The following is published as: Byrne, L.B. 2022. Using the prepositional framework for urban environmental education: Teaching and learning about ecology in, of, for, and with cities. Pp. 231-244 in D. Mutnick et al. eds. The City is an Ecosystem. Routledge Press. DOI:10.4324/9781003217442-22

19. **Using the prepositional framework for urban environmental education: Teaching and learning about ecology *in*, *of*, *for*, and *with* cities**

Loren Byrne, Roger Williams University, Bristol, RI, lbyrne@rwu.edu

Abstract

Urban systems arise from relationships among diverse environmental, social, and technological variables. Teaching and learning about them and their sustainability can be challenging: What should the focus be and how can lessons and courses be structured effectively? One approach is to adopt the "prepositional framework" which refers to ecology *in*, *of*, *for* and *with* cities (where cities means all urban systems). Ecology *in* the city refers to traditional ecological research about biodiversity and ecosystem processes in urbanized places. Ecology *of* cities focuses on holistic examinations of urban systems, including feedbacks among social and ecological variables, nutrient flows at larger scales, and ecosystem services. Ecology *for* cities integrates normative, applied perspectives to guide research needed *for* increasing human well-being and sustainability. Ecology *with* cities emphasizes collaboration, communication and education among diverse stakeholders to advance research and its application (e.g., citizen science, sustainable urban design). This chapter presents example topics and teaching activities from an undergraduate urban ecology course that help students develop integrated, interdisciplinary knowledge and skills about ecology *in*, *of*, *for* and *with* cities. Hopefully these examples will inspire others to use the prepositional framework to support student achievement of diverse scientific, environmental and sustainability learning outcomes.

Keywords
urban social-ecological-technological systems, urban sustainability, ecology for cities, ecology with cities, environmental education, interdisciplinary, learner-centered teaching

Introduction

A central goal of teaching is to help students understand and further investigate patterns and processes of the "world" broadly defined. Achieving this aim is not always straightforward because many patterns and processes are not observable at spatiotemporal scales perceived by human senses nor are obvious without relevant knowledge. Further, many characteristics of the world are best understood using abstract representations created by humans, including uncommon words (jargon), metaphors, theories, and mathematical equations (Borghi et al. 2018, Desai et al. 2018). Among such abstractions, conceptual frameworks help organize ideas to show interrelationships among variables and terms (e.g., Wald & Daniel 2020). Such frameworks establish common languages that can catalyze shared understanding, effective communication and collaboration among diverse people (including teachers and students). Developing and comparing different frameworks can also reveal divergent views and facilitate finding common ground. Frameworks are especially important in environmental sciences that focus on interacting variables which exist over many spatiotemporal scales (e.g., Groffman et al. 2004a, Scherer et al. 2017).

Among the most complex environmental systems are those in which humans are a dominant driver of patterns and processes. This includes urban areas, conceptualized as social-ecological-technological systems (SETS), for which many frameworks have been developed that provide excellent starting points for teaching and learning about them (reviewed in Zhou et al. 2021). For example, near the beginning of my undergraduate urban ecology course, I have students compare four different foundational conceptual frameworks that integrate natural and social sciences (Grimm et al. 2000, 2008, Alberti et al. 2003, Pickett and Cadenasso 2006). In small groups, students identify their strengths and limitations to understand the complexity of urban SETS and need for interdisciplinary approaches to effectively manage and improve their biodiversity, ecosystem services, capacities to promote human health, and overall sustainability (McPhearson et al. 2016).

Such interdisciplinary teaching about urban ecology has received increasing attention (e.g., Berkowitz et al. 2003, Barnett et al. 2011, Tidball and Krasny 2011, Biberhofer and Rammel 2017), and the scientific foundations to support courses about urban SETS is well established. However, educators may find the breadth of topics overwhelming to adapt into courses, syllabi and lessons. Likewise, students may find the study of urban SETS challenging because it requires skills for abstract systems thinking. Indeed, teaching and learning about complex urban systems is inherently difficult for people of all levels and backgrounds: Where should one begin and how is best to proceed? (For more discussion about this question and example learning activities, see Schmitt-Harsh and Harsh (2017).)

A prominent way that the study of urban SETS has been organized is using four main topical areas described by the "prepositional framework" (Byrne 2022). This approach categorizes research and knowledge about urban areas as "ecology ***in, of, for*** and ***with*** cities." Pickett et al. (1997) first articulated the *in* and *of* phrasing with further description and expansion by others (e.g., Grimm et al. 2000; Pickett et al. 2001, 2016; Childers et al. 2015; Grove et al. 2016; McPhearson et al. 2016; Byrne 2021).

