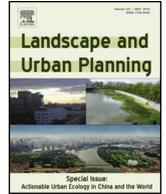




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## Research Paper

## Advancing urban sustainability theory and action: Challenges and opportunities

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## HIGHLIGHTS

- We present a conceptual framework for urban transitions of various kinds.
- We use the concept of inertia to address various theoretical frameworks.
- Inertia in urban ecosystems includes institutional, infrastructural, and social components.
- We explore sustainable solutions that both “tweak” and transform urban inertias.
- We introduce a novel research network to facilitate and inform urban sustainability.

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## ABSTRACT

Urban ecology and its theories are increasingly poised to contribute to urban sustainability, through both basic understanding and action. We present a conceptual framework that expands the Industrial → Sanitary → Sustainable City transition to include non-sanitary cities, “new cities”, and various permutations of transition options for cities encountering exogenous and endogenous “triggers of change”. When investigating and modeling these urban transitions, we should consider: (1) the triggers that have induced change; (2) situations where crisis triggers change; (3) why cities transition toward more sustainable states on their own, in the absence of crisis; (4) what we can learn from new city transitions, and non-sanitary city transitions; and (5) how resource interactions affect urban transition s.

Several existing theoretical frameworks, including sustainability, resilience, adaptation, and vulnerability, may be helpful when considering urban transitions. We suggest that all of these theories interact through inertia in urban systems, and that this multi-faceted inertia—e.g. institutional inertia, infrastructural inertia, and social inertia—imparts degrees of rigidity that make urban systems less flexible and nimble when facing transitional triggers and change. Given this, solutions to urban sustainability challenges may be categorized as those: (1) that “tweak” the current systems and work with or even take advantage of the inertia in those systems, versus; (2) that are more “transformative”, that confront systemic inertia, and that may require new systems. We propose that a model for addressing urban sustainability in the context of relevant theory, and for bridging research and practice, should focus on intercity comparisons. And one mechanism to facilitate this approach is a newly formed interdisciplinary Research Coordination Network (RCN) that focuses on urban sustainability by integrating urban research while incubating solutions-oriented products and collaborative partnerships with practitioners. The Network includes more than two dozen cities in five continents that are in various degrees of transition. In the true vein of sustainability science, our Network activities are incubating societally-relevant

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solutions through projects that will lead to tangible, “on the ground” sustainable solutions for all types of cities. Our ultimate goal is to understand the process by which cities become more sustainable while affecting that process through action inspired by knowledge.

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## 1. Introduction

There are many ways to define “sustainability”, but most interpretations of this concept involve a focus on human needs and values, and an emphasis on the future (e.g. [Brundtland Report, 1987](#)). The pressing needs to promote sustainability have stimulated a new and maturing field of science—sustainability science—that focuses on solving problems and meeting challenges, rather than on traditional disciplines ([Spangenberg, 2011](#)). This new field of inquiry seeks to address symbioses between human activity and the environment ([Rapport, 2007](#)). One specific challenge facing sustainability science is the global increase in urbanization. New and expanding cities present both challenges to and opportunities for sustainability ([Weinstein, 2010](#)). Cities worldwide are facing many challenges, including exploding population, inadequate or failing infrastructure, as well as economic and environmental disruptions. Thus, understanding urban sustainability and improving the ability of policy-makers to achieve sustainable management are pressing needs of the 21st century ([Birch & Wachter, 2008](#); [Naess, 2001](#); [Register, 2006](#)).

Urban ecology as a discipline is increasingly poised to contribute to urban sustainability. In the last 20 years, the discipline of urban ecology has grown from a relatively traditional examination of ecology in cities ([Collins, Kinzig, & Grimm, 2000](#)) to investigations of the ecology of cities ([Grimm, Grove, Pickett, & Redman, 2000](#); [Pickett et al., 1997b](#)). In the former approach, research focuses on traditional ecological structures and functions, but in an urban setting. Studying the ecology of cities is generally a more holistic approach where the city itself is the ecosystem under scrutiny and *Homo sapiens* is acknowledged to not only be part of the system, but in fact the system’s dominant species. Conceptual approaches that guide urban systems research are now typically interdisciplinary and include both biophysical and social–cultural components that interact through the purveyance of ecosystem services and through the press-pulse forces of management and disturbance ([Collins et al., 2011](#); [Grimm et al., 2012](#)). This interdisciplinary nature of contemporary urban ecology, along with its concern with the ecological processes underlying ecosystem services, allies it well with sustainability science.

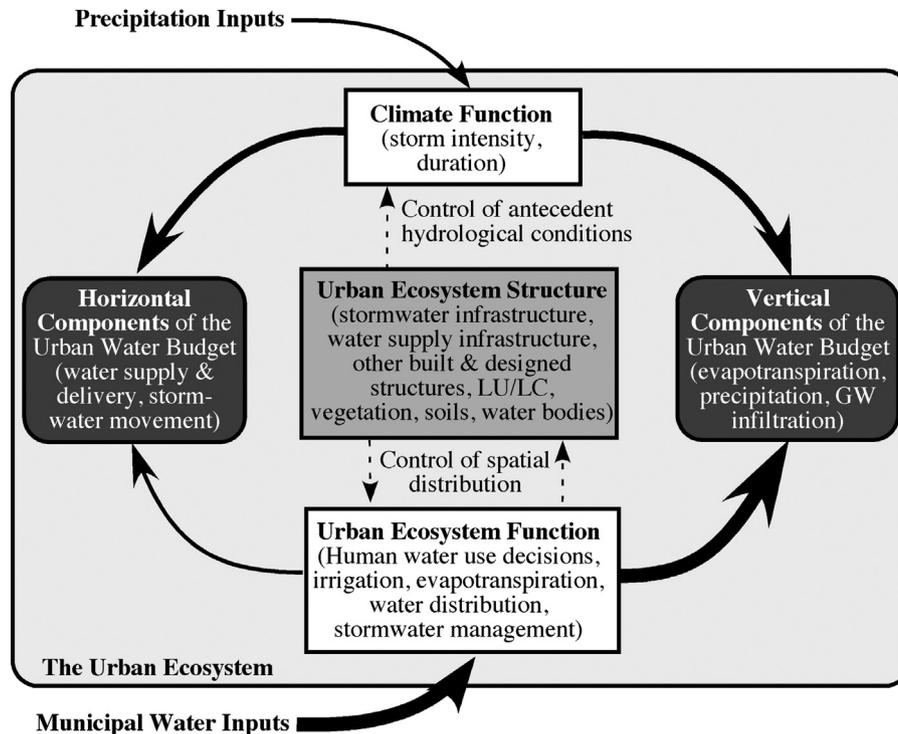
The science behind sustainability is an inherently interdisciplinary endeavor that ultimately seeks solutions to social–ecological problems. That said, because human and biophysical dynamics are inextricably coupled in urban systems, urban sustainability provides opportunities for more transdisciplinary conceptual approaches that do not differentiate between ecological and human-derived structures or between ecological and human-mediated functions ([Pickett & Grove, 2009](#)). In bridging from interdisciplinary to transdisciplinary approaches, our definition of the latter is similar to that of [Ahern, Cilliers, and Niemelä \(2014\)](#), where the focus includes the social, institutional, designed, built, and biophysical components of urban ecosystems and where urban systems research includes not just an array of biophysical, design, engineering, and social expertise but also includes real world city practitioners. To that end, urban sustainability moves us toward an ecology *for* cities, where the “knowledge to action” model invokes using what we have learned about urban ecosystems to actively make cities better and more sustainable places to live.

