



20th Anniversary Paper

Moving Towards a New Urban Systems Science

Peter M. Groffman,^{1*} Mary L. Cadenasso,² Jeannine Cavender-Bares,³
Daniel L. Childers,⁴ Nancy B. Grimm,⁵ J. Morgan Grove,⁶ Sarah E. Hobbie,³
Lucy R. Hutyra,⁷ G. Darrel Jenerette,⁸ Timon McPhearson,⁹
Diane E. Pataki,¹⁰ Steward T. A. Pickett,¹¹ Richard V. Pouyat,¹²
Emma Rosi-Marshall,¹¹ and Benjamin L. Ruddell¹³

¹Department of Earth and Environmental Sciences, City University of New York Advanced Science Research Center and Brooklyn College, New York, New York 10031, USA; ²Department of Plant Sciences, University of California, Davis, California 95616, USA; ³Department of Ecology, Evolution and Behavior, University of Minnesota, Saint Paul, Minnesota 55108, USA; ⁴School of Sustainability, Arizona State University, Tempe, Arizona 85287, USA; ⁵School of Life Sciences and Global Institute of Sustainability, Arizona State University, Tempe, Arizona 85287, USA; ⁶USDA Forest Service, Baltimore Field Station, Baltimore, Maryland 21228, USA; ⁷Department of Earth and Environment, Boston University, Boston, Massachusetts 02215, USA; ⁸Department of Botany and Plant Sciences, University of California Riverside, Riverside, California 92521, USA; ⁹Urban Ecology Lab, Environmental Studies Program, The New School, New York, New York 10003, USA; ¹⁰Department of Biology, University of Utah, Salt Lake City, Utah 84112, USA; ¹¹Cary Institute of Ecosystem Studies, Millbrook, New York 12545, USA; ¹²USDA Forest Service, Research and Development, District of Columbia, Washington 20502, USA; ¹³School of Informatics, Computing, and Cyber Systems, Northern Arizona University, Flagstaff, Arizona 86001, USA

ABSTRACT

Research on urban ecosystems rapidly expanded in the 1990s and is now a central topic in ecosystem science. In this paper, we argue that there are two critical challenges for ecosystem science that are rooted in urban ecosystems: (1) predicting or explaining the assembly and function of novel communities and ecosystems under altered environmental conditions and (2) refining understanding of humans as components of ecosystems in the context of integrated social-ecological systems. We assert that these challenges are also

linchpins in the further development of sustainability science and argue that there is a strong need for a new initiative in urban systems science to address these challenges and catalyze the next wave of fundamental advances in ecosystem science, and more broadly in interdisciplinary and transdisciplinary science.

Key words: community assembly; ecosystem function; evolution; social science; sustainability; urban.

Received 25 April 2016; accepted 13 September 2016;
published online 13 October 2016

Author contributions Peter M. Groffman wrote the first draft of the paper based on input from numerous colleagues in the Baltimore and Phoenix U.S. National Science Foundation Funded Urban Long Term Ecological Research projects. Other authors reviewed the manuscript and provided text on specific aspects.

*Corresponding author; e-mail: peter.groffman@asrc.cuny.edu

INTRODUCTION

Ecosystem-scale research on urban ecosystems has expanded rapidly since the 1990s (McDonnell and Pickett 1993; Alberti and others 2003) and is now a widely accepted component of ecosystem science (Weathers and others 2016). This emergence was driven by the recognition that urban, suburban,

and exurban ecosystems are increasingly where people are living, consuming resources, and producing waste. Urban ecosystems thus have distinct ecological characteristics and important environmental impacts (Grimm and others 2008a, b); and they provide unique and powerful opportunities for basic science advances in ecosystem science (Pickett and others 2011; McPhearson and others 2016). More practically, bringing ecological approaches to challenges associated with urbanization can point towards solutions to some of the most pressing problems in environmental science (Childers and others 2014).

After 25 years of research in urban ecology, we face exciting but challenging opportunities in this discipline. In particular, there are two critical challenges for ecosystem science that are rooted in urban ecosystems: (1) understanding the assembly and function of novel ecological communities and ecosystems under novel environmental conditions and (2) refining understanding of humans as components of ecosystems to create a deeper and more useful understanding of human–environment interactions in the context of integrated social-ecological systems. These challenges are linchpins in the further development of sustainability science, a problem-driven interdisciplinary field dealing with the interactions between human and environmental systems that link knowledge to action to advance the development of social-ecological systems that are ecologically sound, socially equitable, and economically viable (Matson and others 2016). There is a strong need for new initiatives in urban systems science to address these challenges and catalyze the next wave of fundamental advances in ecosystem and environmental science.

