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A Literature Review of Resilience in Urban Forestry

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Abstract. Urban forests provide many benefits to residents and may also improve cities' resilience, the overall capacity to recover from anthropogenic and natural disturbances. Resilience is often considered from an ecological, social, or social-ecological perspective. In this literature review, we synthesize past studies ($n = 31$) to explore resilience in urban forests and green spaces and to understand how social or ecological perspectives have been considered. We found studies that combine resilience and urban forests have been increasing over time. Definitions of both resilience and urban forests are highly variable, but generally the studies increasingly focus on a social-ecological systems approach. The most common theoretical framework applied to understanding urban forests and resilience is a risk and vulnerability assessment approach. Studies were spread across geographies, with some concentration near major research stations and universities with scientists who specialize in resilience and urban green spaces. As more attention is focused on the role of green infrastructure in contributing to urban resilience, we encourage the adoption of consistent definitions, theories, and indicators.

Keywords. Adaptive Capacity; Resilience; Social-Ecological Systems; Urban Forestry; Vulnerability.

INTRODUCTION

Resilience is an emerging policy goal for cities worldwide, as cities struggle to recover from both chronic and acute stressors. Trees and forests are critical components of the urban ecosystem, providing many benefits to residents within cities and contributing to the resilience of the larger social-ecological system. These benefits include, but are not limited to, reducing stormwater runoff, shade and cooling, and human well-being benefits derived from cultural ecosystem services such as aesthetic enjoyment, improved cognitive function, place attachment (the bonding of people to places, Altman and Low 2012), identity, and space for recreation (Roy et al. 2012). Many of these ecosystem services relate to a city's ability to be resilient, however, some ecosystem services have only been modeled (rather than empirically measured) and much remains unknown about their value (Pataki et al. 2011).

Trees in urban settings experience distinct growing conditions due to fragmented landscapes, challenging site conditions, altered climatic conditions, and disturbance regimes (Pretzsch et al. 2017; Scharenbroch et al. 2017). In some cases, these conditions have negative effects, like compacted soils that could reduce the sustainability of the forest and reduce the potential opportunities for forests and trees to provide benefits. In other cases, the urban context can present advantages, like access to light and greater potential for increased stewardship (e.g., street trees) than would be the case in a closed-canopy forest (Hunter 2011). For urban forest managers, it is critical to strategize how to maximize ecosystem services while also addressing urban forest system vulnerabilities and ecosystem disservices (Dobbs et al. 2011; von Döhren and Haase 2015; Steenberg et al. 2017).

The literature on urban forestry and resilience is relatively small compared to the literature on urban resilience more broadly, which was found to include over 300 articles in various fields like agricultural and biological science, engineering, and social science (Meerow et al. 2016). Our broad goal was to compile and synthesize the available literature to determine: (1) the state of the current knowledge on what makes urban forests and green spaces resilient; (2) the extent to which social, ecological, and institutional perspectives are considered in urban forest and green space

resilience; and (3) how theoretical frameworks are used to address resilience of urban forests and green spaces.

Resilience theory provides an opportunity to consider how to understand ecosystem services (and disservices) in relationship to system vulnerabilities. Resilience as a concept was initially identified in the field of systems science (Holling 1973), yet many theoretical developments have occurred to date that have advanced and expanded the concept. Holling defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables." This definition of resilience identifies ideal conditions for maintaining stasis, yet current ecological theory has shifted to also considering system nonequilibrium (Suding et al. 2004; Mori 2011). Since the initial application of the term resilience to ecological systems, resilience theory also has deepened to consider resilience of what, to what (Carpenter et al. 2001), and for whom (Lebel et al. 2006), and has expanded system definitions to consider social-ecological systems (SES) (Walker et al. 2004). An SES is "an ecological system intricately linked with and affected by one or more social systems" (Anderies et al. 2004). Press and pulse dynamics is a term used to represent the interactions of continuous, or "press," disturbances causing a permanent change in the abundance or density of particular species with "pulse" events, short-term disturbances causing an immediate change in the abundance or density of a particular species, after which the species recovers when the disturbance ceases, respectively (Bender et al. 1984). These dynamics were incorporated in the resilience literature and evolved with a social-ecological systems perspective (Smith et al. 2009; Collins et al. 2011). Given these abstract concepts and evolving definitions of resilience, qualitative analysis of attitudes and values around forest resilience has identified a communication challenge with such a large and varied set of terms, with implications for practical application whereby "resilience is a multifaceted concept with an array of potential implications" (Young et al. 2018).