The goal of this chapter is to describe use of the prepositional framework to organize an interdisciplinary urban ecology course using examples from my advanced undergraduate course, which was developed for students majoring and minoring in environmental science, biology and sustainability studies. Brief descriptions of how each of the prepositions relate to the study and management of urban systems are provided in the following sections, alongside example topics and teaching resources. My intent is not to be prescriptive nor offer a fully-formed course outline and lessons; instead, I aim to be inspirational by offering a general structure and illustrative activities that instructors can adopt and develop based on their course contexts and objectives. Though my experience is in higher education, I expect that the framework and some ideas below are relevant to K-12 teaching, for which others have reported urban environmental education initiatives (e.g., Barnett et al. 2011, Abu Baker et al. 2015, Russ 2015, Aloisio et al. 2018, Oliveira et al. 2021; also see Berkowitz et al. 2003 and resources at https://academics.lmu.edu/cures/partners/k12teachers/urbanecolab/). At all levels, more educational efforts about urban SETS are needed given increasing rates of urbanization and their relevance to pursuing a more sustainable future for life on earth. The urban prepositional framework serves as a logical starting point for helping students think about and more effectively engage in diverse SETS around them.

Ecology *in* Cities

Most early urban ecology research investigated traditional ecological variables using standard methods to describe basic patterns and processes. This approach, labeled ecology *in* cities, focuses on abiotic conditions (soils, temperature, water, etc.), non-human organisms (their behaviors, resource use, survival, reproduction, etc.), populations (abundance, distribution, growth), communities (composition, interspecific interactions, food webs) and ecosystem processes (biogeochemical cycles, energy flow) of urban-impacted, outdoor places (Pickett et al. 2001, 2016). Though data about these variables can be collected independently, a main goal of urban ecologists is to integrate them to understand the interacting drivers, including anthropogenic ones, of larger-scale patterns of urban biodiversity and ecosystem functions (e.g., Aronson et al. 2014, Kaushal et al. 2014). Further, comparing urban and non-urban places helps elucidate differences between them to deepen understanding of how urbanization impacts ecological variables (McPhearson et al. 2016). To this end, the basic ecology of uniquely urban habitats like lawns, gardens, and vacant lots is of particular interest since they represent much of the "nature" of urban systems (e.g., Byrne et al. 2008, Rega-Brodsky and Nilon 2016).

To introduce students to ecology *in* cities, attention-grabbing, unique stories and imagery can be used, such as a rat stuck in a manhole cover (Held 2019); birds nesting in odd places (BoredPanda 2015); and otherwise-arboreal koalas moving on the ground through urban landscapes leading to unexpected interactions (Siossian 2018) and deadly outcomes (Buttigieg 2019). The scientific literature is extensive enough that examples can be found to reflect the full range of topics within a general ecology textbook (e.g., McPhearson et al. 2016). An example lesson from my urban ecology course is the student-led "birds & bugs search, share & synthesis" (Byrne, forthcoming) for which each student chooses a peer-reviewed article about urban arthropods or birds, presents it to the class (with one or two slides) and then works with a small group to write a synthetic summary and follow-up research questions (also see Chapter 6 this volume).

Studying basic ecological patterns in urbanized environments may not seem exciting or relevant to some students. However, it is foundational to solving problems relating to biodiversity conservation, environmental quality, human health and sustainability. This can be emphasized through ecology-*in*-cities lessons that support connecting basic and applied ecology issues, e.g., managing endangered, invasive, pest and disease-causing species. For example, to mirror a larger societal controversy, students can evaluate studies about the impacts of domestic cats on urban biodiversity and debate their accuracy, interpretation and relevance to decisions about controlling outdoor cats (e.g., Loss et al. 2018). Such examinations help open students' eyes to the need for reliable biological and environmental knowledge to guide informed management decisions (which are central to the *for* and *with* approaches below). In addition, basic variables included in the study of ecology *in* cities are required to understand the ecology *of* cities.

Ecology *of* Cities

Ecology *in* cities is a reductionistic approach that, while generating valuable and necessary knowledge, is insufficient to fully understand urbanized places. This has led to more holistic studies that examine urban SETS as single, integrated entities with emergent properties (i.e., the urban place is the system, rather than a set of independent variables and systems) (Pickett et al. 2001, 2016, Zhu et al. 2021). From this ecology-*of*-cities view, several key insights emerge that are now accepted as central to urban systems science. First, a fuller range of social, technological and infrastructural (e.g., sewers, roads) variables must be considered as drivers of ecological variables, which can in turn affect the former through interconnected feedback relationships. This contrasts with the *in* view which places ecological variables at the center of study (i.e., the dependent variables impacted by humans and urbanization) while largely ignoring how they affect other parts of the system.