As an example of how the interdisciplinary entanglements in studying urban ecosystems may be made more transdisciplinary, we use the water system, or hydro-ecosystem, of an aridland city (e.g. Phoenix, AZ, USA). In the well-accepted interdisciplinary conceptualization of this urban water system, per [Grimm et al. \(2012\)](#), the structural and functional aspects of the biophysical and social–cultural components are connected, yet remain separated. The purveyance of ecosystem services is a key connection between these two domains, but this conceptualization does not easily incorporate the services provided by the human-derived elements of urban ecosystems. Our more transdisciplinary conceptualization more fully integrates the human with the biophysical by not separating human and ecological structures (e.g. infrastructure, land use/land cover, vegetation, soils, and water bodies) or functions (e.g. water use decisions, water management, evapotranspiration, plant production, and biogeochemical cycling; [Fig. 1](#)). In this example, water enters the city as municipal water supply and as precipitation and, because this example city is located in an arid climate, the former sources dominate the inputs (note the larger input arrow in [Fig. 1](#)). The geomorphological template of the landscape dictates major distribution pathways of water across the city, but human decisions about the management of water, including storm water and water supply, are critical components of this urban hydro-ecosystem structure. Biophysical processes such as evapotranspiration, plant production, biogeochemical processing, and groundwater recharge are important processes in this hydro-ecosystem, but human decisions about water use, landscaping, irrigation, and water management tend to dominate hydro-ecosystem function.

In this example, we separate the water system into horizontal and vertical components of urban water flux ([Fig. 1](#)). Horizontal components are dominated by water purveyance and stormwater runoff, both of which follow the geomorphological and topographic template of the landscape but are strongly regulated by human design and management decisions. Vertical components include evaporation, transpiration by vegetation, and groundwater recharge; these are a function of both ecological processes and human decisions about the magnitude and distribution of those processes. For example, landowners and managers decide on where to locate [i.e. where to plant] vegetation, how much irrigation to apply to that vegetation, and where to locate open water amenities. The design of stormwater infrastructure will also dictate where rainwater infiltrates vertically into the groundwater of the city ([Fig. 1](#)). The challenge with this type of transdisciplinary approach to conceptualizing urban ecosystems is that human and biophysical aspects of structure and function must be both conceptually integrated and practically coupled. The advantage of this approach is that the importance of human decisions and actions in urban ecosystem dynamics is clear, allowing biophysical-human synergies, symbioses, and services to be more easily articulated and quantified. We argue that such synergistic approaches are crucial to understanding and planning for enhanced sustainability of urban systems.

## 2. From contemporary cities to sustainable cities

In the “Global North” (per [Ogden et al., 2013](#), and others), many older cities that began as industrial cities have transitioned over the last century into sanitary cities (as defined by [Grove, 2009](#),



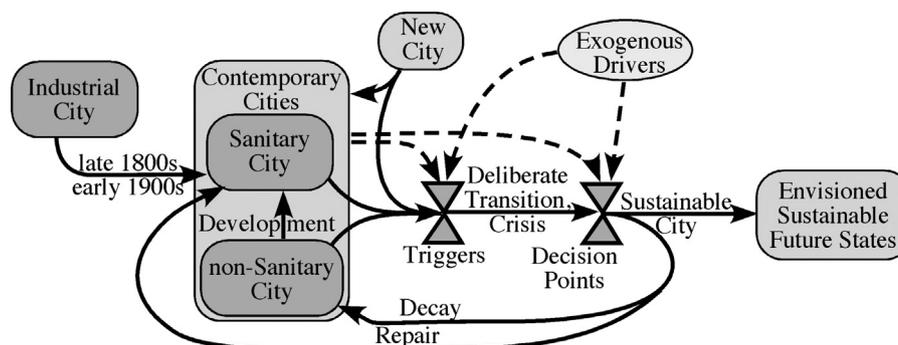
**Fig. 1.** Transdisciplinary conceptualization of the water budget for Phoenix, AZ, USA—the urban hydro-ecosystem. Note that social-cultural and biophysical components of ecosystem structure and function are not separate and must be considered together when quantifying socio-eco-hydrologic processes in the urban system. See text for further explanation.

after Melosi, 2000; Fig. 2). The industrial cities of the eighteenth and nineteenth centuries were highly productive, but were not designed to separate the health and environmental hazards of that industrial production from the inhabitants of the city. As a result, they were not healthy or even comfortable places to live. The transition of these cities to being sanitary cities involved a deliberate redesign of water, sewer, drainage, waste management, and pollution control infrastructure to make them safer for residents. However, the sanitary city urban model is largely dominated by expensive and rigid engineering solutions designed to isolate or displace hazards from people by using stove-piped approaches to manage urban problems. In most cases, these approaches are also highly centralized and require substantial government investments in major infrastructures and maintenance of those infrastructures. Younger cities that have developed in the last 100 years have been able to engineer these hygienic designs into their infrastructure as they have grown. In spite of never having been industrial cities,

we argue that these newer cities fit the Grove (2009) definition of sanitary cities quite well.

Some Global South cities are also sanitary, but many have not yet reached this point. In some cases, these cities have not yet implemented the sanitary infrastructures we describe above, or these infrastructures are only in place in select parts of the cities. In other cases these cities have sanitary infrastructures largely in place but do not have the economic capacity to maintain or even operate the systems. We collectively refer to these contemporary cities as non-sanitary (Fig. 2).

Because of these centralized, rigid infrastructures, many sanitary cities exhibit limited capacity to accommodate sustainable adaptations and practices (Glaeser, 2011; Grove, 2009; Pincetl, 2010). Examples of this are clearest where cities have recently experienced economic downturns. In the U.S., these include older, former industrial cities such as Detroit, MI, USA (Nassauer & Raskin, 2014) and rapidly growing newer sunbelt cities such as Phoenix, AZ,



**Fig. 2.** Conceptualization of transitions in urban ecosystems. Solid lines represent city state transformations or state changes and dashed lines represent influence. The model accommodates the transformations of contemporary cities, in both “sanitary” and “non-sanitary” states, toward being sustainable cities, as well as new cities, that may transition to being “sanitary”, “non-sanitary” or directly toward sustainability as they develop and grow.