Practical applications of resilience concepts in rural forestry continue to focus on resilience to pests, fire, and other ecological disturbances (Halpern 1988; Herbert et al. 1999; Churchill et al. 2013; Reyer et al. 2015; Johnstone et al. 2016). With a growing recognition of the effects of climate change on forest composition and function, applications also now consider mitigation strategies for being resistant to change and adaptive strategies for being resilient (Millar et al. 2007; Cross et al. 2012; Kemp et al. 2015) but accepting of a state change.

When focusing on urban systems, consideration of social components and processes becomes critical to understanding social mechanisms that can affect ecological processes (Berkes et al. 2000). In a review of urban resilience literature, Meerow et al. (2016) found six conceptual tensions, which included defining what is "urban." Here, we examine how resilience has been applied in the field of urban forestry.

In urban areas, one aspect of resilience research related to urban forests has focused on the relationship between social resilience and natural resources stewardship. Social resilience has been conceptualized as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change" (Adger 2000). Greening actions have been identified as a recovery response by people restoring a system to what they knew before (Tidball and Krasny 2007; Tidball et al. 2010). Indicators of social resilience related to public and green spaces across the urban-rural gradient include place attachment, social cohesion (Chan et al. 2006), social networks (Scott 1988), and knowledge exchange and diversification (Berkes and Ross 2013; McMillen et al. 2016). Some such social indicators of resilience, such as place naming (Alderman 2016), shared group narratives (Rappaport 1995), and identity, may be embedded in stewardship. The ability to recognize empirical evidence for these indicators then holds promise for supporting those activities and promoting generalized resilience (Carpenter et al. 2012) to a range of chronic presses and acute disturbances in both social and ecological contexts (McMillen et al. 2016).

Past studies examining urban ecological resilience often focus on ecological variables and processes such as invasive pests and diseases and extreme weather events. Laćan and McBride (2008) used a pest vulnerability matrix to determine how tree species diversity relates to urban forest susceptibility to disease, while McPherson and Kotow (2013) assessed a report card method to understand and measure ecological resilience in terms of size class distribution of the urban forest as well as pest vulnerability. There is

a growing body of literature that provides information on tree susceptibility to extreme weather events like ice storms and hurricanes (Staudhammer et al. 2011) and the role urban forests play in mitigating the consequences of climate change and urban stressors. For example, trees can alleviate increased temperatures related to the urban heat island effect (Gago et al. 2013) and improve the livability of cities and overall landscape resilience. In some studies, the phrase ecological integrity is used to describe the role of urban forests in promoting resilience (Alberti 2010); while such a phrase can be quantified, it can hold context-specific meanings (Tierney et al. 2009). Most measures of ecological resilience acknowledge that the ability to respond is driven by intertwined institutional and community-level decisions. For example, forest resilience to a pest outbreak or disturbance event could be codependent on ecological factors like regeneration and human factors like a decision to initiate a presalvage harvest.

The ecological and social perspectives on how urban forests contribute to overall urban resilience are more often analyzed as distinct concepts. Moreover, it is only recently that the contribution of social resilience and the concept of governance have been recognized as critically important to our understanding of urban forest resilience (e.g., McMillen et al. 2016). Evidence for how urban forests are (or can be made) resilient and how trees and forests contribute to overall urban resilience are critical to bridge the concept of resilience across social and ecological disciplines. In this paper, we provide a literature review of multidisciplinary approaches to resilience to provide new insights for cities wishing to incorporate resilience metrics into planning processes and urban forestry management.

MATERIALS AND METHODS

Search Strategy

Articles were gathered using a combination of snowball and criterion sampling (Patton 2002), beginning with the Science Direct, Web of Science, JSTOR, Ingenta, and Google Scholar databases (Table 1) and pulling citations from papers until there were no longer relevant citations to view. We cross-referenced citations from papers initially discovered from a database to identify new studies not found via our keyword search. We specifically targeted urban forestry, arboriculture, urban planning, and geography literatures. We directly searched journals not indexed by the above databases (e.g., *Cities and the Environment* or *CATE*). We established two criteria for inclusion in our review. The first criterion was that the paper should pertain to (1) urban forests/green spaces AND (2) resilience. The second criterion for inclusion was that the study should either (1) examine the role that urban forests/green spaces play in overall resilience OR (2) examine the role that resilience plays in urban forestry and urban green space management.