Second, the *of* perspective underscores the need to examine urban systems at larger scales including landscapes, watersheds and regions which have emergent properties arising from interactions among their sub-systems over long timeframes. Such expanded spatiotemporal analyses support integrated measurement of urban systems' metabolism (energy and nutrient flow through environmental, social and infrastructure components); ecological footprints; resilience to disturbances; relationships with surrounding ecosystems (e.g., food imports from rural areas); and impacts on larger-scale biodiversity patterns (e.g., regional species loss) and ecosystem processes (e.g., cities' greenhouse gas emissions) (Pickett et al. 2001).

Third, and highly relevant to the *for* and *with* perspectives, this more holistic outlook leads to explicit consideration of human lives and social variables (ethics, economics, aesthetics, etc.) within the scope of urban ecology. In turn, this has spurred scientists to study how ecological variables are translated into urban ecosystem services: the benefits that humans receive from ecosystems, including material goods, processes and conditions that create healthy urban living conditions (reviewed in Ziter 2016 and Tan et al. 2020). Altogether, these and other insights build on those from the ecology-*in* view to generate a more systemic understanding of how diverse social, technological and biophysical patterns and processes interact to form a variety of complex, dynamic urban systems, from neighborhoods through towns, cities, metropolitan regions and even the entire urban-impacted Earth system.

Studying the ecology *of* cities is likely to be more challenging for students because it requires interdisciplinary, synthetic, systems-level thinking skills. However, I have effectively helped students develop their comprehension with a few lessons. First, I broaden their perspective about relationships between ecological and sociocultural variables using the case study of lawns and gardens (described in Byrne 2015; the instructor guide can be obtained by contacting me). As part of this lesson, I share research revealing that household socioeconomic variables (e.g., income) help explain plant abundance and species richness in ornamental gardens, a pattern known as "the luxury effect" (Leong et al. 2018) and "an ecology of prestige" (Grove et al. 2014). Similarly, people's diverse aesthetic preferences are important drivers of urban biodiversity; having students discuss the perspectives of Nassauer (1988) and Byrne and Grewal (2008) facilitates reflection about why people want urban environments to look a certain way and, in turn, how their appearance can feed back to social systems by affecting ecosystem services and choices about how lawns and gardens *should* look to improve their sustainability. In this way, lawns and gardens are an excellent focus for developing insights about the value of the *of*-cities' holistic, multi-scale approach.

To help students think about urban systems across different spatiotemporal scales, I have them present to the class one of five papers that used different subjects, methods and scales to exemplify how scientists study the ecology *of* cities (households: Fissore et al. 2011; city: Baker et al. 2001 and Moore et al. 2013; watersheds: Groffman et al. 2004; continental: Cubino et al. 2019). Using Socratic questions about each paper alone and then for the whole set, I help students develop their own mental models about how social, ecological and technological variables can be integrated to generate holistic understanding of urban SETS and their spatiotemporal dynamics. Each of these papers can also be discussed in the context of ecosystem services and sustainability to link basic and applied concepts. For that, I have used a teaching activity which asks students to critically evaluate research and rhetoric about the effectiveness of green roofs to provide ecosystem services and improve the social-environmental quality of urban systems (Crispo 2016). Such lessons nicely illustrate the ecology-*of*-cities view while also providing a helpful bridge to the next preposition in the framework: ecological knowledge needed *for* improving the quality and sustainability of cities and people's lives.

Ecology *for* Cities

Reflecting broader trends in science, scholars have increasingly conducted studies directly relevant to decisions about how to better design, manage and live in urban SETS. Such applied, use-inspired, actionable research and knowledge are encompassed by the recently described perspective of ecology *for* cities (e.g., Du Toit et al. 2014, Grove et al. 2016, Zhou et al. 2019). Integrating and extending the *in* and *of* views, ecology *for* cities is an explicitly goal-driven, interdisciplinary approach that adopts insights and methods from urban planning, engineering, governance, ethics and other fields relevant to decision making and communicating with stakeholders (Childers et al. 2015, Grove et al. 2016, McPhearson et al. 2016, Pickett et al. 2016). This view recognizes that urban residents, policy makers, planners, managers and others can and should influence the types of questions that urban scientists investigate, inspiring them to more thoughtfully consider the types of information needed to address the practical, everyday challenges faced by urban communities (e.g., environmental justice, managing biodiversity, restoring ecosystem services, reducing pollution, mitigating effects of climate change). At the same time, the scientific integrity of such projects should be maintained with rigorous, objective methods and data analyses (Pickett et al. 2016). Though the phrase ecology *for* cities is relatively new, exemplary applied research and perspectives have a long history, providing plenty of material for urban ecology courses.