THE “COMMUNITIES OF TOMORROW” ARE BEING ASSEMBLED TODAY AT AN URBAN LOCATION NEAR YOU

Much of the early work on urban ecosystems was driven by the idea that urban environmental conditions, with elevated temperatures, atmospheric CO₂ levels, nitrogen (N) deposition and pollutants (for example, ozone, heavy metals), dramatically altered water balances, invasive species introductions, and rapid timescales of transition, were a useful analog for future environmental conditions. Early studies along urban to rural gradients addressed these factors (McDonnell and Pickett 1990; Pouyat and McDonnell 1991; Pouyat and others 1995) and also provided a platform for larger-scale urban “footprint” analyses (Luck and others 2001) and for whole-city flux

analyses (Boyden and others 1981; Baker and others 2001) that broadened the focus of urban ecosystems research to include consequences of a city’s resource use for regional to global processes.

However, interpreting results from urban gradient studies is complicated by the multiple factors that covary along these gradients (McDonnell and Hahs 2008). Further, concerns about the large number of natural and human factors influencing ecosystem processes and biotic community assembly along such gradients hindered extrapolation to broader areas of natural and semi-natural ecosystems. Now, an improved ability to parse diverse factors affecting community assembly (Swan and others 2011; Knapp and others 2012) and the emergence of “novel” communities and ecosystems in many places, that is, assemblages of organisms and environmental conditions that have not necessarily evolved and assembled in the absence of human action over long periods of time (Hobbs and others 2014) has rekindled interest in using urban areas as sentinels of ecosystem response to global change. The functions of novel ecosystems are unknown in many respects and addressing this gap is a frontier challenge in ecosystem science over the next 20–50 years.

The presence of novel ecosystems in urban areas thus represents an excellent opportunity to study the assembly of novel communities and ecosystem function under environmental conditions representative of and/or relevant to the new climates emerging due to global climate change. It is not clear if the often hyper-diverse mixtures of cultivated and spontaneously establishing species that include escaped cultivars, introduced weeds, and remnant or naturally establishing native species will function similarly to the ecosystems that urban systems have largely replaced. Moreover, there is high potential for these novel ecosystems to spread into surrounding non-urban regions and to influence the composition, diversity, and evolution of the continental flora and its ecosystem functions (Johnson and others 2015; McDonnell and Hahs 2015). Indeed, it is likely that areas at the “wildland-(ex)urban interface” with agricultural and less human-dominated ecosystems (Radeloff and others 2005) are where the communities and ecosystems that will dominate the continent over the next 100 years are being assembled. Critically, the linkage of biodiversity and community structure with ecosystem function and services is even more uncertain in urban areas than in natural areas, due to their novel composition and environment. Hence, a focus on novel ecosystem assemblage, its drivers, and its consequences should

facilitate fundamental advances in our ability to understand and predict the structure and function of ecosystems in a rapidly changing world.

In addition to terrestrial environments, urban areas also provide analogs—even harbingers—for aquatic ecosystems of the future. The widespread “urban stream syndrome” that derives from the physical degradation of urban stream channels due to increased high flows (Walsh and others 2005) involves changes in nutrient loads and the presence of a wide range of pharmaceutical compounds used by humans (Kolpin and others 2002) that affect both the structure and function of stream communities (Rosi-Marshall and Royer 2012; Drury and others 2013; Rosi-Marshall and others 2013). Just as in early studies of urban terrestrial ecosystems, the complexity of the physical, chemical, and biological changes associated with the urban stream syndrome have complicated interpretation of results from urban stream studies in the context of broad aquatic ecosystem response to global environmental change. However, improved approaches to community analysis suggest that the prospects for isolating specific effects and making interpretations relevant to whole ecosystem structure over broad areas are promising (Clark and others 2001; Carpenter and others 2009; Scheffer and others 2009; Dodds and others 2010).

The research agenda that can emerge from using urban areas as analogs for the interactions among climates, communities, and ecosystems of the future encompasses a wide range of topics in ecosystem and allied sciences (Table 1). Research on basic ecosystem processes (production, con-

sumption, decomposition, nutrient cycling) in these novel ecosystems will produce fundamental information on fluxes of carbon, water, and nutrients over large areas of the earth. However, understanding the dynamics of these systems from a theoretical and mechanistic perspective will be challenging. How will organisms that have not evolved together over long periods of time interact with the environment and each other to produce functional units and respond to environmental change? How will evolution play out in these assemblages to influence function and response to environmental change and disturbance?

