone else, because [she was] the wife of the president under martial law. And I think that was a watershed with urban planning, they were able to muster together the different agencies that were not coordinated, with conflicting interests, because of the special powers that he had, and he got the undersecretaries and had them [serve as] concurrent*

action officers, so it was more effective and faster in addressing services…" (Interview 36, June 2015).

Similarly, Manasan and Mercado (1999, page 14) note that under the MMC, "the squatter problem was reportedly better controlled; traffic and public transport were better managed; the environment was cleaner and greener." Another interviewee at the MMDA described the MMC to MMDA shift as going from a "German Shepard" to a "Poodle" (Interview 26, June 2015). In its current form, the MMDA is widely regarded as "toothless" and unable to develop a "comprehensive solution" to Manila's myriad infrastructure challenges without angering local governments and the private sector (Interview 37, June 2015).

With little metro-wide oversight, individual municipalities have allowed for-profit developers—many owned by deeply entrenched elite families like the Ayalas—to not only plan housing subdivisions, but whole self-contained "urban systems" or "megaprojects" with their own privileged infrastructure (Shatkin, 2008: 388). The resulting 'modern' and 'sanitized' commercial business districts are designed to appeal to wealthy residents and international firms, and to help the municipalities compete for global status and capital. The public sector is minimally involved in planning these communities. As one urban planner put it, "The system is that it is the private business sector that dictates the pattern and timing of urban development. Government is very reactive" (Interview 24, June 2015). Even the private developers are willing to admit their primacy. Mirasol, president of the Ayala Land Corporation, was quoted in the Singapore Times as saying,

"The fact that there is nobody in the Philippines who regulates urban planning has been great for Ayala Land, because we are probably the only company there that has the scale financially to take on large plots of land…By developing big tracts of land, we become

the government; we control and manage everything. We are the mayors and the governors of the communities that we develop and we do not relinquish this responsibility to the government. But because we develop all the roads, water and sewer systems, and provide infrastructure for power, we manage security, we do garbage collection, we paint every pedestrian crossing and change every light bulb in the streets – the effect of that is how property prices have moved." (Meixian, 2014)

As the quote boasts, this privatized urban development model has increased property values in these communities. The implied result is that low-income residents cannot afford to live there, leaving them no choice but to commute long distances to work in notorious traffic or live in informal settlements in the areas deemed too dangerous for development (Interview 6, July 2013). An obvious solution, according to one respondent, would be for the government to force developers to build low-income housing nearby (Interview 24, July 2015). While policies such as the 1992 Urban Housing and Development Act and the 2012 *Oplan Likas* program for informal settler relocation claim in-city affordable housing to be a priority, most developments occur outside urban centers (Choi, 2016; World Bank, 2016).

Under this planning paradigm, it is largely up to the private sector to work towards more sustainable and resilient urban infrastructure. Admittedly, certain companies are making an effort (Palafox, 2014). The number of Leadership in Energy and Environmental Design (LEED) or locally certified "green" buildings has increased, but some interviewees dismissed this as mostly "green washing" (Interview 20, May 2015; Interview 36, June 2015). This trend may be driven by a desire to attract foreign companies, which multiple architects and planners pointed out are increasingly demanding 'sustainable' office buildings (Interview 24, 36, June 2015). As one planner noted, "If you want to attract a multinational company to put their headquarters [there], they need to be green. So it’s catching on” (Interview 24, June 2015). Next, I explore how these trends play out in the context of electricity and green infrastructure planning.

7.4.1 Electricity infrastructure

As with urban development more broadly, electricity infrastructure was initially dominated by the private sector, then brought progressively under centralized control by the Marcos regime (Navarro et al., 2016). The government-owned National Power Corporation (NPC) and Meralco distribution utility became increasingly insolvent and the Philippines experienced crippling power shortages in the 1990s (Cham, 2007). This led in 2001to the passage of the Electric Power Industry Reform Act (EPIRA), which aimed to create a completely market-based electricity system, regulated by an Energy Regulatory Commission. According to Mouton (2015), Sharma et al. (2004), Bello et al. (2004) and my own interviews with high-level officials in the energy sector, these reforms were in part the result of external pressure from international agencies such as the World Bank and IMF. Proponents claimed that privatization would make the power system more efficient and reliable, free up capital for the government, attract foreign investment, and ultimately better serve consumers (Roxas and Santiago, 2010; Sharma et al., 2004). In the process of privatization, many of Manila’s long-standing elite families (e.g. the Ayalas) have taken and continue to take the opportunity to invest in the industry, often in partnership with foreign corporations (Raquiza, 2017).

While the EPIRA reforms are ongoing, initial results are somewhat ambiguous. Privatization of the power sector was justified on the basis that it would increase reliability and efficiency and prevent a repeat of the 1990s power crisis, but for many reasons supply shortages, system vulnerabilities, and high prices persist (EIA, 2015). According to Navarro (2016) there have been real improvements in reliability and efficiency, however, prices remain higher than before the reforms. Electricity costs in Manila are among the world's highest in the world (EIA, 2015), and to make matters worse, those living in informal settlements without an official grid connection often pay even higher rates because they have to buy it at a markup from neighbors with access to a connection (Porio, 2011). One interviewee ventured a guess that "80 percent of people in these informal settlements pay usurious electricity rates," and yet these communities would "be the areas where electricity will first be compromised" (Interview 6, July 2013). One potential problem is that market-based systems are only efficient if there is fair competition. The electricity industry, however—as with Manila's development more broadly—is controlled by a few powerful corporations that some allege are manipulating the market (Interview 6, July 2013; Mouton, 2015).