Ecology-*for*-cities lessons are valuable because they support broader educational goals such as developing skills for critical thinking, evaluating evidence, and communicating effectively, especially related to translating scientific ideas for general audiences. Focusing on evidence-based decision making in "real world" contexts lends itself well to helping students consider how science can be used *for* addressing urban social-environmental and sustainability issues. For example, as part of lawn-and-garden-ecology lessons, I have introduced the topic of conservation biological control using data about how landscape management affects populations of predatory arthropods that consume harmful pests (which doubles as a lesson on urban food webs; e.g., Kunkel et al. 1999, Ellis et al. 2005, Shrewsbury and Raupp 2006). Students are then asked to prepare a memo for campus landscape managers about actions to help conserve beneficial biodiversity, enhance the ecosystem service of pest consumption, and reduce pesticide use. Also related to biodiversity management, Hane and Korfmacher (2022a, b) describe a pair of activities in which students actively engage in ecology-*for*-cities practices by designing "insect hotels" and campus outdoor spaces to achieve conservation and restoration goals.

Another exemplary topic related to *for* cities is urban greening programs, especially in context of using basic ecological science for informing tree-planting decisions. An exemplary activity I have used begins with students examining data about the role of different tree species in releasing volatile organic compounds (VOCs) that contribute to formation of ground-level ozone pollution (Crumrine 2016). Then students read Churkina et al. (2015) to learn about tree species that form fewer or no VOCs, and then discuss how such information relates to the social and ecological trade-offs surrounding people's planting choices (e.g., some low-VOC-emitting trees may have negative effects on other variables; some high emitters are more suitable for certain locations). Similarly, students can be introduced to the growing body of research about where new trees should be planted to help reduce the urban heat island effect and its negative health outcomes (e.g., Grabmeier 2021). Such topics can help students develop deeper understanding of how the *in*, *of* and *for* perspectives inform each other (e.g., the goals of cleaning and cooling cities' air has led to research about abiotic conditions, tree physiology and where to install new trees) by exemplifying how basic science is relevant to social concerns like environmental racism and justice (marginalized, vulnerable communities often have fewer trees and thus hotter conditions; e.g., see Popovich and Flavelle 2019 and the activity by Long 2016). An emerging tenet of such applied research—and the community-oriented projects it informs—is that working *with* stakeholders is integral to successfully identifying local problems and implementing solutions. This insight points to the fourth dimension of the urban ecology prepositional framework.

Ecology *with* Cities

Alongside increasing applied research *for* societal goals, another trend in science is to directly collaborate *with* people in the processes of data collection, learning, and evidence-based decision making. Such methods challenge scientists to consider different research and teaching methods because just generating information *for* people (and giving it to them) will not always catalyze desired changes. For urban contexts, the phrase ecology *with* cities was proposed by Byrne (2022) to encompass the many ways of engaging and communicating with students, citizens, policy-makers, managers, planners, and others (also see Grove et al. 2016). These ways include citizen/community science, participatory action research, stakeholder engagement, democratization of science, co-production of knowledge, urban designed experiments, civic ecology, and translational ecology (see references in Byrne 2022). In education, pedagogies that have students work *with* information and each other to develop their own knowledge through active engagement (rather than passively listening to lectures) is known as learner-centered teaching (Byrne 2016); this approach reflects ecology *with* cities because it emphasizes the learner's role in collaborating *with* the teacher to achieve learning outcomes, including knowledge about how students can generate positive changes in the urban SETS in which they live and work.