We searched for potential literature to include also using the terms *vulnerability*, *tolerance*, and *sustainability*, as these terms are often used to describe the same concept as resilience. We searched titles, abstracts, and keywords and compared those results to searching the whole text, finding that expanding to the whole text did not add relevant papers because these terms had to be central to the paper and thus always appeared in the abstract or keywords. For the purposes of this review, we define urban forests as trees and forest resources in and around urban community ecosystems (Johnston 1996; Konijnendijk et al. 2006). We define green spaces as parks, gardens, and yards (Jorgensen and Gobster 2010; Hunter and Luck 2015).

Search Results

With the exception of JSTOR, which had a different search structure and thus returned more results, most of the databases returned similar numbers of articles within the different combinations of search terms (Table 1). We used the search list from Science Direct, ensuring that articles found by other databases that were not included in Science Direct were also added to the list. This combined list included 82 potentially relevant articles, accounting for some overlap between search terms. These articles were then assessed with our criterion, resulting in 31 articles for inclusion, 11 articles for background information related to our review topic, and the remainder not used in the review. Of the final 31 coded papers (Appendix Table 1), 18 were found from a database search, 8 were found from a direct search on a journal website, and 5 were pulled from the reference lists of coded papers.

Coding Strategy

Articles were coded for basic information (e.g., authors, year published), study characteristics (e.g., theoretical framework, data analysis type), and resilience characteristics (e.g., treatment of resilience)(Appendix Table 2). We identified theoretical frameworks by

emergent coding and then linking these codes to established theoretical frameworks familiar to the authors or cited in the articles reviewed. We applied Binder et al.'s (2013) broad definition of frameworks as "a set of concepts, values, and practices that constitute the way of viewing the specific reality." We tested our coding strategy with 3 articles and 6 reviewers, with team discussions when disagreement occurred. All articles were then coded by two people independently, with similar discussions when disagreements were found. Finally, two additional coauthors checked coding on a random sample of 5 articles.

RESULTS

Basic Information

The plurality of articles were published in *Urban Forestry & Urban Greening* (n = 9, 29%) while the following journals had two articles each: *Urban Ecosystems*, *Arboriculture & Urban Forestry*, *Environmental Reviews*, *Sustainability*, and *Environmental Science & Policy*. There was one article each in a wide variety of journals from *Forest Policy & Economics* to *Atmosfera*. Articles were published from 1998 to 2017, with a sharp increase in 2013 (Figure 1).

We found that there was little consensus in this literature on the definition of "urban forest." Eleven of the studies (36%) did not define urban forest at all. The remaining 20 all had slightly different definitions. Some relied on definitions from the literature, such as Clark et al. (1997), Rowntree (1984), Konijnendijk et al. (2006), Kenney et al. (2011), and Pickett and Grove (2009). Most included urban trees (e.g., Duryea et al. 2007; Barona 2015), others included parks (McPherson and Kotow 2013; Campbell et al. 2016), and others considered the entire ecosystem of trees and parks (Mincey et al. 2013; Davies et al. 2017).

Study Characteristics

There is wide geographic representation in the 31 articles, with earlier articles studying Western cities in the United States and newer articles spread worldwide (Figure 2). There were several studies in Chicago, Illinois; New York, New York; and in Sacramento, California, as well as one study that examined 15 cities in the United Kingdom.

Of our 31 papers, 20 used a theoretical framework (64%), while 11 did not (36%). The most common theoretical framework was a *risk and vulnerability assessment* approach (20%)(Table 2). The earliest paper published (McPherson 1998) did not have a theoretical framework, but a subsequent paper included in our database (Alberti and Marzluff 2004) put forth a new theoretical framework that explicitly linked urban patterns and ecosystem resilience, which we coded as *resilience measurement*. *Ecosystem services* appeared in the literature by 2008 (e.g., Martin 2008), followed by *risk and vulnerability assessment* (e.g., McPherson and Kotow 2013).

About 39% of the studies (n = 12) used a quantitative approach to data collection and analysis, while 10 used a literature review, 4 used a mixed methods approach, 3 used qualitative approaches, 1 used a conceptual model, and 1 used secondary data. Of the

Table 1. Comparison of database search results listing counts of potentially relevant papers.