Strong centralized planning is needed to ensure that electricity infrastructure is developed to meet Manila's evolving needs (Cham, 2007). Yet by unbundling functions of the power sector, EPIRA makes it more challenging for the government to control. Each entity (transmission utility, generators) now develops their own plan based on their interests. The Department of Energy and Energy Regulatory Commission act as a check, but they can only approve or not approve plans, ultimately they do not control the system. For example, the transmission corporation can identify ideal locations for power plants development (where no new transmission lines will be needed), however, an official from the National Grid Corporation explained that they cannot control where generators propose projects or whether they are approved (Interview 14, July 2013). Similarly, one Climate Change Commission official noted, "I know for a fact that they [DOE] don't have control over the distribution planning… they [the utilities] submit that to the DOE for reviewing but there is very little government control over distribution and transmission" (Interview 6, July 2013). In sum, privatization has left a power vacuum, with no actor truly able to guarantee that new capacity or renewable energy goals will be met. As one energy sector executive observed,

> *"The main issue is there is no institution at the moment that is really into the details of the plan. Because it used to be NPC was doing all the research. They would tell you this resource will be developed and we will commission it on May 15, that's how they plan it, they knew the issues involved. Now the change, tell the private to do everything…The government can't penalize and there is no concrete plan. That is a very difficult situation!"* (Interview 5, July 2013)

Moreover, because of the Local Government Code, the DOE has limited control over how local governments protect critical electricity infrastructure. One DOE official acknowledged that "there is not that much talk going on" between local governments and the private utilities (Interview 1, July 2013). Additionally, while the national government has committed to reducing carbon emissions and expanding renewable energy through the 2008 "Renewable Energy Act" (R.A. 9513), fossil fuel investments have increased and generation share from renewables has decreased post-EPIRA (Marquardt, 2015). In light of these problems, Navarro et al.'s (2016, p. 1) recent assessment concludes that the "regulatory capacity has to be strengthened; and the energy department needs to beef up its planning function."

The reliance on 'privatized planning' has also resulted in the quality of networked electricity infrastructure becoming inconsistent across the city. In many exclusive, privately developed areas (e.g. Bonifacio Global City), developers have begun working directly with utilities for better infrastructure (e.g. buried lines), which improves the relative resilience of their already wealthy clients (Mouton, 2015). Outside of these "premium network spaces" (Graham, 2000), electricity infrastructure for low-income residents tends to be more vulnerable, meaning they are more likely to experience disruptions from extreme weather (Interview 6, July 2013). This last example illustrates the feedbacks between climate change and globalization exposure that reinforce existing inequalities.

7.4.2 Green Infrastructure

A similar pattern can be observed for the development of green infrastructure. There is no coordinated effort to create an interconnected network of public (or private) green space across the city. Green infrastructure development is largely left up to individual municipalities and private developers, and according to one developer, a key barrier for expansion is the failure of markets to recognize the value of it (Interview 37, June 2015). As pressure for (sub)urban development increases, publicly and privately owned green spaces are converted to more profitable uses (Boquet, 2015). As a result there is essentially “no park system” left in Manila (Interview 18, May 2015).

What green areas do remain are often exclusive private spaces, such as golf courses or the tree-lined boulevards of the wealthy gated ‘villages’ of Dasmarinas or Forbes Park. These stand in stark contrast to the highly polluted ‘public’ streets and spaces (Connell, 1999). Thus, “with the globalization of Metro Manila and other cities, government is playing a reduced role in city building and space has been bifurcated between the privately planned “global city” for the middle and upper classes and the neglected and marginalized spaces of the rest of the population” (Shatkin, 2005: 600). This phenomenon is not unique to Manila (e.g. Heynen and Perkins, 2005).

Manila's decentralized planning is also problematic because connectivity is considered a crucial principle of green infrastructure planning (Ahern, 2007). Moreover, natural systems span multiple jurisdictional boundaries, so effective coordination is essential to their management. As one interviewee noted, "There's a very strong focus on local authority, sure fine, but when you are in the same watershed, the same river basin, the same floodplain it doesn't make sense to stop your planning at your boundary" (Interview 24, June 2015).

At the 2016 green infrastructure workshops, it became clear that officials from different municipalities varied in terms of their knowledge and implementation of greening policies. Pasig City, for example, was one of the areas hardest hit in 2009 by typhoon Ondoy. The storm served as an important "wake up call" according to a member of the municipal government (Interview 19, May 2015). Consequently, the city embarked on an internationally recognized Green City program that includes various urban greening projects, such as the implementation of a green roof on Pasig City Hall, the development of a greenway, and a tree-planting campaign (Interview 19, May 2015; Porio, 2015). According to an official from an international non-profit organization, Pasig City "is one of the more forward thinking cities in terms of thinking about sustainability" (Interview 21, May 2015). Yet as part of Pasig City's efforts to reduce flood risks, thousands of informal settlers were relocated from the riverbanks. If informal settler displacement is considered a form of gentrification, as Choi (2016) and Ortega (2016a) argue, then green infrastructure expansion may indeed be leading to eco-gentrification.