USA and Miami, FL, USA. More dramatically, these cities are seeing a cascade of economic perturbations and social–ecological outcomes, such as foreclosure and abandonment of houses throughout entire neighborhoods (Johnson, Turcotte, & Sullivan, 2010; Nassauer & Raskin, 2014). The ensuing collapse of the tax base is now causing infrastructure that was key to these cities being sanitary to not be maintained and thus to deteriorate, which further contributes to the challenges facing these cities. In some cases, sanitary sewer, storm drainage, and drinking water systems have become fragile or unexpectedly intertwined. Some urban amenities that formerly attracted residents and civic activity, such as parks and public spaces, are now being neglected and are suffering from poor maintenance or a lack of social programming (Boone, Buckley, Grove, & Sister, 2010). In their analysis of the effects of land vacancy in Detroit, Nassauer and Raskin (2014) categorize these threatened sanitary city services as either “malleable”—including garbage pick-up, snow removal, and public transportation—or “sunk capital assets”—including sanitary and storm sewers and roads. These cities, or parts of these cities, are arguably in crisis. Harvey (2010) has compared these recession-induced urban crises to a “financial Katrina”, named after Hurricane Katrina that decimated New Orleans, LA, USA in 2005. Understanding the environmental and social implications of these disruptions is crucial to improving urban ecosystems.

In considering what might replace sanitary cities, a candidate city model is the sustainable city (for various definitions, see Beatley, 2000; Bosselman, 2009; Grove, 2009; Pickett, Cadenasso, & Grove, 2004; Pickett, Buckley, Kaushal, & Williams, 2011). In a general sense, this transition from sanitary toward enhanced urban sustainability parallels a shift from a focus on human health to a focus on human well-being. An equal emphasis is placed on the environmental and social/equity processes undergirding human well-being (e.g. Steiner, 2014; Wolch, Byrne, & Newell, 2014). Thus, as cities become more sustainable they should employ adaptive, integrated management to reduce demands on resources, to reduce impact on waste processing and absorption downstream, and to exploit the ecological work that can take place within an urban region (Beatley, 2000; Birch & Wachter, 2008; Farr, 2008; Platt, 2006). We argue that developing and applying this model will require: (1) an understanding that sustainability, per se, is a process and not an outcome or endpoint (Rees & Wackernagel, 1996); (2) scientific knowledge of urban areas as complex, heterogeneous social–ecological systems (Pickett et al., 1997a; Redman, Grove, & Kuby, 2004); (3) understanding social, economic, biophysical, institutional, and technological constraints and emerging modes of governance (Ostrom, 2005; Pincetl, 2010); and (4) the perspectives of the extended fields of urban design and planning (Jarzombek, 2003; Steiner, 2011). Because sustainability is a process and not an endpoint, there is actually no final or ultimate state known as a sustainable city, per se. Rather, sustainability is a multi-faceted goal, even a constantly shifting target, and cities may follow more [or less] sustainable trajectories toward that goal or target. To emphasize this, we depict sustainable city as an arrow and not a state variable in Fig. 2.

We use our conceptual model of urban transformations (Fig. 2) to describe a variety of contemporary urban situations. For example, many cities around the world that have existed for more than about 100 years began as industrial cities (USA examples include Atlanta, GA; Baltimore, MD; Chicago, IL; Detroit, MI; and New York, NY), while many newer cities have been built as either sanitary cities (e.g. Las Vegas, NV, USA; Miami, FL, USA; and Phoenix, AZ, USA) or are what we describe as largely non-sanitary cities (i.e. those where much of the urban population does not enjoy the health-related benefits of a sanitary city). Many such cities are accreting informal or unplanned development that is not yet what Grove (2009) would describe as sanitary, although more affluent

neighborhoods of these cities enjoy the full benefits of the sanitary city (e.g. Sao Paulo, Brazil; Johannesburg, South Africa; Mumbai, India).

In many parts of the Global South, and particularly in China, an untold number of new cities are being established that to varying degrees fit the sanitary city mold (Fig. 2). Interestingly, there are a few examples of new cities that are being planned—to various degrees—to be [more] sustainable in ways in which, if they are successful, their development may largely bypass the sanitary city state. Examples that show varying degrees of success but that represent this idea of “sustainability from the beginning” include the Municipality of Haarlemmermeer in The Netherlands, the Tianjin Eco-City near Singapore, and Masdar in the United Arab Emirates. McHale, Bunn, Pickett, and Twine (2013) used a rural livelihood framework to posit that in some regions of the Global South, such as much of sub-Saharan Africa, relationships between rural and urban are novel enough to suggest a need to rethink our Global North views of what is “urban”. In these settings, rural and urban boundaries are blurred by the two-way movement of people and resources that is driven by an attempt to support livelihoods and well-being. These novel relationships may also be viewed as “new cities” in our conceptual framework (Fig. 2).

Resilience science provides a conceptual vocabulary to describe the rich array of urban states and transformations we have generalized in Fig. 2. We label these transformations as state changes and refer to the tipping points for change as triggers, per the parlance of resilience science (Rockstrom et al., 2009; Scheffer, Carpenter, Foley, Folke, & Walker, 2001). Tipping points that are responsible for deliberate transitions or crisis in many contemporary cities are driven by some combination of exogenous drivers that include both natural events, such as hurricanes, tsunamis, or earthquakes, and human-caused events, such as financial market collapse or inner city flight. Tipping points may also result from events within the cities themselves, or parts of cities, such as when local real estate markets collapse and whole neighborhoods or parts of cities are largely abandoned (i.e. Nassauer & Raskin, 2014). Tipping points may also reflect deliberate decisions, in the absence of crisis, that are aimed at making cities more sustainable. At the decision point, or intervention point in the rubric of sustainability science (Loorbach, 2010), a city may: (1) be unable to maintain its existing infrastructure and services and thus decay into a non-sanitary city; (2) attempt to simply repair damage to existing infrastructure and services in hopes of maintaining the city’s current state; or (3) consider more transformational changes that set in motion a sustainable trajectory (in Fig. 2 we refer to this as the sustainable city). By focusing on the transition from contemporary cities to sustainable future states, or from cities that are either new cities or that do not yet exist to sustainable cities, we do not deny that there may be other pathways through which cities may evolve (Montgomery, 2008). We recognize that, as with sustainability itself, these are processes and not endpoints or outcomes, and that they are broad logics that help us to understand the ways in which resources are governed, consumed, and allocated in cities. In many parts of the world, cities that are relatively sustainable may be entirely new settlements (Bai, Roberts, & Chen, 2010; Normile, 2008; Register, 2006) or may arise from cities that have been neither industrial nor sanitary in the past (i.e. McHale et al., 2013; United Nations Population Fund, 2007). Learning how to enable and encourage sustainable transitions that include adaptive mechanisms responding to 21st century challenges (Yohe & Tol, 2002) requires an understanding of the myriad transitions urban systems may experience, or have the potential to experience. We argue that the contemporary to sustainable transition is a test case from which broader lessons may emerge.