NOW THAT WE HAVE ACCEPTED HUMANS AS COMPONENTS OF ECOSYSTEMS, WHAT DO WE DO WHEN THEY TELL US THINGS WE DO NOT WANT TO HEAR?

Over the last 25 years, ecologists have moved from treating people as external drivers, that is, “outside the box” agents impacting ecosystems (mostly negatively), to viewing humans as an inherent part of both the challenges of and solutions afforded by urban ecosystems. We have begun to merge traditional ecological approaches and questions with studies in environmental sociology, geography, economics, and psychology, and other social sciences to understand how these perceptions, values, and social institutions influence the behavior of urban residents (Short Gianotti and others 2016). This social-ecological research is a fundamental

Table 1. Research Priorities in Urban Ecosystems

1. Predicting or explaining the assembly and function of novel communities and ecosystems under altered environmental conditions:
 - a. The emergence of “novel” communities and ecosystems, that is, assemblages of organisms and environmental conditions that have not necessarily evolved and assembled in the absence of human action over long periods of time has rekindled interest in using urban areas as sentinels of community and ecosystem response to global change.
 - b. Research on basic ecosystem processes (production, consumption, decomposition, nutrient cycling) in these novel ecosystems will produce fundamental information on fluxes of carbon, water and nutrients over large areas of the earth.
 - c. How will organisms that have not evolved and assembled over long periods of time interact with the environment and each other to produce functional units and respond to environmental change? How will evolution play out in these assemblages to influence function and response to environmental change and disturbance?
2. Understanding humans as components of ecosystems to create a deeper and more useful understanding of human–environment interactions in the context of integrated social-ecological systems:
 - a. How do human values and concerns about the biotic components of urban ecosystems shape the structure and functioning of urban ecosystems?
 - b. Co-production of knowledge with stakeholders that takes into account their values and perceptions, even when these values and perceptions are contrary to scientific consensus.
 - c. Over the past 20 years, scientists working in urban areas have learned to successfully “play in a new space.” Ecosystem ecologists must continue to work with geographers, engineers, sociologists, anthropologists, economists, and others in the “urban space” to address fundamental questions about ecosystems and broader issues of sustainability.

advance in environmental science and is facilitating the ability of society to address a wide range of environmental problems from climate change, to the environmental impacts of food production, to the sustainability of our human settlements and the biosphere.

These advances have not come easily. Challenges of working across disciplines (economics, sociology, anthropology, engineering, design, geography, ecology) long a focal topic in this Journal, and the subject of an early special issue (Turner and Carpenter 1999), in collecting data involving people (Cook and others 2004; Grove and others 2015a), and in navigating the interface between basic and applied science have led to uneven progress towards an effective integrated urban systems science and to the emergence of new challenges (McPhearson and others 2016). One of these challenges is to increase our nascent understanding of the ways that the values and concerns that people express about the biotic components of urban ecosystems shape the structure and functioning of urban ecosystems. This challenge likely arises from the difficulties inherent in working across the social science and ecological disciplines to co-generate research questions about the relationships between people and the non-human components of ecosystems. A great advance in environmental science over the past 25 years has been the realization that we need to engage in a dialog with stakeholders to frame ecological questions in contexts that are relevant to these stakeholders rather than just informing (or hectoring) them about what they should value and how they should behave (Groffman and others 2010).

The challenge now is to rework the model of merely passing knowledge and “educating” urban residents and policy-makers into one where knowledge is co-produced with stakeholders and thus inherently takes into account their perceptions, values and institutions, even when these are contrary to scientific consensus. For example, the concept of ecosystem services has developed into a policy-supporting, accounting, and evaluation tool (Kremer and others 2015, 2016). This evaluation is meant to occur through increased scientific understanding of the feedbacks between ecosystem functions and their human benefits, as well as the importance of environmental stewardship, management, and planning to ensure these benefits are provided sustainably to urban residents over time (McPhearson and others 2015). And yet, not all ecosystem functions are beneficial, and many ecosystem services remain poorly understood or valued by urban residents and decision-makers due

in part to difficulty in communicating environmental values to stakeholders and vice-versa. Traditionally, the biological branch of ecology (as opposed to human ecology) is not a discipline that integrated or addressed normative concerns such as social inequality, political ecology, or diverging value systems. This challenge, which has emerged in a wide range of issues from climate change, to invasive species management, to agriculture and home lawn best-management practices, is a critical constraint on our ability to develop a basic science understanding of human-dominated ecosystems (Harden and others 2014) and to develop solutions to long-standing environmental problems. However, the prospects for progress in addressing this challenge are very promising in urban ecosystems, where the vast majority of human–environment interactions occur and the opportunities for engagement with decision-makers through participatory and transdisciplinary science and citizen science are abundant (Grove and others 2015b).