7.4.3 Interactions and feedbacks

Globalization, climate change, and contextual factors interact to shape infrastructure planning in Manila. For example, globalization has helped to spur Manila's growth, driving migration from the outer provinces into Manila. This urbanization has led to an increase in impervious surfaces, development in environmentally sensitive areas, groundwater extraction, and other factors that increase flooding during extreme weather events (Boquet, 2015; Rodolfo and Siringan, 2006). Moreover, because of privatized planning, the aforementioned lack of central low-income housing, and difficulties associated with commuting, many migrants move to informal settlements in areas that are vulnerable to floods (Porio, 2011). This "inadequacy of shelter" presents a major problem for climate change adaptation (Interview 24, June 2015). As already discussed, these informal settlers tend to be the hardest hit by climactic events (Zoleta-Nantes, 2002). Additionally, with a lack of adequate affordable housing, it is difficult for local governments to justify green infrastructure developments. One interviewee pointed explicitly to this connection:

> *"If you want to promote more open space you can't do it unless you address the housing problem. And you can't address the housing problem without addressing the poverty problem because of people's inability to pay, so the problems are interconnected"* (Interview 24, June 2015).

Furthermore, because individual cities in Manila compete for global investments and firms, they are eager to separate themselves from the rest of Manila's infrastructure failures. The easiest solution for these cities seems to be ever-larger privatized megaprojects and planning, perpetuating a vicious cycle. Shatkin (2008, page 384) describes this as "the imperative of the private sector to seek opportunities for profit by cutting through the congested and decaying spaces of the 'public city' to allow for freer flow of people and capital, and to implant spaces for new forms of production and consumption into the urban fabric."

Another interesting connection that emerged in the interviews, but would need further corroboration, was the possibility that local governments in Manila use climate change to excuse ineffective infrastructure planning. As an official at the Climate Change Commission told me,

> ***"****They just use climate change as a scapegoat for everything. 'And now you can blame me as a mayor for not doing anything because the climate is changing.' That's the emerging mindset. You've seen that in many press releases, 'the floods that we have had are because of climate change and not because of poor planning or land use planning or lack of political will in moving people out of harm's way'"* (Interview 6, July 2013).

These are just a few examples of how the processes of globalization and climate change interact in different ways in Manila. Next, I examine how urban infrastructure planning responses affect urban climate resilience, or Manila's ability to withstand climate impacts.

7.5 Examining Manila's urban climate resilience

While many scholars and policymakers attest that urban climate resilience is critical, there is no agreement on how to assess it (Leichenko, 2011; Tyler et al., 2016). A real measurement of resilience is probably only possible in the wake of a climactic event. Various indicators have been proposed (e.g. ARUP, 2014), but these require extensive data. Moreover, quantitative metrics may not capture critical urban governance dynamics (Zaidi and Pelling, 2015). Another possibility is to examine normative characteristics of urban systems and processes that are thought to enhance resilience (Lu and Stead, 2013; Tyler and Moench, 2012). Meerow and Stults (2016) identified 16 of these characteristics through an extensive literature review (for characteristic definitions and illustrative sources see Table 18). Examples of system characteristics include *robustness*, *diversity*, and *efficiency*. Other characteristics, such as *iterative process*, *forward-thinking*, and *feedback,* relate to urban governance. While acknowledging that additional research is needed to validate these characteristics, I use them here to guide a preliminary evaluation of the urban climate resilience implications of infrastructure planning in Manila.

Table 18 Urban resilience characteristics[18]

Characteristic	Definition
Robustness	Ensuring municipal-wide infrastructure and organizations can withstand external shocks and quickly return to the previous operational state
Redundancy	Having back-up systems, infrastructure, institutions, and agents
Diversity	Ensuring a diverse economy, infrastructure, and resource base (e.g. not relying on single mode of operation, solution, or agent/institution)
Integration	Making sure that plans and actions are integrated across multiple departments and external organizations
Inclusivity	Ensuring that all residents have access to municipal infrastructure and services, including providing an opportunity for all people to participate in decision-making processes
Equity	Ensuring that the benefits and impacts associated with actions are felt equitably throughout the municipality
Iterative Process	Creating a process whereby feedback and lessons learned are continually used to inform future actions
Decentralization	Decentralizing services, resources, and governance (e.g., solar or wind energy; stronger local governance)
Feedback	Building mechanisms so that information is rapidly fed back to decision-makers or system operators
Environmental	Protecting natural systems and assets
Transparency	Ensuring that all municipal processes and operations are open and transparent
Flexibility	Making municipal operations and plans flexible and open to change when needed
Forward- Thinking	Integrating information about future conditions (i.e., population, economy, weather) into community planning and decision-making
Adaptive Capacity	Ensuring that all residents have the capacity to adapt to climate change
Predictable	Ensuring that systems are designed to fail in predictable, safe ways
Efficiency	Enhancing the efficiency of government and external operations

At the national level, the Philippines has taken steps to prepare for climate change. The 2009 Climate Change Act (R.A. 9729), for example, requires all local government units to develop their own local climate change action plans in addition to a Disaster Risk Reduction

[18] reproduced from Meerow and Stults (2016), see the article for the sources of these characteristics

Management Plan with the express goal of fostering resilience. Thus, a legislative framework exists for plans and policies to prepare Manila for climate change. However in the city's decentralized system, some local governments such as Pasig City have forged ahead with preparations, while others are left behind. Deregulation and reliance on the private sector further limit the government's ability to steer adaptation in the public interest. Metro-level coordination and preparations are limited.

The following quote, from an official in the Climate Change Commission, suggests that because of this metro governance structure and resulting infrastructure systems, Manila as a whole is not very resilient to climate impacts.