Database	Resilience	Vulnerability	Tolerance	Sustainability	Search terms
Science Direct	30	45	20	103	Urban forest
	7	2	1	18	Greenspace
JSTOR*	907	9	7	7	Urban forest
	20	22	19	61	Greenspace
Web of Science	25	24	13	54	Urban forest
	4	1	2	33	Greenspace
Google Scholar	4	14	3	17	Urban forest
	4	1	3	10	Greenspace
Ingenta Connect	0	2	0	1	Urban forest
	0	0	0	0	Greenspace

*JSTOR: The term "urban forest" was considered as two separate searches. Focused on botany, ecology, horticulture, gardening, environmental, geography, and urban studies related journals only.

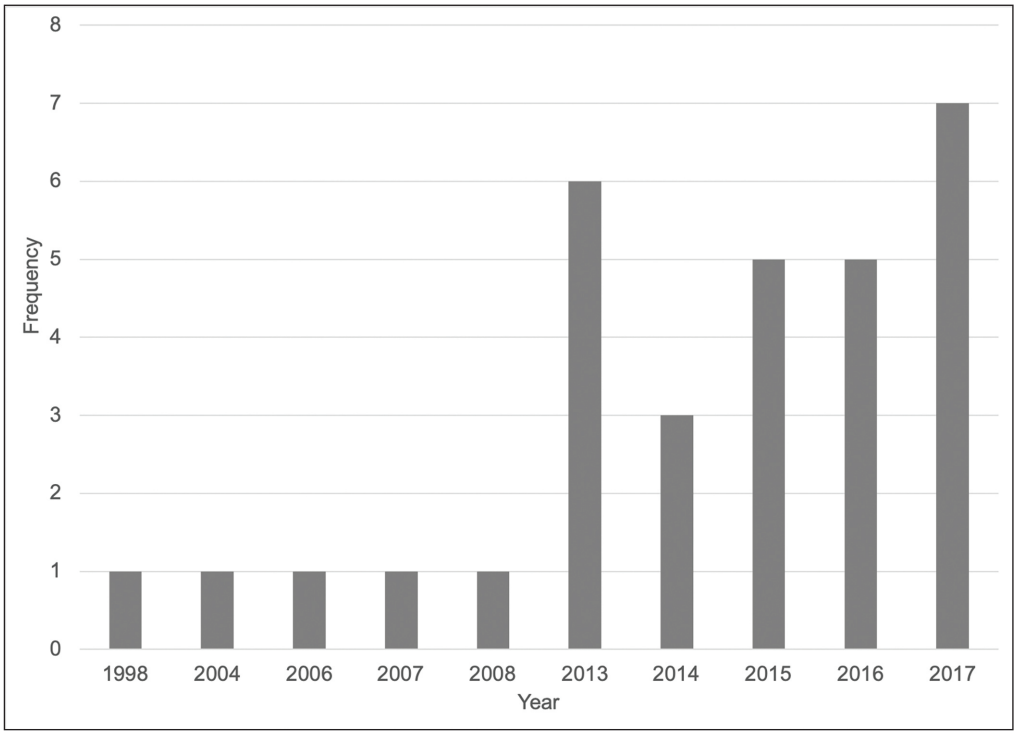

Figure 1. Number of articles published over time on urban forests and resilience.

4 articles that collected data with a mixed methods approach, 1 analyzed the data quantitatively and the other 3 analyzed data qualitatively.

Resilience Characteristics

Resilience was defined and discussed in a wide variety of ways. The articles were categorized and coded using the resilience *of what*, *to what*, *for whom* framework (Table 3, Carpenter et al. 2001), bearing in mind that few articles explicitly used this framework. Rather, they described general resilience. The majority of articles focused on resilience of an ecological component or system as the target of the study, but there was a fairly even distribution of studies that considered pulse events, such as insect outbreaks, and press events, such as climate change, when measuring resilience. Finally, most studies tried to understand how the resilience of urban forests to various stressors might impact various actors within cities (e.g., McPherson 1998). These actors ranged from urban residents to urban forest managers. Some studies considered governments and planning boards as the practitioners who would use this information to improve urban resilience.