Students can be introduced to the *with* perspective by examining and evaluating case studies of community gardening, tree planting and restoration projects that involved local people in their design and implementation (e.g., Sipilä and Tyrväinen 2005, Moran et al. 2019). Urban citizen science projects can be analyzed to learn about methods for engaging people in studying their local environments (e.g., Taylor et al. 2021). For deeper engagement, students can be given opportunities to collect data for existing projects (e.g., for birds: https://celebrateurbanbirds.org/cub/instructions and fireflies: https://www.massaudubon.org/get-involved/community-science/firefly-watch) or partner with a local organization to complete a service-learning project (Tidball and Krasny 2011). In my class, some students helped a local conservation committee by investigating how communities around the U.S. reduced impacts on water quality from lawn fertilizer and making recommendations for effective actions. For another project, sustainability majors worked with campus landscape managers to research, design and build a nesting platform for osprey, a coastal bird-of-prey. In such projects, a key goal is for students to learn about the need to *and* how to communicate and collaborate effectively with stakeholders (see Chapters 5 and 18, this volume). This, combined with discussions of other ecology-*with*-cities examples, will help prepare them to become more effective urban stewards and leaders who engage with others to improve the sustainability of urban SETS.

Conclusion

Urban ecology's prepositional framework organizes the field's diverse interdisciplinary themes into a simple, accessible outline. Thus, it provides an effective approach to teaching and learning about the complexity and often abstract nature of urban SETS because it can help students organize and synthesize their knowledge. Further, the four prepositional categories overlap and have feedback relationships. For example, data about ecology *in* cities informs ecology *of* and *for* cities; goals developed from an ecology-*for*-cities view can influence *in* and *of* research agendas. This can help facilitate development of students' systems thinking skills for integrating insights from all four perspectives. In addition, an urban ecology course designed using the prepositional framework emphasizes the value of generating and using scientific evidence while working *with* diverse stakeholders to study and manage complex urban social-ecological challenges. To that end, I hope this chapter will inspire others to develop rich, learner-centered lessons that help students understand the many basic and applied dimensions of urban ecology and how to help transform urban SETS into healthier, more sustainable places for everyone.

References

Abu Baker, Mohammed A., Sara E. Emerson, and Joel S. Brown. 2015. "Studying Behavioral Ecology on High School & College Campuses: A Practical Guide to Measuring Foraging Behavior Using Urban Wildlife." *The American Biology Teacher* 77 (6): 432–438.

Alberti, Marina, John M. Marzluff, Eric Shulenberger, Gordon Bradley, Clare Ryan, and Craig Zumbrunnen. 2003. "Integrating humans into ecology: opportunities and challenges for studying urban ecosystems." *BioScience* 53, no. 12: 1169-1179.

Aloisio, Jason M., Brian Johnson, James D. Lewis, J. Alan Clark, Jason Munshi-South, Su-Jen Roberts, Deborah Wasserman, Joseph Heimlich, and Karen Tingley. 2018. "Pre-college urban ecology research mentoring: promoting broader participation in the field of ecology for an urban future." *Journal of Urban Ecology* 4, no. 1: juy023.

Aronson, Myla FJ, Frank A. La Sorte, Charles H. Nilon, Madhusudan Katti, Mark A. Goddard, Christopher A. Lepczyk, Paige S. Warren, et al. 2014. "A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers." *Proceedings of the Royal Society B* 281, no. 1780: 20133330.

Baker, Lawrence A., Diane Hope, Ying Xu, Jennifer Edmonds, and Lisa Lauver. 2001. "Nitrogen balance for the Central Arizona–Phoenix (CAP) ecosystem." *Ecosystems* 4, no. 6: 582-602.

Barnett, Michael, Meredith Houle Vaughn, Eric Strauss, and Lindsey Cotter. 2011. "Urban environmental education: Leveraging technology and ecology to engage students in studying the environment." *International Research in Geographical and Environmental Education* 20, no. 3: 199-214.

Berkowitz, Alan R., Charles H. Nilon, and Karen S. Hollweg, eds. 2003. *Understanding Urban Ecosystems: A New Frontier for Science and Education*. Springer Science & Business Media.

Biberhofer, Petra, and Christian Rammel. 2017. "Transdisciplinary learning and teaching as answers to urban sustainability challenges." *International Journal of Sustainability in Higher Education* 18, no. 1: 63-83.

BoredPanda. 2015. “59 Unusual Bird Nests Built in The Weirdest Places.” Accessed July 9, 2021. https://www.boredpanda.com/unusual-bird-nests/.

Borghi, Anna M., Laura Barca, Ferdinand Binkofski, and Luca Tummolini. 2018. "Varieties of abstract concepts: development, use and representation in the brain." *Philosophical Transactions of the Royal Society B* 373, no. 1752: 20170121.

Buttigieg, Melissa. 2019. “'It will haunt me': Sad story behind photo of dead koala 'cradling' her joey” Accessed July 9, 2021. https://au.news.yahoo.com/sunshine-coast-koala-cradling-joey-road-death-093616940.html.