> *"I think Metro Manila is not very resilient as a metropolis. Our energy infrastructure is very exposed and very sensitive, has a very high sensitivity, our transport infrastructure grounds to a halt if we have rains that are average for the season, classes are suspended, work stops, and transportation is compromised. All these things affect the nation, it's not just traffic that is causing us billions it's actually the kind of development that you see all around Manila. We don't have zoning laws, at least not zoning laws you would really want to have, and resilience is about good planning, planned development, and not a shotgun approach to development, and that's the difficulty that a metropolis like Manila [has], where each component city would have a plan of its own…So everything is, I would say, designed on a very thin thread, and you see what happened in 2009 when the big rains came..."* (Interview 6, July 2013).

Resilience is often associated with *robustness*, or the strength to easily withstand shocks (Eraydin et al., 2013). It is true that Manila as a city has continued to persist through numerous natural disasters, such as Typhoon Ondoy, and certain infrastructure systems continue to be strengthened. The electricity system, for example, has become more reliable and efficient in recent years (Cham, 2007; Navarro et al., 2016). Yet the economic disruption, infrastructure failures, and loss of life caused by even relatively minor storms (as noted in the quote above) suggest that robustness still needs to be improved, and that infrastructure systems are not sufficiently *predictable* in the sense that they are 'safe to fail' when inevitable disruptions occur. In 2013, for example, breakdowns in several large power plants that generate Manila's electricity led to a "cascading outage" and blackouts (Navarro et al., 2016: 33). This suggests a lack of functional *redundancy*, or spare capacity, in the electricity system. Many of the city's other infrastructure systems, such as the transportation network, are similarly overburdened.

Manila's electricity grid's reliance on relatively few large power plants could also be seen as a lack of *diversity*. This is compounded by a growing dependence on fossil fuels for electricity generation. The Philippines was an early leader in renewable energy, but in recent years it has fallen behind other Asian countries in terms of decentralized renewable energy development, which is often associated with resilience (Newman et al., 2009). Conversely, privatization has increased the diversity of actors involved in the electricity sector, although perhaps still not enough, since there are concerns that potential collusion and market manipulation drive up prices.

This allegation suggests a need for improved regulatory oversight. Indeed, the suggestion is that because elite families have disproportionate power in the metropolis, market competitiveness and the expected *efficiency* gains of privatization are being undermined. Looking at urban governance more broadly, one urban planner suggested that "one of the reasons why we are slow to reform is because government is controlled by a few vested families" (Interview 24, June 2015).

Even where we do see system-wide infrastructure improvements, a major concern is the lack of *equity* and *inclusivity*. In the last few decades, Manila has led the Philippine's impressive economic growth, but that has mostly benefited a wealthy minority. Income inequality is enormous, such that the wealthiest 30 percent are responsible for 90 percent of the country's consumption while nearly a quarter of Manila's population lives in poverty (Roberts, 2011). Manila has become an increasingly polarized city. Gleaming office buildings, resort condominiums, and gated tree-lined subdivisions are juxtaposed with makeshift huts and dangling electricity wires in informal settlements crowded along the riverbanks. When a typhoon hits the city it is undoubtedly disruptive for the wealthy elite, but studies indicate that disasters have a greater impact on the livelihoods and *adaptive capacity* of the urban poor, such as informal settlers (Zoleta-Nantes, 2002). For example, a study by Israel and Briones (2014) in one municipality estimated that poor households affected by a typhoon or flood within the last year had a seven percent lower per capita income than those that were not.

Protection of *environmental* assets is considered another important component of urban resilience. Yet few natural areas remain in Manila. For example, mangroves provide ecological benefits and coastal protection, but they have been largely eliminated in Manila Bay (Shaw et al., 2010). Where efforts are being made to expand green space, it may improve the environment of wealthier residents living nearby, but cause gentrification and forced relocation of informal settlers, thus perpetuity inequity (Ortega, 2016a).

When asked to identify the biggest obstacles to improving Manila's infrastructure, resilience, and ability to cope with climate impacts, interviewees repeatedly pointed to ineffective planning (e.g. Interview 1 and 7, July 2013; 26, 31, 36, and 37, June 2015) or "administrative fragmentation" (Interview 24, June 2015). Similarly, Roberts (2011, page 32) argues that "the failure of the planning and development control system to manage development risks has resulted in Metro Manila putting itself at even greater risk of future catastrophe."

Indeed, the current mode of governance for Manila appears inconsistent with a number of resilience characteristics. Heavy reliance on the private-sector for infrastructure development is arguably problematic for *transparency* (Shatkin, 2008)*,* and has limited the government's capacity and *flexibility* to change policy directions. For example, government officials expressed concern that they have limited control over power system planning following the EPIRA reforms. As it currently stands, some individual local governments in Manila are taking some steps to prepare for climate change, but there is a lack of *integration* through a meaningful metro-wide planning process. As Boquet (2015, p. 465) writes, "There is no lack of planning at the level of individual local governments (LGU, local government units) and in private master-planned real estate developments. The problem lies in the fragmented and decentralized governance of the metropolis." Without a clear vision or strong leadership for the metro region, it is difficult to have metro-level *forward-thinking* planning that incorporates information about future projections into decisions as part of an *iterative process*. As one interviewee observed, "If there is no master plan for Metro Manila than we are planning for failure" (Interview 6, July 2013). Without an empowered coordinating agency, it also becomes difficult to share critical information and best practices across governance units and actors. According to one disaster risk reduction expert, the lack of clear channels for rapid *feedback* and coordination between municipalities is problematic for disaster response. "In post-disaster settings where communication and coordination are more difficult, what is the assurance that they are going to be able to talk to each other and coordinate their activities?" (Interview 21, May 2015).