Although the majority of studies focused on ecological components or systems as the target of resilience measurement and understanding, the dominant disciplinary perspectives across the 31 studies were social-ecological (n = 17) and ecological (n = 13). Only one study was conducted with an entirely social perspective (McMillen et al. 2016). While 13 of the studies did not explicitly describe which system components they used to measure resilience, 18 studies did describe specific variables. Of the 13 studies that did not identify system components, 4 were ecologically focused, while the other 9 were social-ecological perspectives. The data collection and analysis methods of the studies without specific variables related to resilience included all types (e.g., qualitative, quantitative, literature review). The studies that included measured system components had anywhere from 1 to over 10 variables measured, ranging from ecological characteristics like drought tolerance to social characteristics like institutional robustness (Table 4). Some variables were straightforward, like relative species abundance, while others were more complex to measure, like adaptive capacity.

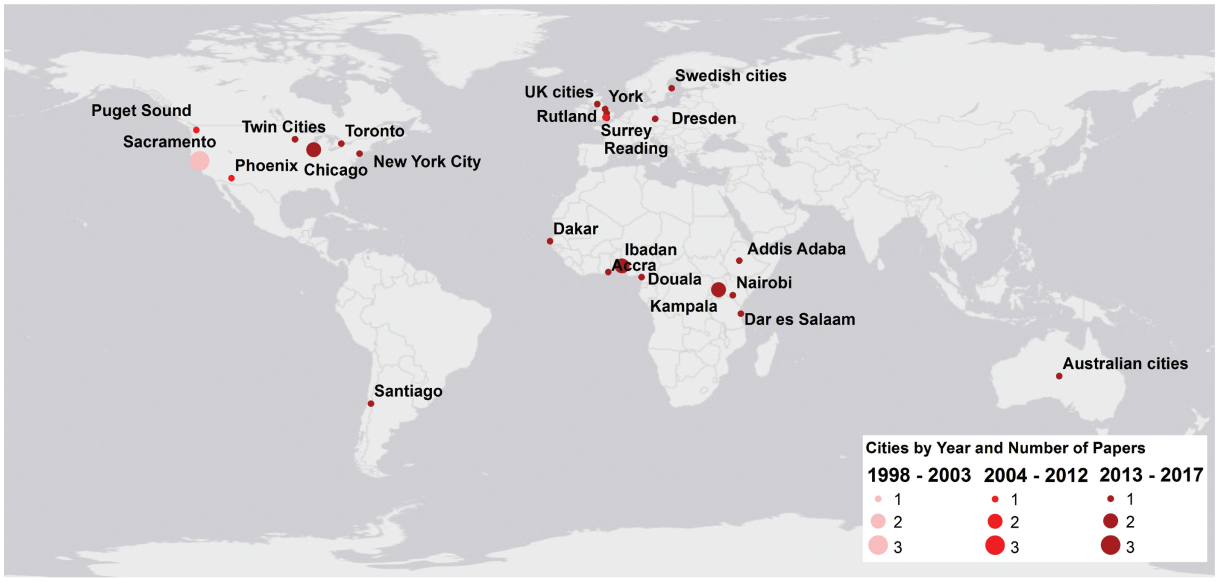

Figure 2. Study locations for articles on urban forests and resilience.

Table 2. Frequency of theoretical frameworks used in the analyzed studies and the definition of each framework.

Theoretical framework	Frequency	Definition
Direct resilience measurement	5	Focused on system resilience, drawing on a set of resilience papers like Carpenter et al. 2001, Gunderson and Holling 2001, Holling 2001, Folke 2006
Energy or land use model	3	Focused on land use, land change, and spatially explicit data (Turner 1994, Lambin et al. 2001)
Ecosystem services	3	Focused on services provided by ecosystems and their relationship to human well-being (MEA 2005)
Risk and vulnerability assessment	7	Focused on understanding system vulnerability, drawing on seminal framework papers like Turner et al. 2003
Institutional analysis and development	1	Focused on institutional analysis (Ostrom 2011)

DISCUSSION

Our literature review of the resilience concept as applied to urban forests and green spaces indicates that there is not yet consensus on what makes the urban forest more resilient, nor the degree to which urban forests improve overall resilience in cities. The state of the current knowledge (Goal 1) on what makes urban forests and green spaces resilient is still early exploration of ecological and social components driving ecosystem function and urban resident well-being. Emerging themes from an ecological perspective were tree/plant diversity (species, age, function) and drought tolerance. If forest community composition shifts more rapidly under climate change, it is possible that urban environments will serve as pilot cases for species migration, and new opportunities for innovative urban silviculture may arise. Social themes we identified were resilience-facilitating legislation, institutions, and public acceptance.