MOVING TOWARDS A NEW URBAN SYSTEMS SCIENCE

There is great potential for a new period of urban systems science that will produce fundamental advances in our basic scientific understanding of community assembly and ecosystem structure, function, and response to global environmental change (McPhearson and others 2016). Urban ecosystems offer unique and powerful opportunities to understand the processes involved in the assembly of ecological communities under altered environmental conditions, how novel ecosystems function, how they are likely to persist or change in response to changes in climate and atmospheric chemistry, and how they will interact with social and economic systems over the next several decades. More broadly, the urban system science initiative that we propose here could catalyze the novel interdisciplinary and transdisciplinary research that is fundamental to advancing sustainability science, and to advancing urban sustainability in the cities where we live and work (Childers and others 2014).

What would a new initiative in urban systems science look like? One possible model is the social-ecological-technological-systems (SETS) approach that is guiding a current urban Sustainability Research Network project on Urban Resilience to Extreme Events (<http://URExSRN.net>) (Grimm and others 2016; McPhearson and others 2016). The SETS approach recognizes that understanding

and managing urban ecosystems cannot proceed without consideration of social, ecological, and technological aspects of environmental phenomena and provides a platform for considering and integrating these aspects to address specific research and practical questions. This approach requires a greater integration of the engineering and design disciplines with the natural and social sciences (ACERE-Advisory Committee for Environmental Research and Education 2015).

Over the past 20 years, scientists working in urban areas have learned to successfully “play in a new space.” Progress in understanding urban ecosystems cannot be made in isolation. Ecosystem ecologists have learned how to work with geographers, engineers, designers, sociologists, anthropologists, economists, and others in the “urban space.” Urban ecosystem ecology is a shining example of how interdisciplinary research develops and produces advances in both basic and applied science. The two directions in urban system science emphasized here: (1) developing the science of community assembly and ecosystem function in human-dominated environments and (2) building on rapid progress in understanding humans as integral components of urban ecosystems will lead to additional progress in some of the most compelling scientific questions in each component discipline and in integrated sustainability science. The environmental challenges of the 21st century require great advances in our understanding of interactions between human and environmental systems to produce knowledge and approaches to enable the development of more ecologically sound, equitable, and economically viable social-ecological systems.

ACKNOWLEDGEMENTS

The authors acknowledge support from the NSF Long Term Ecological Research Program for work in Baltimore (DEB-1027188) and Phoenix (DEB-1026865), from the NSF Urban Resilience to Extreme Weather-related Events Sustainability Research Network (URExSRN; SES-1444755), and from the NSF Urban Sustainability Research Coordination Network (RCN-1140070).

REFERENCES

ACERE-Advisory Committee for Environmental Research and Education. 2015. America's Future: Environmental Research and Education for a Thriving Century. A Report by the NSF Advisory Committee for Environmental Research and Education.