It is interesting that *decentralization* seems to be somewhat problematic for Manila. The resilience literature suggests that decentralized systems should generally be less vulnerable than highly centralized ones because when something disrupts a central unit, the entire system is jeopardized, whereas in a decentralized system it would only impact a small part of the whole (Ahern, 2011). However, other research suggests that with respect to governance, decentralization can create "a silo effect" that hinders interagency communication and fragments administration, which make it more difficult to respond to climate change (Holgate 2007 in Bulkeley, 2010). This silo effect makes it challenging to have strong leadership around such a complex issue (Gupta et al. 2010). I am not suggesting that decentralization is inherently bad, or advocating a return to centralized martial law, rather I want to point out that when combined with such a strong focus on free market ideology and private-sector led development in the Manila context, decentralization does not necessarily seem to enhance resilience.

7.6 Conclusion

Scholars and policymakers alike increasingly recognize that coastal megacities need to find ways to become more resilient in the face of climate change and other threats (Blackburn and Pelling, 2014). For these cities to adapt to climate impacts, significant changes need to be made to urban infrastructure systems (electricity, transportation, waste, etc.), changes that require considerable coordination and investment (Kamal-Chaoui, 2008). Yet urban infrastructure planning does not occur in a vacuum. It is shaped by global and local forces. In this paper, I have argued that the double exposure framework can be usefully applied to understand how the global processes of climate change and globalization affect urban infrastructure planning and potentially shape urban climate resilience (Table 18). I have also emphasized that the intensity of this exposure is amplified by the city's biophysical, socio-economic, and historical context. In other words, it would be an oversimplification to claim that neoliberal urbanism has simply been externally imposed on the Philippines, or that it would have the same the same result in other urban contexts (Shatkin, 2008). It is therefore valuable to examine these global processes, but not at the exclusion of "sub-global contexts" (Kelman et al., 2016: S135). This also underlines the need for in-depth, place-based research.

For a variety of factors both global and local, the government takes a back seat to the private sector in urban development in Manila, and metro-wide planning has been eschewed in favor of more local government autonomy. This has sparked inter-city competition, even though the fortunes of municipalities are intrinsically connected, and the private sector has taken advantage of this. The result is fragmented governance and physical infrastructure systems and persistent social and physical inequality, characteristics that are not associated with enhanced resilience in the literature. Thus, I would argue that these processes are limiting the city's ability to cope with climate impacts.

This paper is not meant to solely paint a bleak picture for the future of Manila. Rather, the goal is to unpack key processes that may hinder the resilience of a vibrant city so that efforts can be made to address them. There is no doubt that the challenges are daunting, but the Philippines is endowed with many resources. Individual cities within Manila, and even some private companies, are taking steps to enhance resilience, but metropolitan coordination and leadership are needed. One interesting new development is the "Greenprint 2030," a World Bank funded initiative to identify a future vision for the city and a "spatial strategy" to achieve it through stakeholder engagement (MMDA, 2015). But at the time of this research it was unclear how this plan would be implemented, whether it would also address the hegemony of the private sector in urban development, and who will benefit from the proposed changes. More research is needed that critically unpacks who wins and who loses in efforts to build more 'resilient' infrastructure. Recent work on gentrification in Manila (e.g. Choi, 2016; Ortega, 2016b) provides a foundation for this avenue of research.

Table 19 Summary of key double exposure framework components as applied to Manila

Framework Component	Manifestation in Manila
Process of global change	Global Environmental Change: Climate Change Globalization: Neoliberal urbanism
Exposure	Increased risk of flooding and extreme weather events Decentralization and economic liberalization Global interconnectedness and competition
Contextual Environment	Physical geography High poverty rates and income inequality Informal settlements History (colonialism, dictatorship)
Infrastructure Planning Responses	Privatization of planning Lack of integrated, metro-wide planning
Outcomes	Polycentric, polarized metropolis Increased inequality Uneven urban climate resilience

The Manila case has important implications for our broader understanding of the politics of urban climate adaptation planning. It shows that efforts to improve urban infrastructure are a critical element of a city's response to climate change, but that infrastructure planning is shaped not only by its exposure to climate impacts, but also by globalization and associated neoliberal political and economic restructuring, all of which are mediated by the historical and cultural context. These processes also interact, reinforcing existing inequalities and leading to uneven urban climate resilience.

This paper has shown how the double exposure framework can be applied to better understand urban infrastructure planning, addressing an observed gap in the literature. I also connected the double exposure framework to the emerging body of critical literature on networked urban infrastructure systems. While I focused on electricity and green infrastructure systems, future research should examine these processes in the context of other networked infrastructure systems, such as waste, water, transportation, etc. —which may lead to different conclusions. I also emphasized the importance of contextual factors including geography and history, so it would be useful to compare the Manila case study with other cities in the Global North and South to see how patterns differ. Because I focus on how urban infrastructure planning responses impact a city's resilience, this work has implications for the expanding body of literature on urban resilience. For example, the Manila case calls into question the universal desirability of decentralization, which is sometimes cited as a characteristic of resilient systems. As research on urban climate resilience continues to expand, system and process characteristics and metrics for urban resilience may become clearer. Of course, it would also be valuable to study Manila's response in the wake of a climactic event. Finally, the lessons learned from Manila can be used to improve urban infrastructure and resilience planning processes in emerging megacities around the world.