Byrne, Loren B. 2015. “Exploring lawns and gardens as complex socio-ecological systems.” Accessed July 11, 2021. https://www.aacu.org/stirs/casestudies/byrne

Byrne, Loren B. 2016. “Learner-Centered Teaching for Environmental and Sustainability Studies.” In *Learner-Centered Teaching Activities for Environmental and Sustainability Studies*, edited by Loren B. Byrne, 1-28. New York: Springer.

Byrne, Loren B. 2022. Ecology with cities. *Urban Ecosystems* 25 (3):835-837.

Byrne, Loren B. In press. “Synthesizing Science.” In *The Pocket Instructor: Writing*, edited by A.I. Wilkins and K. Shaw. Princeton, Princeton University Press.

Byrne, Loren B., Mary Ann Bruns, and Ke Chung Kim. 2008. "Ecosystem properties of urban land covers at the aboveground–belowground interface." *Ecosystems* 11, no. 7: 1065-1077.

Byrne, Loren B., and Parwinder Grewal. 2008. "Introduction to ecological landscaping: a holistic description and framework to guide the study and management of urban landscape parcels." *Cities and the Environment* 1, no. 2: 20 pp.

Childers, Daniel L., Mary L. Cadenasso, J. Morgan Grove, Victoria Marshall, Brian McGrath, and Steward TA Pickett. 2015. "An ecology for cities: A transformational nexus of design and ecology to advance climate change resilience and urban sustainability." *Sustainability* 7, no. 4: 3774-3791.

Churkina, Galina, Rüdiger Grote, Tim M. Butler, and M. Lawrence. 2015. "Natural selection? Picking the right trees for urban greening." *Environmental Science & Policy* 47: 12-17.

Crispo, E. 2016. “Evaluating the Effectiveness of Green Roofs: A Case Study for Literature Research and Critical Thinking.” In *Learner-Centered Teaching Activities for Environmental and Sustainability Studies*, edited by Loren Byrne, 253-259. New York: Springer.

Crumrine, P.W. 2016. “Don’t Blame the Trees: Using Data to Examine How Trees Contribute to Air Pollution.” In Learner-Centered Teaching Activities for Environmental and Sustainability Studies, edited by Loren Byrne, 245-250. New York: Springer.

Cubino, Josep Padullés, Jeannine Cavender-Bares, Sarah E. Hobbie, Diane E. Pataki, Meghan L. Avolio, Lindsay E. Darling, Kelli L. Larson et al. 2019. "Drivers of plant species richness and phylogenetic composition in urban yards at the continental scale." Landscape Ecology 34, no. 1: 63-77.

Desai, Rutvik H., Megan Reilly, and Wessel van Dam. 2018. "The multifaceted abstract brain." *Philosophical Transactions of the Royal Society B* 373, no. 1752: 20170122.

Du Toit, Marie, Juanee Cilliers, Francois Retief, and Ernst Drewes. 2014. "Actionable urban ecology in China and the world: integrating ecology and planning for sustainable cities." *Landscape and Urban Planning* 125: 207-208.

Ellis, Jodie A., A. D. Walter, John F. Tooker, Matthew D. Ginzel, Peter F. Reagel, Emerson S. Lacey, Ashley B. Bennett, Erik M. Grossman, and Lawrence M. Hanks. 2005. "Conservation biological control in urban landscapes: manipulating parasitoids of bagworm (Lepidoptera: Psychidae) with flowering forbs." *Biological Control* 34, no. 1: 99-107.

Fissore, C., L. A. Baker, S. E. Hobbie, J. Y. King, J. P. McFadden, K. C. Nelson, and I. Jakobsdottir. 2011. "Carbon, nitrogen, and phosphorus fluxes in household ecosystems in the Minneapolis-Saint Paul, Minnesota, urban region." *Ecological Applications* 21, no. 3: 619-639.

Grabmeier, Jeff. 2021. “Throwing shade: Measuring how much trees, buildings cool cities.” Accessed July 9, 2021. https://news.osu.edu/throwing-shade-measuring-how-much-trees-buildings-cool-cities/

Grimm, Nancy B., J. Grove Grove, Steward TA Pickett, and Charles L. Redman. 2000. "Integrated approaches to long-term studies of urban ecological systems." *BioScience* 50, no. 7: 571-584.

Grimm, Nancy B., Stanley H. Faeth, Nancy E. Golubiewski, Charles L. Redman, Jianguo Wu, Xuemei Bai, and John M. Briggs. 2008. "Global change and the ecology of cities." *Science* 319, no. 5864: 756-760.