Several processes and conditions must be considered to model and exploit the contemporary to sustainable transition (Fig. 2):

1. The endogenous and exogenous *triggers* that have led to stresses and crises in contemporary cities must be documented and the causes behind them elucidated (Graham & Marvin, 2001; Lucy & Phillips, 2000).
2. Cases in which contemporary cities are in crisis or are under threat as complex systems must be understood (Graham & Marvin, 2001; Nassauer & Raskin, 2014).
3. We should explore the motivations that are deliberately moving contemporary cities to become more sustainable—that is, cities that are undergoing this transition because of desire, not crisis (e.g. Steiner, 2014).
4. We must expand our view of cities beyond the Global North model of the sanitary city to include non-sanitary cities that are more likely to occur in developing, or Global South nations, and to include regions that have not yet urbanized or are urbanizing in novel ways (e.g. new cities in Fig. 2).
5. The interaction of key resources that affect all cities provides a focus for understanding the opportunities and constraints that may characterize cities that are more sustainable (Brunner, 2007; Kennedy, Cuddihy, & Engel-Yan, 2007).

The ongoing and emerging urban transformations may involve or invoke significant transformations in how resources are used in city–suburban–exurban mosaics or in novel urban arrangements per McHale et al. (2013). An example of a resource interaction that is critical to the dynamics of all cities is the *nexus of water and energy*. Water excess in storms or floods, clean water deficits, water contamination, and alternative ways to manage water in cities are of concern in both mesic and arid environments (Gandy, 2004; Gleick, 2009). However, managing or adapting to excesses, deficits, and impaired water quality all depend on energy availability, cost, allocation, and incentive structures, among other factors (Adams, 1975; Ripl, 1994; Stokes & Horvath, 2011). Energy itself is key to understanding the growth and form of urban systems (Brunner, 2007; Cottrell, 1955; Olson, 1982; Oswald & Baccini, 2003; Puselli & Tiezzi, 2009). For example, in hot, arid cities such as Phoenix, AZ, USA, the water–energy nexus often plays out as trade-offs. It takes tremendous energy in infrastructure and management to move water hundreds of miles across the desert to the city, yet a surprising amount of the city's electricity is generated by hydropower (Bolin, Seetharam, & Pompeii, 2010; Gober, 2010). Roughly 70% of all water consumed in Phoenix is used outdoors, much of it to irrigate lush urban landscapes that provide shade and microclimatic cooling, reducing the Urban Heat Island effect and potentially reducing energy demand (Gober, 2010; Guhathakurta & Gober, 2010). Similar water–energy trade-offs and conflicts exist in most cities (Cromwell, Smith, & Raucher, 2007). As cities transition to more sustainable future states, or to less desirable non-sustainable states, these resource trade-offs will either be part of the decision-making equations or part of the crisis response calculus.

### 3. Interacting theories in the urban setting

Urban sustainability, as both a research topic and a platform for solutions-oriented activities, entails a number of interacting theoretical constructs, including sustainability, resilience, adaptation, and vulnerability (Janssen & Ostrom, 2006). We suggest that a better understanding of how these concepts relate to one another may come from concrete, empirically motivated urban sustainability research and action. Furthermore, these four concepts likely all play a role in the crisis or collapse of contemporary cities—for

example, the underfunding and devolution of municipal governments (Graham & Marvin, 2001)—and in the deliberate transition of contemporary cities not in crisis to more sustainable futures. We posit that sustainability is a process driven by values that express society's preferences, with urban system resilience as the goal. Resilience may, however, produce both benefits for and burdens on urban systems. Furthermore, engineered resilience is not the same as urban resilience. Engineered resilience is inherently rigid and focused on unchanging stability while the resilience of an urban system likely depends on adaptive processes operating in both the social (Yohe and Tol, 2002) and biophysical (Gunderson and Pritchard, 2002; Walker et al., 2004) realms of the city, and on the existence, spatial distribution, and social variation of vulnerability.

Theories of alternate stable states and state change thresholds in the context of resilience theory have real relevance and application to urban social–biophysical systems (Folke, 2006). Many of the triggers we discuss above are, in fact, events that push cities or parts of cities toward or over state change thresholds. Many strategies for making cities more resilient and less vulnerable to perturbations—both exogenous and endogenous—take the form of engineered solutions that are often structurally rigid, not inherently adaptive (Coaffee, 2008), and seek to keep urban systems within their current state space. This may be because people prefer constancy and predictability. Governance structures and institutions are often overburdened by the task of maintaining these rigid infrastructures and have little time or freedom to pursue more adaptive, nimble, and longer-term approaches (Ernstson et al., 2010). Further problems come from the expectations of citizens who are at minimal risk because city infrastructures and institutions are designed and [ostensibly] prepared to protect them from all reasonable vulnerabilities. Yet when perturbations are large enough that structures or institutions fail, the now non-resilient and vulnerable city often changes state to a much less desirable condition—and often at considerable human, social, economic, and environmental cost. One need look no further than the example of New Orleans, LA, USA and Hurricane Katrina in 2005 or the New York City, USA region and Superstorm Sandy in October 2012 for clear evidence of this kind of costly, catastrophic, and systemic failure.

We suggest that another way to think about rigid structures, features, and characteristics is from the viewpoint of the inertia they impart on urban systems. Folke (2006) briefly discussed institutional and organizational inertias as they relate to adaptive governance. We argue that many contemporary cities, particularly sanitary cities, have substantial inertia throughout the urban ecosystem: (1) Built or engineered structures impart an inflexible physical inertia on urban infrastructure; it is difficult and expensive to make substantive changes to the built environment of cities—we pour a lot of concrete when we make cities; (2) the stove-piped governance in many cities bring considerable institutional inertia to change—it seems no accident that often the most monolithic buildings in a city house city government, and (3) there is often considerable social inertia that must be overcome when considering novel solutions and new systems—this is the “change is good as long as it happens to somebody else” mentality. More recent applications of resilience theory to urban systems suggest that urban resilience may be built by nurturing self-organizational features, adaptive learning, positive feedbacks, and diversity in processes, institutions, and culture (IFRC 2004). Tidball and Krasny (2007) argued that “civic ecology” actions that integrate social, natural, economic, and physical capital—such as urban community greening—build these very features into the urban fabric, making cities more resilient to perturbations and more adaptive in their responses to state change and disturbance. In this very issue Wolch et al. (2014) and Steiner (2014) make similar arguments. But the various inertias that characterize urban systems may hinder such

approaches. Urban sustainability must be sensitive to these challenges as dynamic new solutions are conceived, presented, and [hopefully] implemented.