Appendix 7.1

Table 20 Interview list (Individual and company names anonymized)

National government
Climate Change Commission
Department of Energy, Energy Policy and Planning Bureau
Department of Energy, The Electric Power Industry Administration Bureau
Department of Public Works and Highways, National Capital Region
Energy Regulatory Commission
Regional government
Metro Manila Development Authority, Environmental Management Division
Metro Manila Development Authority, Flood Control and Sewerage Management Office
Metro Manila Development Authority, Planning Division
Local government
Makati Mayor's Office, Department of Environmental Services
Pasig City, elected official
Pasig City, City Environment and Natural Resources Office
Pasig City, Office of Disaster Risk Reduction
Pasig City, Parks and Playgrounds division
Quezon City, Green Building Unit
International organizations
Asian Development Bank
German Corporation for International Cooperation (GIZ) (two different individuals)
Earthquake and Megacities Initiative (EMI)
Greenpeace
National organizations
Federation of Philippine Industries
Philippine Green Building Council
Private utilities
Manila Water
Meralco
National Grid Corporation Philippines
Government-owned companies
Philippine National Oil Company (two interviews)
Private companies
Private architecture firms (two different companies)
Private environmental consultant
Private environmental planning firm
Private power company
Private real estate developers (two different companies)
Research institutions
Manila Observatory
University of the Philippines, Electrical and Electronics Engineering Institute
University of the Philippines, National College of Public Administration & Governance
University of the Philippines, School of Urban and Regional Planning

Appendix 7.2

Table 21 Local governments and organizations represented at 2016 green infrastructure workshops

Ateneo de Manila University
Laguna Lake Development Authority
Makati City
Malabon City
Mandaluyong City
Manila Observatory
Muntinlupa City
Panghulo, Obando, Bulacan Barangay
Pasig City
Quezon City
San Juan City
Valenzuela City

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Chapter 8 Conclusion

This dissertation research was motivated by a theoretically and practically relevant question: *What is urban resilience and how can we make cities more resilient in the face of climate change and other threats in a way that is sustainable and just?* The six preceding chapters provide important insights related to this question, while also pointing to new avenues for future research. In this concluding chapter I first summarize the key findings, contributions, and limitations of the dissertation and then outline my future research plans.

8.1 Summary of major findings and contribution

A growing number of scholars, organizations, and cities are planning for urban resilience in the face of climate change and other threats. Green infrastructure is one strategy they use. My research helps to advance existing knowledge of urban resilience, green infrastructure, and climate adaptation, particularly as they relate to the urban geography and planning fields. I suggest that the three most important contributions of this dissertation are: 1) An improved understanding of different definitions and characteristics of urban resilience in both research and practice; 2) A general framework for critically operationalizing urban resilience in different empirical contexts; and 3) The development and application of the Green Infrastructure Spatial Planning modeling approach for assessing spatial synergies, tradeoffs, and hotspots between resilience benefits and facilitating more strategic planning of green infrastructure.

In *Chapter 2: Defining urban resilience: A review,* my two colleagues and I proposed a new definition for urban resilience, which already appears to be gaining traction. This was motivated by findings from a systematic review of the burgeoning academic literature on urban resilience. This bibliometric review revealed 25 distinct definitions of urban resilience, all of which failed to adequately address inconsistencies in the literature. These conceptual tensions included variable conceptualizations of the ‘urban’, different understandings of system equilibrium, questions of whether resilience is always positive or neutral (or negative), and whether it encompasses mechanisms for system change, adaptation or general adaptability; and timescales of action.

In contrast, our proposed definition is carefully worded to state a position on each of these tensions. In this definition, resilience is based on the assumption that systems are in a state of non-equilibrium, it is seen as a desirable state, it encompasses multiple pathways for change (persistence, transition, and transformation), and it highlights the importance of adaptive capacity and timescales.

I presented a conceptual schematic of the urban system in conjunction with the definition to serve as a heuristic for thinking through the complex and multi-scalar components of cities. In this conceptualization, urban systems are made up of four interconnected subsystems: 1) governance networks; 2) networked material and energy flows; 3) urban infrastructure and form; and 4) socio-economic dynamics, all of which interact across spatial and temporal scales. The proposed definition is purposefully broad so that it could keep functioning as a boundary object, bringing together diverse disciplines and stakeholders. I argued that applying the definition to specific urban contexts requires careful consideration of questions related to resilience for whom, what, when, where, and why? I thus first introduced the ‘Five Ws’ framework in Chapter 2, although I greatly expanded on it in Chapter 3.

Chapter 2 was published in the journal *Landscape and Urban Planning* in 2016*,* and has since been designated by *Web of Science* as a 'hot paper', placing it among the top 0.1 percent of recently published social science papers in terms of citations. The fact that the paper and definition are being sfrequently cited in the literature (e.g. Calderón-Contreras and Quiroz-Rosas, 2017; Derickson, 2017; McPhearson et al., 2016) suggests that it does indeed fill a gap. The 'Five Ws' framework has also been adopted in the grey literature (Aspen Global Change Institute, 2016; Fundacion idea, 2017), intimating that others think it can help to structure applications of the resilience concept. This study was motivated by my own desire to make sense of the rapidly emerging urban resilience literature and conceptual ambiguity**—**and this need is clearly shared by others.

