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Editorial

Advancing understanding of the complex nature of urban systems

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ABSTRACT

Cities and urbanized regions are complex, dynamic, and highly integrated systems linking social, ecological, and technical infrastructure domains in ways that create deep challenges for good governance, policymaking, and planning. The combination of impacts from climate change in cities, air pollution, rapid population growth, multiple sources of development pressure and overall urban system complexity make it difficult for decision-makers to develop and guide development trajectories along more livable, equitable, and at the same time, more resilient pathways. Advancing urban sustainability and resilience agendas requires expanding the scope of inter- and trans-disciplinarity approaches, moving beyond the historically separate social–ecological and socio-technical approaches to jointly study social–ecological–technical infrastructure systems in cities. We take urban complexity as a given and suggest that in both research and practice we need to better capture and understand feedbacks, interdependencies, and non-linearities which create uncertainties and challenge the efficacy of governance practices to achieve normative goals for society. Here, we explore new methods, tools, and approaches to advance our understanding of urban system complexity through a series of journal special issue articles that examine urban structure–function relationships, urban sustainability transitions, green space availability, social–ecological memory, functional traits, and urban land use scenarios.

1. The challenge of rapid urban change

Cities are hotspots for global change. Climate change, urban population expansion, and development pressures are already affecting urban areas and their residents and will pose a range of challenges to urban planning and decision making in the future. For example, citizens are likely to experience climate change impacts most directly in cities (White et al., 2005; The World Bank, 2010) with key impacts including rising temperatures and heat waves, reduction in air quality, as well as extreme rainfall events and biological responses to a changing climate (Bonn et al., 2014). Urbanization is an ongoing and dynamic process related to many interlinked pressures, such as land conversion, soil sealing, densification of built-up areas, increases in traffic and air pollution, and decrease in urban green spaces, all of which pose significant challenges to ecosystem functionality and human well-being around the world.

Cities and urban areas are changing at a rapid pace and are predicted to double in population size to 6.5 billion residents by 2050 (UN, 2014), driving fast changes in social, ecological, and infrastructural dynamics of urban systems. Some of the challenges facing urban decision-makers entail the creation of viable urban transition pathways in order to equitably secure fresh and clean air, available clean drinking water, energy and food for reasonable prices, high quality recreational space and an overall more livable environment (McHale et al., 2015). Articulation of visions and aspirations for creating 'green cities' and 'smart cities' (Downton, 2009) further suggest that urban decision-makers need new approaches, methods, and tools for understanding urban system complexity in order to limit trade-offs and maximize opportunity for improving the lives of urban residents. This need implies a key role for scholars to demonstrate where opportunities exist for improving both resilience and sustainability, and to identify trade-offs that need to be avoided in order to fundamentally achieve many of the normative goals we have for urban societies. These goals include, but are not limited to: equitable access to urban services, resilience to climate change, economic upheaval and other threats, and transforming our cities toward sustainability as a critical part of achieving global sustainability (Andersson et al., 2014; Hansen et al., 2015; McPhearson et al., 2015). Indeed, global sustainability is dependent on cities and urban regions around the world to steadily transition toward more sustainable development processes and patterns, given that the majority of natural resource consumption, waste generation, energy use and more, occurs in cities (Haase, 2014).

1.1. Urban systems and complexity

Urban systems, including small, large, and mega-cities as well as urbanized regions, are classic examples of complex systems (Batty, 2008; Bettencourt et al., 2007; Bettencourt, 2013a,b) exhibiting

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emergent properties, some of which can be difficult to explain, such as nonlinear dynamics, feedbacks, and high interconnectivity and unpredictability, while also having modular interlinked subsystems that can create redundancy and exhibit resiliency. These and other complex behaviors make urban systems challenging to understand and, what is more, to govern, when seeking to improve resilience while transforming toward more sustainable development pathways and patterns (Rodríguez-Rodríguez et al., in press). In some cases, the complexity of urban system processes and patterns both within and across interconnected urban regions—where sustainable choices made in one place are not truly sustainable if they create social, economic, or environmental trade-offs elsewhere—clearly represent 'wicked' problems faced by today's urban planners, policymakers, and managers (Kaczorowska et al., in press; McPhearson et al., 2016).