### 3.1. From theory to action: opportunities for success in cities

Solutions to urban sustainability challenges may be categorized into two types: (1) Solutions that “tweak” the current systems, be they infrastructural, institutional, or social systems—or a combination—and that work with or even take advantage of the inertia in those systems, versus; (2) Solutions that are more transformative and may thus require new systems or new ways of doing business, and that directly confront systemic inertias. The former types of solutions are obviously easier to palate and to implement, but this approach begs several questions: Can a truly more sustainable future for a city emerge from the accumulation of solutions that “tweak” existing systems, or is transformative change necessary? What cities, or types of cities, demonstrate sufficient flexibility, adaptability, and nimbleness in their systemic inertias to allow success with an accumulation of “tweaking” solutions? For what cities, or types of cities, can sustainable futures only come from transformational systemic change? Are new cities, or cities that are not yet cities, (per Fig. 2) better primed for transformational changes because they have not yet built up systemic inertias?

The opportunities to enhance urban sustainability in the future are great. First, a vast amount of urbanization remains on the horizon. Many mid-sized cities are expected to emerge over the coming decades, especially in Asia and Africa (United Nations Population Fund, 2007). Although the growth and emergence of megacities—those housing more than 20 million persons—will be impressive, much urbanization will soon be occurring in places that are not yet urban, or in scenarios that we do not currently define as urban. Furthermore, urbanized lifestyles, livelihoods, and investments will affect extensive areas that are now considered rural and may not develop the kinds of infrastructure expected of the sanitary city (McHale et al., 2013). Further opportunities for enhancing sustainability could well come from the considerable infrastructure replacement that will likely be required in contemporary sanitary cities in the next few decades. Rather than replace this infrastructure with the same construction and design that comes from the sanitary city models (i.e. “repair” in Fig. 2), green infrastructure, green engineering, and management that relies on adaptive and cross-disciplinary approaches may be employed (Ahern et al., 2014; Steiner, 2014).

We posit that a rich opportunity for real solutions to urban sustainability challenges will come from close collaboration among urban systems scientists, representing all traditional social and biophysical disciplines, and urban designers and planners (Felson, Bradford, & Terway, 2013; Steiner, Simmons, Gallagher, Ranganathan, & Robertson, 2013). Indeed, pioneering urban designers have for decades called for and implemented designs based on bio-ecological understanding and principles (Lyle, 1999; McHarg, 1969; Spirn, 1984; Steiner, 2014). However, contemporary ecology provides new insights and approaches that may be useful for designers (Felson et al., 2013; Pickett et al., 2013). For example, patch dynamics, a spatial and functional modeling approach to systems, provides a powerful platform both for understanding urban ecosystems and for interaction between urban researchers and urban designers (McGrath et al., 2007). Furthermore, designers have been among the first to adopt sustainability thinking (Curwell, Deakin, & Symes, 2005), but we suggest that the theories of resilience may provide a firmer scientific foundation for advancing sustainable design (Musacchio, 2009; Pickett et al., 2004). A new, spatially extensive, dynamic, and adaptive concept of city-suburban-exurban complexes is summarized in the “metacity” concept (McGrath & Pickett, 2011). The desire and examples of

**Table 1**

List of cities with representation in the Urban Sustainability Research Coordination Network as of September 2013.

Continent	Cities
North America	Asheville NC; Atlanta GA; Austin TX; Baltimore MD; Boston MA; Chicago IL; Detroit MI; Los Angeles CA; Madison WI; Miami FL; Minneapolis-St. Paul MN; Montreal Canada; New York City NY; Phoenix AZ; Portland OR; Raleigh-Durham-Chapel Hill NC; Sacramento CA; Salt Lake City UT; San Juan PR; Seattle WA; Tampa FL; Vancouver Canada; Washington D.C.
Europe	Colmer France; Nancy France; Paris France; Sheffield UK; Strasbourg France; Stockholm Sweden; Toulouse France
Asia	Beijing China; Shanghai China; Singapore
South America	Osorno Chile; Puerto Williams Chile; San Lorenzo Paraguay; Temuco Chile; Valdivia Chile
Africa	Accra Ghana; Bushbuckridge South Africa; Cape Town South Africa; Kumasi Ghana; Tamale Ghana
Australia	Sydney

ecologically informed sustainable urban design finds expression in new varieties of urbanism—the theory and normative assumptions adopted by these forward-thinking and progressive designers. These concepts are expressed in various threads of urbanism, including landscape urbanism, ecological urbanism, and sustainable urbanism, to name but three recent strands (Beatley, 2000; Farr, 2008; Jabareen, 2006; Jenks & Jones, 2010; Williams, 2007).

### 3.2. Advancing theory and action in urban sustainability

Understanding how cities, as complex adaptive social-biophysical systems, behave seems overly challenging, and moving beyond understanding to identifying and implementing real-world solutions for urban sustainability often seems downright daunting. We propose that one viable approach for bridging research to practice, or knowledge to action, focuses on intercity comparisons. This approach is being facilitated through a newly formed interdisciplinary Research Coordination Network (RCN) that focuses on urban sustainability by integrating urban research while incubating solutions-oriented products and collaborative partnerships with practitioners. Comparisons among emerging, established, and changing cities present major opportunities to enhance our understanding of the mechanisms of sustainability in urban systems. Some urbanists have identified the current situation of many cities as a crisis, as noted earlier, and many examples exist (e.g. Bernt & Rink, 2010; Kirkpatrick & Smith, 2011; Pieterse, 2008). Formerly industrial cities in the U.S. and Europe have lost population and revenue as factory jobs have moved to distant countries. These cities—Detroit MI USA for example—have been referred to as “shrinking cities” (per Nassauer & Raskin, 2014). Other cities, such as the Miami, Phoenix, and Las Vegas examples we presented above, saw crisis due to financial market collapse that led to the deflation of the real estate bubble, which in turn has resulted in reduced tax bases and foreclosure-induced home and neighborhood abandonment. This is similar to the Detroit scenario of abandonment and vacancy, but with different drivers. However, there are specific interactions of global, national, and regional factors that are important for assessing degrees of urban crisis (Garcia, 2010) and, hence, the nature of response. Still other cities, across the world, are seeing proactive transitions to more sustainable models without the stimulus of crisis (Beatley, 2000).