In *Chapter 3: Urban resilience for whom, what, when, where, and why?* I expanded the theoretical framework introduced in Chapter 2 to demonstrate how and why it could be applied in practice. This paper (published as a coauthored article in *Urban Geography*) contributes to a clearer conceptualization of the politics of urban resilience planning, which critics of the resilience concept claim is often neglected (Cretney, 2014). First, I compared resilience with the related concepts of sustainability, vulnerability, and adaptation, identifying considerable conceptual confusion, but also potentially important distinctions stemming from the concepts' different theoretical legacies. I then took stock of the major emerging critiques of the resilience agenda, which could be summed up as a need to critically examine the underlying politics of resilience initiatives. I introduced a three-part process to address these criticisms. First, the definition and urban system conceptual schematic from Chapter 2 were proposed as a boundary object for fostering collaboration. Second, I argued that the five Ws framework can guide careful negotiation of the contested decisions, scalar dimensions, and tradeoffs inherent in applying resilience empirically. Third, the implications of these decisions must be examined in different empirical contexts.

Using two potential scenarios of green infrastructure spatial planning in Los Angeles, I showed how different choices related to the five Ws —for example, prioritizing one resilience benefit of green infrastructure (e.g. stormwater abatement) over another (e.g. alleviating park poverty) or changing the scale of analysis—could lead to markedly different spatial priorities with both winners and losers. This simple example highlighted the inherently contested nature of planning for urban resilience and the probability of inherent tradeoffs. This underscores the need to critically examine the politics and practices of resilience planning and to develop inclusive processes that consider potential tradeoffs and varying stakeholder priorities. I developed the GISP model (Chapters 4 and 5) to address this gap, and to provide a general approach for assessing spatial tradeoffs, synergies, and hotspots where green infrastructure resilience benefits are needed most, taking into account local stakeholder priorities.

Chapter 4: Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit confirmed the importance of such a strategic planning process, since my colleague and I identified important tradeoffs and synergies between green infrastructure benefit criteria. The findings of this paper also suggested that these planning processes could be improved in Detroit. At least at the census tract scale, green infrastructure siting in Detroit did not seem to be focused in neighborhoods where multiple social and environmental benefits were needed most. For example, local stakeholders indicated that reducing social vulnerability was an important priority, but green infrastructure projects did not seem concentrated in the most socially vulnerable areas. The model also showed that green infrastructure could be developed in areas that simultaneously abate stormwater, urban heat island, and air pollution in Detroit, but that there may be a tradeoff between maximizing these benefits and habitat connectivity. These findings complicate assumptions of green infrastructure multifunctionality and confirm the need to account for tradeoffs (Haase et al., 2014; Kremer et al., 2016). The initial application of the GISP model in Detroit also confirmed its value as a practical planning tool and as a stakeholder-informed approach for assessing potential synergies and tradeoffs in green infrastructure benefits.

In *Chapter 5: A Green Infrastructure Spatial Planning model for evaluating ecosystem service tradeoffs and synergies in three coastal megacities* I showed that the GISP modeling approach can be applied in a wide range of cities. I did find, however, that data availability and quality was a major challenge, particularly for Manila. As a consequence, I am hesitant to draw any sweeping conclusions from this preliminary Manila model and I am working to acquire better data. As accessibility to geospatial data continues to improve, the models can be easily updated and the basic GISP modeling approach can be applied in additional cities to guide green infrastructure siting and other spatial planning decisions.

Interestingly, despite the fact that different data sources were used for the three megacities and Detroit, I found several consistent synergy and tradeoff patterns. In all four cities I found synergies between stormwater, urban heat island, and air quality benefit criteria, and a tradeoff between these criteria and increasing landscape connectivity. This suggests that even if stormwater continues to be the focus of green infrastructure investments, it may still be strategically sited to capture urban heat island and air quality co-benefits. I also found that local stakeholder priorities differed, which is not surprising given the cities' diverse geographies. Managing stormwater was identified as an important aim in all four cities, and improving landscape connectivity was generally viewed as among the least important criteria. The relative importance of improving air quality or reducing social vulnerability, for example, differed considerably across the cities. This variation confirms the importance of identifying local preferences and incorporating them into green infrastructure and resilience planning processes (Hansen & Pauleit, 2014).

In *Chapter 6: Comparing conceptualizations of urban climate resilience in theory and practice* I worked with a colleague to combine a literature review and survey data to compare academics' and practitioners' understandings of urban resilience in the context of climate change. The results indicate a number of discrepencies that present a challenge for the theory-practice interface. I found that the majority of surveyed local government officials still adopted a more engineering, or "bounce back" conceptualization of resilience, while the academic literature seemed to be moving towards a "bouncing forward" understanding that included the capacity for positive change. This is potentially problematic, because if resilience is simply about returning to a prior state or maintaining the status quo, it is indeed an inherently conservative goal for cities and precludes sustainability transformations (Cretney, 2014; Joseph, 2013; MacKinnon & Derickson, 2012). As a follow-up to Chapter 2, this study also showed that practitioners are even more divided than academics on the meaning and value of resilience.

I also reviewed the academic literature for system and process characteristics associated with urban resilience in Chapter 6, ultimately producing a list of 16 commonly cited characteristics. Surveyed practitioners collectiviely confirmed the importance of all of these characteristics, but they did not incorporate many of them into their free response definitions of resilience. Moreover, the characteristics that they rated as most salient and occasionally did reference (e.g. robustness) were not the most commonly cited in the academic literature (e.g. diversity, flexibility, redundancy). These results raise a number of questions for future research.