- Alberti M, Marzluff JM, Shulenberg E, Bradley G, Ryan C, Zumbunnen C. 2003. Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. *BioScience* 53:1169–79.
- Baker LA, Hope D, Xu Y, Edmonds J, Lauver L. 2001. Nitrogen balance for the central Arizona–Phoenix (CAP) ecosystem. *Ecosystems* 4:582–602.
- Boyden SV, Millar S, Newcombe K, O'Neill B. 1981. The ecology of a city and its people: the case of Hong Kong. Canberra: Australian National University Press.
- Carpenter SR, Folke C, Scheffer M, Westley F. 2009. Resilience: accounting for the noncomputable. *Ecol Soc* 14:13.
- Childers DL, Pickett STA, Grove JM, Ogden L, Whitmer A. 2014. Advancing urban sustainability theory and action: challenges and opportunities. *Landsc Urban Plan* 125:320–8.
- Clark JS, Carpenter SR, Barber M, Collins S, Dobson A, Foley JA, Lodge DM, Pascual M, Pielke R Jr, Pizer W, Pringle C, Reid WV, Rose KA, Sala O, Schlesinger WH, Wall DH, Wear D. 2001. Ecological forecasts: an emerging imperative. *Science* 293:657–60.
- Cook WM, Casagrande DG, Hope D, Groffman PM, Collins SL. 2004. Learning to roll with the punches: adaptive experimentation in human-dominated systems. *Front Ecol Environ* 2:467–74.
- Dodds WK, Clements WH, Gido K, Hilderbrand RH, King RS. 2010. Thresholds, breakpoints, and nonlinearity in freshwaters as related to management. *J N Am Benthol Soc* 29:988–97.
- Drury B, Scott J, Rosi-Marshall EJ, Kelly JJ. 2013. Triclosan exposure increases triclosan resistance and influences taxonomic composition of benthic bacterial communities. *Environ Sci Technol* 47:8923–30.
- Grimm NB, Cook EM, Hale RL, Iwaniec DM. 2016. A broader framing of ecosystem services in cities: benefits and challenges of built, natural, or hybrid system function. In: Seto DC, Solecki W, Griffith CA, Eds. *The Routledge Handbook of Urbanization and Global Environmental Change*. Abingdon: Routledge.
- Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu JG, Bai XM, Briggs JM. 2008a. Global change and the ecology of cities. *Science* 319:756–60.
- Grimm NB, Foster D, Groffman P, Grove JM, Hopkinson CS, Nadelhoffer KJ, Pataki DE, Peters DPC. 2008b. The changing landscape: ecosystem responses to urbanization and pollution across climatic and societal gradients. *Front Ecol Environ* 6:264–72.
- Groffman PM, Stylinski C, Nisbet MC, Duarte CM, Jordan R, Burgin AJ, Previtali MA, Coloso J. 2010. Restarting the conversation: challenges at the interface between ecology and society. *Front Ecol Environ* 8:284–91.
- Grove JM, Cadenasso ML, Pickett STA, Machlis G, Burch WR Jr. 2015a. *The Baltimore School of Urban Ecology*. New Haven: Yale University Press.
- Grove JM, Roy Chowdhury R, Childers DL. 2015b. Co-design, co-production, and dissemination of social-ecological knowledge to promote sustainability and resilience: Urban experiences from the U.S. Long Term Ecological Research (LTER) network. *Glob Land Proj News* 11:6–11.
- Harden CP, Chin A, English MR, Fu R, Galvin KA, Gerlak AK, McDowell PF, McNamara DE, Peterson JM, Poff NL, Rosa EA, Solecki WD, Wohl EE. 2014. Understanding human-land-