This new Urban Sustainability RCN is focused on research to better understand and apply the various transitions to more sustainable future states shown in Fig. 2, as a test case from which broader lessons may emerge. Some of the cities represented in

this Urban Sustainability RCN (Table 1) are now in crisis and are struggling to provide the social and infrastructural services characteristic of the a sanitary city. Our intercity comparative approach is particularly timely because we are now observing first-hand the opportunities to understand and promote sustainable paths and futures for cities. This network of cities, of disciplines, and of skills (Table 1; Andersson, 2006) exploits experiences and expertise from nearly 70 urban scientists, designers, and planners from more than 40 cities across six continents that are in varying degrees of transition. The Network adheres to a philosophy on collaboration, synthesis, and incubation of new ideas (Pickett, 1999; Pickett, Burch, & Grove, 1999; Taylor, 2005) that broadly follows proven strategies (Carpenter et al., 2009; Pickett, 1999; Pickett et al., 1999). Most of the Network's synthetic and integrative work is done in small, thematic, and self-selected Working Groups (6–10 participants), with products that include meta-analyses, comparative synthesis, publications, proposals, and outreach. In the true sentiment of sustainability science, Network activities are precursors to generating societally-relevant solutions and are incubating new projects that are leading to tangible, "on the ground" sustainable solutions. We firmly believe that now is the time for urban systems scientists to be advancing solutions to real world problems rather than simply studying those problems (Chapin et al., 2011; Kingsland, 2005).

How the various features of crisis, collapse, and transition may translate into incentives for sustainability is a crucial practical and theoretical issue (Curwell et al., 2005). Through the Network's Working Groups, we are addressing the following questions: (1) To what extent are phenomena that are perceived as crises likely to become transition-inducing triggers, or tipping points, in different cities? (2) What drivers, internal and external influences, and (un)intentional (dis)incentives are likely to push a city in transition along a sustainable trajectory versus to some other less desirable state (Fig. 2)? Answers to such questions are important not only for managing our contemporary cities, but also for understanding and modeling urban sustainability as a process, an option, and a future. Indeed, the common assertions about the value of urban sustainability are best viewed as hypotheses to be tested across many cities (Jenks & Jones, 2010)—hence the need for and value in this Urban Sustainability RCN.

To realize the greatest benefits of urban sustainability research, we must first meet several theoretical and practical considerations, including: (1) inter-city comparisons must represent different contexts of environmental change, different economic contexts, different social/cultural contexts, and therefore, different positions along a gradient of vulnerability and collapse, and (2) the concept of sustainability itself must be treated as a process, not a utopic terminal state, with feedbacks that account for "system learning". By focusing Urban Sustainability RCN activities on a broad range of cities, our synthesis and solution-generating activities are accessing different points along this gradient more effectively than would a comparison of a small number of cities (McDonnell, Hahs, & Breuste, 2009). Furthermore, a nimble, flexible, open network approach allows us to add cities as frameworks for comparison evolve or fall in.

In practical terms, this Urban Sustainability RCN allows researchers and practitioners to exchange knowledge and experiences between their Working Groups and across the network of cities. Research results, experiences in applying sustainability and its component concepts, and knowledge of both successful and unsuccessful solutions are being shared across the network (Bai et al., 2010). This is important because sustainability often does not leave the metaphorical level (Larson, 2011). As a process, though, it is most effective at the practical level. In other words, different cities and the mix of disciplines represented in the Urban Sustainability RCN provide a variety of lenses on sustainability, which

together will generate a more complete and well-tested view of the process.

#### 4. Summary

The theories and research of urban ecology are increasingly poised to contribute to urban sustainability. Urban sustainability is rapidly expanding beyond interdisciplinary approaches to include transdisciplinarity because human and biophysical structures and dynamics are inextricably linked in cities. We present a conceptual framework that expands the industrial to sanitary to sustainable city transition to include non-sanitary cities, new cities, and various permutations of transition options for cities encountering exogenous and endogenous triggers of change. As both contemporary and new cities transition toward more sustainable future states, the focus on human health that defines the sanitary city is expanding to include human well-being, with particular emphasis on environmental and social equity.

Several existing theoretical frameworks, including sustainability, resilience, adaptation, and vulnerability, may be helpful when considering urban transitions. Sustainability is driven by values that express society's preferences, seemingly with urban system resilience as the goal. Urban system resilience is typically equated to infrastructural rigidity and strength, but it also likely depends on both social and biophysical adaptive processes, and on the existence, spatial distribution, and social variation of vulnerability. These theories interact through inertias in urban systems, and these multi-faceted inertias—institutional, infrastructural, social, and others—impart degrees of rigidity that make urban systems less flexible and nimble when facing transitional triggers and change. Given this, we categorize solutions to urban sustainability challenges as those that: (1) "tweak" the current systems and work with or even take advantage of the inertias in those systems, or (2) are more transformative, that confront systemic inertias, and that demand new systems.

One approach for addressing urban sustainability in the context of relevant theory, and for bridging research and practice, is a focus on intercity comparisons, and this is the goal of a newly formed interdisciplinary Research Coordination Network (RCN) that focuses on urban sustainability by integrating urban research while incubating solutions-oriented products and collaborative partnerships with practitioners. This Urban Sustainability RCN includes nearly 70 participants working in over 40 cities on six continents that are in various degrees of transition. Network activities are incubating societally-relevant solutions through projects that are leading to tangible, on-the-ground sustainable solutions for all types of cities. Our ultimate goal is to not only understand the process by which cities become more sustainable, but to also affect that process through action inspired by knowledge.

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#### References

- Adams, R. N. (1975). *Energy and structure: A theory of social power*. Austin: University of Texas Press.