Although resilience was originally measured and understood from an ecological perspective (Holling 1973), a number of studies considered the entire social-ecological systems (SES) perspective (Goal 2). We attribute this shift in perspective to the rise in SES methods and theoretical frameworks more generally and to several key works that link the concept of resilience with SES (e.g., Folke 2006). Although SES research approaches to resilience were present in the majority of articles, the next most common was an ecological approach, perhaps reflecting the origins

Table 3. Resilience perspectives (codes derived from emergent coding process).

Resilience of what	**Count**	**Examples**
Ecological component	10	Trees, urban trees, tree species
Ecological system	8	Urban forest, parks
Social component	1	People
Social system	1	Neighborhood
Social-ecological system	8	Road tree management system, community gardens
Resilience to what	**Count**	**Examples**
Pulse	17	Insect outbreak, hurricanes
Press	11	Climate change, development pressure
Pulse and press	2	Urbanization and pests/diseases
Resilience for whom	**Count**	**Examples**
Actors	21	Urban forest managers, urban residents
Organizations	2	City planning agencies
Actors and organizations	4	City government and urban residents
Non-human actors	2	Trees

Table 4. Compilation of measured system components that may indicate resilience as identified in reviewed articles, summarized by data collection method and overall resilience perspective.

Resilience perspective	**Data collection method**	**System components**
Ecological	Literature review	Relative species abundance (Kendal et al. 2014)
Ecological	Quantitative	Diversity of ecological functions (Estevo et al. 2017) Drought resilience index (Fahey et al. 2013) Drought tolerance (Sjöman et al. 2015) Heat flux characteristics (Rafael et al. 2016) Soil moisture, chlorophyll content of leaves, and carbon fixation capacity (Percival et al. 2006) Species dominance, age structure, pest threat, and potential asset loss (McPherson and Kotow 2013) Vitality (Gillner et al. 2014)
Social	Qualitative	Place attachment, collective identity, social cohesion, social networks, knowledge exchange, and diversity (McMillen et al. 2016)
Social-ecological	Literature review	Ecosystem health and human health (Kattel et al. 2013) Exposure to disturbance, sensitivity, and adaptive capacity (Steenberg et al. 2017) Institutional robustness (Mincey et al. 2013) Species selection, diversity, naturalization, resource access, social awareness, and budget (Ordóñez and Duinker 2014)
Social-ecological	Mixed methods	Resilience facilitating legislation (Jepson and Arakelyan 2017) Public acceptance of resilience-increasing means and measures (Jepson and Arakelyan 2017) Soil and geomorphic conditions, proximity to Lake Michigan, tree species composition, presence or threat of pests and diseases, urban heat island effects, relative ozone pollution, and amount of impervious cover (Brandt et al. 2016)
Social-ecological	Quantitative	Species diversity, age diversity, condition, and suitability (McPherson 1998) Intensity of built environment and density of human settlement (Steenberg et al. 2017)

of the term. It is important to note that although many of the papers in our review raised an SES perspective in the framing of the study, very few actually measured the range of SES variables in their study, but rather focused on a narrow set of variables.

We found no consistent theoretical framework (Goal 3) applied to studies that link resilience and urban forests. Resilience is often used synonymously with "adaptive capacity" (Gallopín 2006), and thus climate-related vulnerability assessments seem to be the most common theoretical framework and tool applied to this research. Indeed, the lack of consistent treatments of the resilience concept is consistent with past critiques, particularly in relation to tensions across disciplinary perspectives (Davidson 2010; Olsson et al. 2015). Yet even with those critiques, researchers reflecting on forest management and extreme weather events point out that resilience approaches have emphasized social-ecological interactions, uncertainty in predicting change, as well as reaction to and recovery from disturbances (Rist and Moen 2013; de Bruijn et al. 2017). In this way, "resilience thinking" has become a useful perspective for integrated considerations of human and ecological systems in natural resource management (Rist and Moen 2013), notwithstanding the ongoing academic debates concerning definitions of resilience.