For example, Superstorm Sandy posed a "wicked problem" for New York City (NYC) when it struck the United States eastern seaboard on October 29th, 2012. Sandy was dramatic, destroying 72,000 homes, 250,000 cars, causing tens of billions of dollars in infrastructural damage, displacing thousands of residents, and completely disrupting one of the largest regional economies in the world. However, the wickedness of Sandy was not the magnitude of the storm damage or any particular local disaster. The wickedness of the problem lay in exposing the sensitivity and vulnerability of the complex system of NYC, where a single storm event simultaneously affected a very dense social, ecological, and technical infrastructural network, disrupting the "heart" of the city system. System complexity combined with a major disturbance created conditions that are still felt in NYC and are mirrored in a number of similar urban disasters worldwide (e.g. the Fukushima earthquake, the Christmas Tsunami, and Hurricane Katrina).

An alternative urban example are the poor living and poor health conditions of slum dwellers in the West African urban belt (e.g. Lagos) where some of the world's largest waste areas have been created, driven by Western urban consumption which produces vast electronic waste (in combination with remnants of offshore oil exploitation; Lagos Waste Water Management, 2013). Here, lowest income urban dwellers, dependent on these waste streams for their livelihoods, daily confront a variety of intersecting urban system dynamics which challenge the very notion of livability and equity.

In the context of this complexity and additional urban challenges, can we understand the dynamic social–ecological and infrastructural complexity of urban systems? Can we understand this complexity well enough to inform and improve decision-making for transitions toward more resilient and sustainable cities? Addressing urban complexity and existing and growing urban challenges comprehensively and adequately suggest the need for:

(1) Bringing together existing concepts, tools, indicators and data for improved understanding and analysis of complex urban systems,
(2) Developing these approaches individually further to provide state-of-the-art decision-support, and
(3) Shedding light on complementary and overlapping explanatory power of these concepts, indicators, and tools for improving decision-making toward more livable, equitable, sustainable, and resilient cities.

In this editorial, emphasizing contributions from the accompanying journal Special Issue articles, we take on the challenge of understanding urban complexity characterized by spatial heterogeneity, as well as dynamic and multiple feedbacks between primarily social and ecological components of cities. Our goal is to shed light on different and coexisting approaches to analyze and assess urban systems for an improved understanding of urban complexity. We do not present a collection of indicators, rather an *indication* of where progress is being made on advancing understanding of urban complexity.

2. Advancing methods, tools and approaches to understand urban system complexity

Here we introduce the journal special issue in *Ecological Indicators*, "Navigating urban complexity: Advancing understanding of the complex nature of urban social–ecological–technical systems," devoted to the emerging theme of complex urban systems.

Since there is no single way to (1) investigate the urban social–ecological and infrastructural system and their complexity, and (2) govern urban systems for improving resilience to specific urban challenges, or advance urban sustainability, we review a collection of articles from different entry points to investigate complexity in urban systems across multiple levels in urban planning and governance. This special issue actively links different areas of scholarship including advancing interdisciplinary urban ecosystems research, integrative indication systems, methods and tools using social–ecological systems assessment and valuation, and next-generation urban planning approaches that adopt social–ecological frameworks for sustainability and resilience. In this way we take up the thread of the academic dialog on social–ecological systems, which includes important frameworks of ecosystem services and its links to resilience and transformation. The initial selection of contributed papers approaches urban complexity and the urban social–ecological systems from different entry points, methodologically and thematically. The papers examine urban structure–function relationships, urban sustainability transitions, green space availability, social–ecological memory, functional traits, and urban land use scenarios.

2.1. Urban form and structure classification as a tool for exploring urban structure–function relationships

Urban form, the spatial patterns of the built, infrastructural, and embedded biotic components of cities, is a critical component of urban structure and major driver of urban complexity. Linking urban form and structure to functioning could provide a novel starting point for examining complex urban system patterns and processes and generate a unique platform upon which to build cross-city comparative research (McPhearson et al., 2016). Defining urban structure and uncovering key relationships between urban structure and ecological processes is often challenging in urban landscapes characterized by heterogeneity and patchy spatial patterns (Pickett and Cadenasso, 2009; Zhang et al., 2013).

In order to understand the often complex spatial and temporal patterns of urban landscape structure, compare patterns across cities, or inform urban design and planning principles, it will be important to understand the extent and variability of the relationships between urban landscape structures and their functions (Larondelle et al., 2014). An example of recent advances includes a simple and reproducible approach for classifying the structure of urban landscapes (STURLA) that utilizes heterogeneous, composite classes, which represent combinations of built and natural features, and examines the response of a landscape function – surface temperature (Hamstead et al., in this issue).

In their paper, Hamstead et al. build a quantitative, reproducible cellular grid-based approach for classifying the STURLA. The use of land use composites defined *a posteriori*, based on compositions of adjacent structural elements, allow the authors to approach urban complexity at the city scale including different specific response units, such as urban land use within a city. Authors used indicators focused on connecting landscape structure to function (surface

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