- Ahern, J., Cilliers, S., & Niemelä, J. (2014). The concept of ecosystem services in adaptive urban planning and design: Encouraging transdisciplinarity. *Landscape & Urban Planning*, 125, 254–259.
- Andersson, E. (2006). Urban landscapes and sustainable cities. *Ecology and Society*, 11, Art 34.
- Bai, X. M., Roberts, B., & Chen, J. (2010). Urban sustainability experiments in Asia: Patterns and pathways. *Environmental Science & Policy*, 13, 312–325.
- Beatley, T. (2000). *Green urbanism: Learning from European cities*. Washington, DC: Island Press.
- Bernt, M., & Rink, D. (2010). Not relevant to the system: The crisis in the backyards. *International Journal of Urban and Regional Research*, 34, 678–685.
- Birch, E. L., & Wachter, S. M. (2008). *Growing greener cities: Urban sustainability in the twenty-first century*. Philadelphia: University of Pennsylvania Press.
- Bolin, B., Seetharam, M., & Pompeii, B. (2010). Water resources, climate change, and urban vulnerability: A case study of Phoenix, Arizona. *Local Environment*, 15(3), 261–279.
- Boone, C. G., Buckley, G. B., Grove, J. M., & Sister, C. (2010). Parks and people: An environmental justice inquiry in Baltimore, Maryland. *Annals of the Association of American Geographers*, 99(4), 767–787.
- Bossellman, P. (2009). *Urban transformation: Understanding city design and form*. Washington, DC: Island Press.
- Brundtland Report. (1987). *Our common future*. New York: Oxford University Press.
- Brunner, P. H. (2007). Reshaping urban metabolism. *Journal of Industrial Ecology*, 11, 11–13.
- Carpenter, S. R., Armbrust, E. V., Arzberger, P. W., Chapin, F. S., III, Elser, J. J., Hackett, E. J., Ives, A. R., Kareiva, P. M., Leibold, M. A., Lundberg, P., Mangel, M., Merchant, N., Murdoch, W. W., Palmer, M. A., Peters, D. P. C., Pickett, S. T. A., Smith, K. K., Wall, D. H., & Zimmerman, A. S. (2009). Accelerate synthesis in ecology and environmental sciences. *BioScience*, 59, 699–701.
- Chapin, F. S., III, Pickett, S. T. A., Power, M. E., Jackson, R. B., Carter, D. M., & Duke, C. (2011). Earth stewardship: A strategy for social–ecological transformation to reverse planetary degradation. *Journal of Environmental Studies and Science*, 1, 44–53.
- Coaffee, J. (2008). Risk, resilience, and environmentally sustainable cities. *Energy Policy*, 36(12), 4633–4638.
- Collins, J. P., Kinzig, A., & Grimm, N. B. (2000). A new urban ecology. *American Scientist*, 88(5), 416–425.
- Collins, S. L., Carpenter, S. M., Childers, D. L., Gragson, T. L., Grimm, N. B., Grove, J. M., Harlan, S. L., Knapp, A. K., Kofinas, G. P., Magnuson, J. J., McDowell, W. H., Melack, J. M., Ogden, L. A., Ornstein, D., Robertson, G. P., Smith, M. D., Stephen, R., Swinton, & Whitmer, A. (2011). An integrated conceptual framework for socio–ecological research. *Frontiers in Ecology & the Environment*, (96), 351–357.
- Cottrell, F. (1955). *Energy and society: The relation between energy, social change, and economic development*. Westport, CT: Greenwood Press.
- Cromwell, J. E., Smith, J. B., & Raucher, R. S. (2007). *Implications of climate change for urban water utilities*. Washington, DC: Association of Metropolitan Water Agencies.
- Curwell, S., Deakin, M., & Symes, M. (2005). *Sustainable urban development. Vol. 1. The framework and protocols for environmental assessment*. New York: Routledge.
- Ernstson, H., van der Leeuw, S. E., Redman, C. L., Meffert, D. J., Davis, G., Alfson, C., & Elmqvist, T. (2010). Urban transitions: On urban resilience and human-dominated ecosystems. *AMBIO*, 39, 531–545.
- Farr, D. (2008). *Sustainable urbanism: Urban design with nature*. Hoboken: Wiley.
- Felson, A. J., Bradford, M. A., & Terway, T. M. (2013). Promoting earth stewardship through urban design experiments. *Frontiers in Ecology and Environment*, 7(11), 362–367.
- Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analysis. *Global Environmental Change*, 16(3), 253–267.
- Gandy, M. (2004). Rethinking urban metabolism: Water, space and the modern city. *City*, 8, 363–379.
- Garcia, M. (2010). The breakdown of the Spanish urban growth model: Social and territorial effects of the global crisis. *International Journal of Urban and Regional Research*, 34, 967–980.
- Glaeser, E. (2011). *Triumph of the city: How our greatest invention makes us richer, smarter, greener, healthier, and happier*. New York: Penguin Press.
- Gleick, P. H. (2009). *The world's water: 2008–2009*. Washington, DC: Island Press.
- Gober, P. (2010). Desert urbanization and the challenges of water sustainability. *Current Opinion in Environmental Sustainability*, 2(3), 144–150.
- Graham, S., & Marvin, S. (2001). *Splintering urbanism: Networked infrastructures, technological mobilities and the urban condition*. New York: Routledge.
- Grimm, N. B., Grove, J. M., Pickett, S. T. A., & Redman, C. L. (2000). Integrated approaches to long-term studies of urban ecological systems. *BioScience*, 50, 571–584.
- Grimm, N. B., Redman, C. L., Boone, C. G., Childers, D. L., Turner, B. L., & Harlan, S. (2012). Viewing the urban socioecological system through a sustainability lens: Lessons and prospects from the Central Arizona–Phoenix LTER program. In S. J. Singh, S. J. Singh, et al. (Eds.), *Long-term socio-ecological research, human–environment interactions* (pp. 217–246). Dordrecht, The Netherlands: Springer Publications.
- Grove, J. M. (2009). Cities: Managing densely settled social–ecological systems. In F. S. Chapin III, G. P. Kofinas, & C. Folke (Eds.), *Principles of ecosystem stewardship: Resilience-based natural resource management in a changing world* (pp. 281–294). New York: Springer.
- Guhathakurta, S., & Gober, P. (2010). Residential land use, the urban heat island, and water use in Phoenix: A path analysis. *Journal of Planning Education and Research*, 30(1), 40–51.
- Gunderson, L. H., & Pritchard, L., Jr. (2002). *Resilience and the behavior of large-scale systems*. Washington, DC: Island Press.
- Harvey, D. (2010). *The enigma of capital: And the crises of capitalism*. Oxford, England: Oxford University Press.
- Jabareen, Y. R. (2006). Sustainable urban forms: Their typologies, models, and concepts. *Journal of Planning Education and Research*, 26, 38–52.
- Janssen, M. A., & Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society*, 11(2), 37–48.
- Jarzombek, M. (2003). Sustainability, architecture, and nature: Between fuzzy systems and wicked problems. *Thresholds*, 26, 54–56.
- Jenks, M., & Jones, C. (2010). *Dimensions of the sustainable city*. New York: Springer.
- Johnson, M. P., Turcotte, D. A., & Sullivan, F. M. (2010). What foreclosed homes should a municipality purchase to stabilize vulnerable neighborhoods? *Networks & Spatial Economics*, 10, 363–388.
- Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology*, 11, 43–59.
- Kingsland, S. E. (2005). *The evolution of American ecology, 1890–2000*. Baltimore: Johns Hopkins University Press.
- Kirkpatrick, L. O., & Smith, M. P. (2011). The infrastructural limits to growth: Rethinking the urban growth machine in times of fiscal crisis. *International Journal of Urban and Regional Research*, 35, 477–503.
- Larson, B. (2011). *Metaphors for environmental sustainability: Redefining our relationship with nature*. New Haven: Yale University Press.
- Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance*, 23, 161–183.
- Lucy, W. H., & Phillips, D. L. (2000). Suburban decline: The next urban crisis. *Issues in Science and Technology*, 27, 55–62.
- Lyle, J. T. (1999). *Design for human ecosystems: Landscape, land use, and natural resources*. Washington, DC: Island Press.
- McDonnell, M. J., Hahs, A. K., & Breuste, J. H. (2009). *Ecology of cities and towns: A comparative approach*. New York: Cambridge University Press.
- McGrath, B., & Pickett, S. T. A. (2011). The metacity: A conceptual framework for integrating ecology and urban design. *Challenges*, 2011, 55–72.
- McGrath, B. P., Marshall, V., Cadenasso, M. L., Grove, J. M., Pickett, S. T. A., Plunz, R., & Towers, J. (2007). *Designing patch dynamics*. New York: Columbia University Graduate School of Architecture, Preservation and Planning.
- McHale, M. R., Bunn, D. N., Pickett, S. T. A., & Twine, W. (2013). Urban ecology in a developing world: Why advanced socioecological theory needs Africa. *Frontiers in Ecology and the Environment*, <http://dx.doi.org/10.1890/120157>
- McHarg, I. L. (1969). *Design with nature*. New York, NY: Doubleday Press.
- Melosi, M. V. (2000). *The sanitary city: Urban infrastructure in America from colonial times to the present*. Baltimore: Johns Hopkins University Press.
- Montgomery, M. R. (2008). The urban transformation of the developing world. *Science*, 319, 761–764.
- Musacchio, L. R. (2009). The scientific basis for the design of landscape sustainability: A conceptual framework for transnational landscape research and practice of designed landscapes and the six Es of landscape sustainability. *Landscape Ecology*, 24, 993–101.
- Naess, P. (2001). Urban planning and sustainable development. *European Planning Studies*, 9, 503–524.
- Nassauer, J. I., & Raskin, J. (2014). Urban vacancy and land use legacies: A frontier for urban ecological research, design, and planning. *Landscape & Urban Planning*, 125, 245–253.
- Normile, D. (2008). China's living laboratory in urbanization. *Science*, 319, 740–743.
- Ogden, L., Heynen, N., Oslander, U., West, P., Kassam, K., & Robbins, P. (2013). Global assemblages, resilience, and earth stewardship in the anthropocene. *Frontiers in Ecology and the Environment*, 11(7), 341–347.
- Olson, S. (1982). Urban metabolism and morphogenesis. *Urban Geography*, 3, 87–109.
- Ostrom, E. (2005). *Understanding institutional diversity*. Princeton: Princeton University Press.
- Oswald, F., & Baccini, P. (2003). *Netzstadt*. Basel: Springer.
- Pickett, S. T. A., Burch, W., Jr., Dalton, S., Foresman, T. W., & Rowntree, R. (1997). A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems*, 1, 185–199.
- Pickett, S. T. A., Burch, W. R., Jr., Dalton, S. D., & Foresman, T. W. (1997). Integrated urban ecosystem research. *Urban Ecosystems*, 1, 183–184.
- Pickett, S. T. A. (1999). The culture of synthesis: Habits of mind in novel ecological integration. *Oikos*, 87, 479–487.
- Pickett, S. T. A., Burch, W. R., Jr., & Grove, J. M. (1999). Interdisciplinary research: Maintaining the constructive impulse in a culture of criticism. *Ecosystems*, 2, 302–307.
- Pickett, S. T. A., Cadenasso, M. L., & Grove, J. M. (2004). Resilient cities: Meaning, metaphor, and models for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning*, 69(4), 369–384.
- Pickett, S. T. A., & Grove, J. M. (2009). Urban ecosystems: What would Tansley do? *Urban Ecosystems*, 12, 1–8.
- Pickett, S. T. A., Buckley, G. L., Kaushal, S. S., & Williams, Y. (2011). Social–ecological science in the humane metropolis. *Urban Ecosystems*, 14(3), 319–339.
- Pickett, S. T. A., Cadenasso, M. L., & McGrath, B. P. (2013). *Resilience in urban ecology and urban design: Linking theory and practice for sustainable cities*. Dordrecht, The Netherlands: Springer-Verlag Publishing.
- Pieterse, E. (2008). *City futures: Confronting the crisis of urban development*. New York: Zed Books.