Lastly, *Chapter 7: Double exposure, infrastructure planning, and urban climate resilience in coastal megacities: A case study of Manila* presented a detailed, qualitative case study of the complex factors that shape urban infrastructure planning and climate resilience in Metropolitan Manila. I showed that the double exposure framework could be applied to understand how global processes of climate change and globalization shape urban infrastructure planning (addressing an identified gap in the literature), reinforce existing inequalities, and lead to uneven urban climate resilience. This chapter thus helps to connect emerging (yet often distinct) literatures on double exposure, urban infrastructure planning, and urban climate resilience. The Manila case also highlighted that these processes have to be understood in the context of the city's particular historical, biophysical, and socio-economic environment. This underscores the importance of in-depth, place-based research as a complement to the more quantiative modeling presented in Chapters 4 and 5. Chapter 7 also demonstrated that in the absence of clear approach for measuring resilience, the characteristics identified in Chapter 6 could be used to structure a preliminary evaluation. Furthermore, the Manila case raised questions about whether decentralization is always a desirable characteristic of urban governance that supports resilience.

8.2 Future research agenda

As I move forward in my academic career, I plan to continue conducting research in three overlapping focus areas related to my previously stated overarching research question: 1) Advancing theories of urban resilience; 2) Urban green infrastructure to enhance social-ecological resilience; and 3) Urban climate change adaptation planning. In this section I will discuss some of my research plans in each of these three areas.

8.2.1 *Advancing conceptualizations of urban resilience*

The concept of urban resilience grows ever more omnipresent, yet it is also increasingly contested. I plan to continue working with colleagues to develop frameworks for urban resilience that resolve conceptual confusion and address critiques in order to advance theoretical and practical understandings of urban resilience. To this end, I am already working with colleagues on a meta-analysis of the numerous recent resilience review papers to identify the latest trends in definitions and characteristics of the term.

One specific project that I hope to begin shortly would build on my dissertation research that looked at how academic and local government 'experts' conceptualize resilience by adding the missing public opinion piece of the puzzle. I plan to conduct a survey experiment that examines public perceptions of the resilience concept. Moreover, I will test the widely stated, but largely unsubstantiated claim that resilience has a more positive connotation than other concepts like vulnerability, adaptation, or sustainability (McEvoy et al., 2013; Weichselgartner & Kelman, 2015). In the survey I will first assess whether invoking the term resilience really does lead to more support for associated policies. And second, I will test whether people's descriptions of the meaning of resilience are more positive than for other concepts.

There are a number of other ways in which I might build on the study presented in Chapter 6. I could survey urban climate resilience scholars about the importance of resilience characteristics or expand the practitioner survey beyond the US. I would also like to find ways to 'test' theorized resilience characteristics in different urban contexts.

I am equally interested in examining how resilience is actually being operationalized in different cities, particularly through the Rockefeller Foundation's 100 Resilient Cities program. Each of the network's member cities has to hire a 'chief resilience officer' and develop a resilience plan. I plan to work with colleagues to evaluate these plans, understand how these individuals are putting resilience principles into practice, and evaluate whether the focus on resilience is transforming urban planning or merely relabeling the status quo.

8.2.2 Green infrastructure to enhance urban social-ecological resilience

Like resilience, the popularity of green infrastructure and nature-based solutions only appears to be growing among scholars and practitioners. I see numerous opportunities to expand on my dissertation work in this area. First, I would like to improve the three megacity's models presented in Chapter 5. I am still working on identifying better data (particularly for Manila) and improving indicators. I want to acquire more weighting survey responses for Los Angeles to even out the number of respondents for each city. I also have qualitative data from interviews with key green infrastructure and urban planning decision-makers in Los Angeles (5 interviews, one workshop), New York (6 interviews, one workshop), and Manila (22 interviews, two workshops) that I could code and use to provide more context on green infrastructure planning processes, opportunities, and challenges in the three cities.

I have discussed the possibility of working with colleagues to expand on the GISP models that I have made for both New York and Detroit. In particular, the current models could be used to identify high priority census tracts for more in-depth site-level evaluation. New York City has detailed data on current green infrastructure project locations, which I plan to compare with modeled results, as I did in Detroit. I can continue developing the GISP model, for example by moving towards a raster-based or parcel-level approach, or apply it in other cities. I am also exploring a number of different ways in which the GISP model could be extended in the future to increase its utility, for example by coupling it with a cost-benefit model or incorporating data on green infrastructure performance. The GISP model assumes that green infrastructure is beneficial, but it would be interesting to incorporate potential 'disservices' and green or eco-gentrification concerns into future planning studies and tools.

In my dissertation I focused on green infrastructure, but a city's resilience is critically shaped by multiple interdependent infrastructure systems, including food, energy, water, and transportation. I also see the GISP model as a broader spatial planning approach that could be applied to other infrastructure spatial planning decisions, such as siting urban agriculture, distributed energy, or climate adaptation investments. Finally, I will continue conducting in-depth, qualitative studies of how infrastructure governance shapes differential resilience outcomes in cities in the US and the Global South, like I did for Manila in Chapter 7.

8.2.3 Urban climate change adaptation

While the opportunities and challenges for urban climate change adaptation was not the main focus of my dissertation, I have collaborated on several related projects during my doctorate (e.g. Nordgren, Stults, & Meerow, 2016; Stults & Meerow, 2017), and I plan to make this a major emphasis in the future. In particular, I have established valuable connections in the Philippines and would like to continue working there. Manila is one of the world's most vulnerable cities to climate impacts, which makes it an important place to study adaptation. Phoenix, with its extreme heat and water vulnerabilities, would be an interesting city in which to examine these issues, as would my hometown of South Florida.

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