- scape interactions in the “Anthropocene”. *Environ Manag* 53:4–13.
- Hobbs RJ, Higgs E, Hall CM, Bridgewater P, Chapin FS, Ellis EC, Ewel JJ, Hallett LM, Harris J, Hulvey KB, Jackson ST, Kennedy PL, Kueffer C, Lach L, Lantz TC, Lugo AE, Mascaro J, Murphy SD, Nelson CR, Perring MP, Richardson DM, Seastedt TR, Standish RJ, Starzomski BM, Suding KN, Tognetti PM, Yakob L, Yung L. 2014. Managing the whole landscape: historical, hybrid, and novel ecosystems. *Front Ecol Environ* 12:557–64.
- Johnson MTJ, Thompson KA, Saini HS. 2015. Plant evolution in the urban jungle. *Am J Bot* 102:1951–3.
- Knapp S, Dinsmore L, Fissore C, Hobbie SE, Jakobsdottir I, Kattge J, King JY, Klotz S, McFadden JP, Cavender-Bares J. 2012. Phylogenetic and functional characteristics of household yard floras and their changes along an urbanization gradient. *Ecology* 93:S83–98.
- Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999–2000: a national reconnaissance. *Environ Sci Technol* 36:1202–11.
- Kremer P, Andersson E, McPhearson T, Elmqvist T. 2015. Advancing the frontier of urban ecosystem services research. *Ecosyst Serv* 12:149–51.
- Kremer P, Hamstead Z, Haase D, McPhearson T, Frantzeskaki N, Andersson E, Kabisch N, Larondelle N, Rall EL, Voigt A, Baró F, Bertram C, Gómez-Baggethun E, Hansen R, Kaczorowska A, Kain J-H, Kronenberg J, Langemeyer J, Pauleit S, Rehman K, Schewenius M, van Ham C, Wurster D, Elmqvist T. 2016. Key insights for the future of urban ecosystem services research. *Ecol Soc* 21:29.
- Luck AM, Jenerette DG, Wu J, Grimm BN. 2001. The urban funnel model and the spatially heterogeneous ecological footprint. *Ecosystems* 4:782–96.
- Matson PM, Clark WC, Andersson K. 2016. Pursuing sustainability: a guide to the science and practice. Princeton (NJ): Princeton University Press. p 231p.
- McDonnell MJ, Hahs AK. 2008. The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. *Landsc Ecol* 23:1143–55.
- McDonnell MJ, Hahs AK. 2015. Adaptation and adaptedness of organisms to urban environments. *Annu Rev Ecol Evol Syst* 46:261–80.
- McDonnell MJ, Pickett STA. 1990. Ecosystem structure and function along urban rural gradients—an unexploited opportunity for ecology. *Ecology* 71:1232–7.
- McDonnell MJ, Pickett STA, Eds. 1993. Humans as components of ecosystems: the ecology of subtle human effects and populated areas. New York: Springer.
- McPhearson T, Andersson E, Elmqvist T, Frantzeskaki N. 2015. Resilience of and through urban ecosystem services. *Ecosyst Serv* 12:152–6.
- McPhearson T, Pickett STA, Grimm NB, Niemela J, Alberti M, Elmqvist T, Weber C, Haase D, Breuste J, Qureshi S. 2016. Advancing urban ecology toward a science of cities. *BioScience* 66:198–212.
- Pickett STA, Cadenasso ML, Grove JM, Boone CG, Groffman PM, Irwin E, Kaushal SS, Marshall V, McGrath BP, Nilon CH, Pouyat RV, Szlavecz K, Troy A, Warren P. 2011. Urban ecological systems: Scientific foundations and a decade of progress. *J Environ Manag* 92:331–62.
- Pouyat RV, McDonnell MJ. 1991. Heavy metal accumulations in forest soils along an urban-rural gradient in southeastern New York, USA. *Water Air Soil Pollut* 57–8:797–807.
- Pouyat RV, McDonnell MJ, Pickett STA. 1995. Soil characteristics of oak stands along an urban-rural land use gradient. *J Environ Qual* 24:516–26.
- Radeloff VC, Hammer RB, Stewart SI, Fried JS, Holcomb SS, McKeefry JF. 2005. The wildland–urban interface in the United States. *Ecol Appl* 15:799–805.
- Rosi-Marshall E, Royer T. 2012. Pharmaceutical compounds and ecosystem function: an emerging research challenge for aquatic ecologists. *Ecosystems* 15:867–80.
- Rosi-Marshall EJ, Kincaid DW, Bechtold HA, Royer TV, Rojas M, Kelly JJ. 2013. Pharmaceuticals suppress algal growth and microbial respiration and alter bacterial communities in stream biofilms. *Ecol Appl* 23:583–93.
- Scheffer M, Bascompte J, Brock WA, Brovkin V, Carpenter SR, Dakos V, Held H, van Nes EH, Rietkerk M, Sugihara G. 2009. Early-warning signals for critical transitions. *Nature* 461:53–9.
- Short Gianotti AG, Getson JM, Hutyra LR, Kittredge DB. 2016. Defining urban, suburban, and rural: a method to link perceptual definitions with geospatial measures of urbanization in central and eastern Massachusetts. *Urban Ecosystems*: 1–11.
- Swan CM, Pickett STA, Szlavecz K, Warren P, Willey KT. 2011. Biodiversity and community composition in urban ecosystems: coupled human, spatial, and metacommunity processes. In: Niemelä J, Breuste JH, Guntenspergen G, McIntyre NE, Elmqvist T, James P, Eds. *Urban ecology: patterns, processes, and applications*. New York: Oxford University Press. p 179–86.
- Turner GM, Carpenter RS. 1999. Tips and traps in interdisciplinary research. *Ecosystems* 2:275–6.
- Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP. 2005. The urban stream syndrome: current knowledge and the search for a cure. *J N Am Benthol Soc* 24:706–23.
- Weathers KC, Groffman PM, Van Dolah E, Bernhardt ES, Grimm NB, McMahon K, Schimel JP, Paolisso M, Maranger R, Baer S, Brauman K, Hinckley E. 2016. Frontiers in ecosystem ecology from a community perspective: the future is boundless and bright. *Ecosystems* (in press).