- Pincetl, S. (2010). From the sanitary to the sustainable city: Challenges to institutionalizing biogenic (nature's services) infrastructure. *Local Environment*, 15, 43–58.
- Platt, R. H. (2006). *The humane metropolis: People and nature in the twenty-first century city*. Amherst: University of Massachusetts Press.
- Puselli, R. M., & Tiezzi, E. (2009). *City out of chaos: Urban self-organization and sustainability*. Cambridge: MIT Press.
- Rapport, D. J. (2007). Sustainability science: An ecohealth perspective. *Sustainability Science*, 2, 77–84.
- Redman, C. L., Grove, J. M., & Kuby, L. (2004). Integrating social science into the Long-Term Ecological Research (LTER) Network: Social dimensions of ecological change and ecological dimensions of social change. *Ecosystems*, 7, 161–171.
- Rees, W., & Wackernagel, M. (1996). Urban ecological footprints: Why cities cannot be sustainable—and why they are a key to sustainability. *Environmental Impact Assessment Review*, 16, 223–248.
- Register, R. (2006). *Ecocities: Rebuilding cities in balance with nature*. Gabriola Island, BC: New Society Publishers.
- Ripl, W. (1994). Management of water cycle and energy flow for ecosystem control: The energy-transport-reaction model (ETR) model. *Ecological Modelling*, 78, 61–76.
- Rockstrom, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., III, Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., & Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461, 472–475.
- Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, 413, 591–596.
- Spangenberg, J. H. (2011). Sustainability science: A review, an analysis, and some empirical lessons. *Environmental Conservation*, 38(3), 275–287.
- Spirn, A. W. (1984). *The granite garden: Urban nature and human design*. New York: Basic Books.
- Steiner, F. (2011). *Design for a vulnerable planet*. Austin: University of Texas Press.
- Steiner, F. (2014). Frontiers in urban ecological design and planning research. *Landscape & Urban Planning*, 125, 304–311.
- Steiner, F., Simmons, M., Gallagher, M., Ranganathan, J., & Robertson, C. (2013). The ecological imperative for environmental design and planning. *Frontiers in Ecology and Environment*, 7(11), 355–361.
- Stokes, J., & Horvath, A. (2011). Life-cycle assessment of urban water provision: Tool and case study in California. *Journal of Infrastructure Systems*, 17, 15–24.
- Taylor, P. J. (2005). *Unruly complexity: Ecology, interpretation, engagement*. Chicago: University of Chicago Press.
- Tidball, K. G., & Krasny, M. E. (2007). From risk to resilience: What role for community greening and civic ecology in cities? In A. E. J. Wals (Ed.), *Social learning towards a sustainable world* (pp. 149–164). The Netherlands: Wageningen Academic Press.
- United Nations Population Fund. (2007). *State of world population 2007: Unleashing the potential of urban growth*. New York: United Nations Population Fund.
- Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society*, 9(5).
- Weinstein, M. P. (2010). Sustainability science: The emerging paradigm and the ecology of cities. *Sustainability: Science, Practice & Policy*, 6(1), 1–5.
- Williams, D. E. (2007). *Sustainable design: Ecology, architecture, and planning*. Hoboken: John Wiley & Sons, Inc.
- Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape & Urban Planning*, 125, 234–244.
- Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity – Moving toward a working definition of adaptive capacity. *Global Environmental Change*, 12, 25–40.