Groffman, Peter M., Charles T. Driscoll, Gene E. Likens, Timothy J. Fahey, Richard T. Holmes, Christopher Eagar, and John D. Aber. 2004. "Nor gloom of night: a new conceptual model for the Hubbard Brook ecosystem study." *BioScience* 54, no. 2: 139-148.

Groffman, Peter M., Neely L. Law, Kenneth T. Belt, Lawrence E. Band, and Gary T. Fisher. 2004. "Nitrogen fluxes and retention in urban watershed ecosystems." *Ecosystems* 7, no. 4: 393-403.

Grove, J. Morgan, Daniel L. Childers, Michael Galvin, Sarah Hines, Tischa Muñoz-Erickson, and Erika S. Svendsen. 2016. "Linking science and decision making to promote an ecology for the city: practices and opportunities." *Ecosystem Health and Sustainability* 2, no. 9: e01239.

Grove, J. Morgan, Dexter H. Locke, and Jarlath PM O’Neil-Dunne. 2014. "An ecology of prestige in New York City: Examining the relationships among population density, socio-economic status, group identity, and residential canopy cover." *Environmental Management* 54, no. 3: 402-419.

Hane, Elizabeth and Karl Korfmacher. 2022a. “Insect ‘bee&bees’ and pollinator penthouses: teaching students about pollinators and their services in an urban environment.” *Urban Ecosystems*, in press.

Hane, Elizabeth and Karl Korfmacher. 2022b. “Engaging students in redesigning a local urban space to improve ecosystem services.” *Urban Ecosystems*, in press.

Held, Amy. 2019. “German Firefighters Work To Free Rotund Rat Stuck In Manhole Cover.” Accessed July 9, 2021. https://www.npr.org/2019/02/27/698547607/watch-german-firefighters-work-to-free-rotund-rat-stuck-in-manhole-cover

Kaushal, Sujay S., William H. McDowell, and Wilfred M. Wollheim. 2014. "Tracking evolution of urban biogeochemical cycles: past, present, and future." *Biogeochemistry* 121, no. 1: 1-21.

Kunkel, Brian A., David W. Held, and Daniel A. Potter. 1999. "Impact of halofenozide, imidacloprid, and bendiocarb on beneficial invertebrates and predatory activity in turfgrass." *Journal of Economic Entomology* 92, no. 4: 922-930.

Leong, Misha, Robert R. Dunn, and Michelle D. Trautwein. 2018. "Biodiversity and socioeconomics in the city: a review of the luxury effect." *Biology Letters* 14, no. 5: 20180082.

Long, Joshua. 2016. "Helping Students Envision Justice in the Sustainable City." In *Learner-Centered Teaching Activities for Environmental and Sustainability Studies*, edited by Loren B. Byrne, 227-232. New York: Springer.

Loss, Scott R., Tom Will, Travis Longcore, and Peter P. Marra. 2016. "Responding to misinformation and criticisms regarding United States cat predation estimates." *Biological Invasions* 20, no. 12: 3385-3396.

McPhearson, Timon, Steward TA Pickett, Nancy B. Grimm, Jari Niemelä, Marina Alberti, Thomas Elmqvist, Christiane Weber, Dagmar Haase, Jürgen Breuste, and Salman Qureshi. 2016. "Advancing urban ecology toward a science of cities." *BioScience* 66, no. 3: 198-212.

Moore, Jennie, Meidad Kissinger, and William E. Rees. 2013. "An urban metabolism and ecological footprint assessment of Metro Vancouver." *Journal of Environmental Management* 124: 51-61.

Moran, Sharon, Meredith Perreault, and Richard Smardon. 2019. "Finding our way: A case study of urban waterway restoration and participatory process." *Landscape and Urban Planning* 191: 102982.

Morin, Erica A. 2016. "Location, Location, Location! Analyzing Residential Development in Environmentally-Fragile Areas." In *Learner-Centered Teaching Activities for Environmental and Sustainability Studies*, edited by Loren B. Byrne, 155-162. New York: Springer.

Nassauer, Joan Iverson. 1988. "The aesthetics of horticulture: neatness as a form of care." *HortScience* 23, no. 6: 973-977.

Oliveira, Sofia S., Joana Pereira, Paulo Santos, and Ruth Pereira. 2021. "Assessing Soil Quality in Schoolyards: A Hands-On Activity for Middle School Students." *The American Biology Teacher* 83, no. 5: 331-336.

Pickett, Steward, T., A., William R. Burch Jr, Shawn E. Dalton, and Timothy W. Foresman. 1997. "Integrated urban ecosystem research." *Urban Ecosystems* 1, no. 4: 183-184.

Pickett, Steward TA, and Mary L. Cadenasso. 2006. "Advancing urban ecological studies: frameworks, concepts, and results from the Baltimore Ecosystem Study." *Austral Ecology* 31, no. 2: 114-125.

Pickett, Steward TA, Mary L. Cadenasso, J. Morgan Grove, Charles H. Nilon, Richard V. Pouyat, Wayne C. Zipperer, and Robert Costanza. 2001. "Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas." *Annual Review of Ecology and Systematics* 32, no. 1: 127-157.

Pickett, Steward TA, Mary L. Cadenasso, Daniel L. Childers, Mark J. McDonnell, and Weiqi Zhou. 2016. "Evolution and future of urban ecological science: ecology in, of, and for the city." *Ecosystem Health and Sustainability* 2, no. 7: e01229.

Popovich, Nadja and Christopher Flavelle. 2019. "Summer in the City Is Hot, but Some Neighborhoods Suffer More." *New York Times*, August 9, 2019. Available at https://www.nytimes.com/interactive/2019/08/09/climate/city-heat-islands.html

Rega-Brodsky, Christine C., and Charles H. Nilon. 2016. "Vacant lots as a habitat resource: nesting success and body condition of songbirds." *Ecosphere* 7, no. 11: e01578.

Russ, Alex, ed. 2015. Urban Environmental Education. Ithaca, NY and Washington, DC: Cornell University Civic Ecology Lab, NAAEE and EECapacity.

Scherer, Hannah H., Lauren Holder, and Bruce Herbert. 2017. "Student learning of complex Earth systems: Conceptual frameworks of Earth systems and instructional design." *Journal of Geoscience Education* 65, no. 4: 473-489.

Schmitt-Harsh, Mikaela, and Joseph A. Harsh. 2017. "Engaging nonscience majors in urban ecology: Recommendations for course design." *Journal of Environmental Studies and Sciences* 7, no. 4: 550-561.

Shrewsbury, Paula M., and Michael J. Raupp. 2006. "Do top-down or bottom-up forces determine Stephanitis pyrioides abundance in urban landscapes?." *Ecological Applications* 16, no. 1: 262-272.

Siossian, Emma. 2018. "Knock, knock, there's a koala at the door: It's breeding season and the marsupials are on the move." Accessed July 9, 2021. https://www.abc.net.au/news/2018-07-09/koala-an-unexpected-visitor-at-the-front-door/9931558

Sipilä, Maija, and Liisa Tyrväinen. 2005. "Evaluation of collaborative urban forest planning in Helsinki, Finland." Urban Forestry & Urban Greening 4, no. 1: 1-12.

Tan, Puay Yok, Jingyuan Zhang, Mahyar Masoudi, Jahson Berhane Alemu, Peter J. Edwards, Adrienne Grêt-Regamey, Daniel R. Richards, et al. 2020. "A conceptual framework to untangle the concept of urban ecosystem services." *Landscape and Urban Planning* 200: 103837.

Taylor, Mark Patrick, Cynthia F. Isley, Kara L. Fry, Xiaochi Liu, Max M. Gillings, Marek Rouillon, Neda S. Soltani, Damian B. Gore, and Gabriel M. Filippelli. 2021. "A citizen science approach to identifying trace metal contamination risks in urban gardens." *Environment International* 155: 106582.

Tidball, Keith G., and Marianne E. Krasny. 2011. 2010. "Urban environmental education from a social-ecological perspective: Conceptual framework for civic ecology education." *Cities and the Environment* 3, no. 1: Article 11.

Wald, Navé, and Ben Kei Daniel. 2020. "Enhancing students' engagement with abstract ideas through conceptual and theoretical frameworks." *Innovations in Education and Teaching International* 57, no. 4: 496-505.

Zhou, Weiqi, Brendan Fisher, and Steward T.A. Pickett. 2019. "Cities are hungry for actionable ecological knowledge." *Frontiers in Ecology and the Environment* 17: 135.

Zhou, Weiqi, S. T. A. Pickett, and Timon McPhearson. 2021. "Conceptual frameworks facilitate integration for transdisciplinary urban science." *Urban Sustainability* 1, no. 1: 1-11.

Ziter, Carly. 2016. "The biodiversity–ecosystem service relationship in urban areas: a quantitative review." *Oikos* 125, no. 6: 761-768.