Additionally, we found no consistent definition and treatment of the urban forest, thus there was difficulty assessing how urban forests might contribute to overall resilience in cities, given that some research treats urban street trees as separate from larger contiguous blocks of forest (e.g., city parks). Different types of urban forest provide different benefits and are more sensitive or tolerant to different stressors. For example, street trees are more widely distributed spatially, so they can help to alleviate the urban heat island and provide shade for buildings (Rosenzweig et al. 2009). However, these trees are managed on an individual basis and thus have higher maintenance costs compared to a stand with natural regeneration (Donovan and Butry 2010).

Further research could explore municipal sustainability plans and urban forest master plans to explore how managers have practically applied resilience of urban trees and green spaces to urban green infrastructure. Research could also focus on institutional analyses of agencies and nonprofits who manage urban forests in order to understand how application of resilience affects organizational structure and function. Moreover, future research could evaluate what is in formal (written) plans at the city or municipal level compared to testimony from forestry practitioners on how and if they deal with resilience in their job.

Like Meerow et al. (2016), we found varying definitions of urban resilience as applied to urban forests and green spaces, based on the subject area of the articles' authors. The contributions of urban forests to overall urban resilience has not yet been well documented, but there is a growing awareness of the importance of trees and green spaces to social well-being. As more attention is focused on the extent to which green infrastructure improves urban resilience, we encourage the adoption of consistent definitions, theories, and critical system components to communicate about and consistently assess resilience within urban forestry.

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Résumé. Les forêts urbaines fournissent de multiples bienfaits aux citoyens et peuvent également améliorer la résilience des villes, cette capacité à récupérer de perturbations d'origine humaine ou naturelles. La résilience est souvent considérée d'un point de vue écologique, social ou socio-écologique. Dans cette revue de littérature, nous avons fait une synthèse de recherches antérieures (n = 31) afin d'étudier la résilience dans les forêts urbaines et les espaces verts et comprendre la manière dont les perspectives sociales ou écologiques ont été prises en compte. Nous découvrîmes que les recherches qui combinaient résilience et forêts urbaines se sont multipliées au fil du temps. Les définitions, tant de la résilience que des forêts urbaines, sont très variables mais de manière générale ces études mettent l'accent sur une approche socio-écologique des systèmes. Le cadre théorique le plus couramment appliqué à la compréhension des forêts urbaines et de la résilience est une approche d'évaluation des risques et des vulnérabilités. Les recherches provenaient de toutes régions géographiques avec une certaine concentration autour d'universités et de centres de recherches où on retrouve des scientifiques se spécialisant en résilience et en espaces verts urbains. Alors qu'une attention accrue est accordée au rôle de l'infrastructure verte dans la résilience urbaine, nous encourageons l'adoption de définitions, de théories et d'indicateurs cohérents.

Zusammenfassung. Urbane Forste liefern viele Vorteile für die Anwohner und können auch die Belastbarkeit der Städte verbessern, die allgemeine Kapazität, sich von anthropogenen und natürlichen Störereignissen zu erholen. Belastbarkeit wird oft aus einer ökologischen, sozialen oder sozio-ökologischen Perspektive betrachtet. In dieser Literaturübersicht synthetisieren wir vergangene Studien (n = 31), um die Belastbarkeit urbaner Forste und Grünräumen zu erkunden und um zu verstehen, wie soziale oder ökologische Perspektiven zu betrachten sind. Wir fanden Studien, die kombinieren daß Belastbarkeit und urbane Forste über die Zeit anstiegen. Die Definitionen von Belastbarkeit und urbane Forste sind hoch variable, aber generell fokussieren die Studien auf einen sozio-ökologischen Ansatz. Das am meisten angewendete theoretische Rahmenwerk zum Verständnis von urbanen Forsten und Resilienz ist eine Risiko- und Gefährdungsanalyse. Die Studien waren geographisch weit verbreitet mit einigen Konzentrationen in der Nähe von bedeutenden Forschungseinrichtungen und Universitäten mit Wissenschaftlern, die im Bereich Resilienz und urbanen Grüanlagen spezialisiert waren. Wenn mehr Aufmerksamkeit auf die Rolle der grünen Infrastruktur als Beitrag zur urbanen Reslienz fokussiert, möchten wir die Adoption von einheitlichen Definitionen, Theorien und Indikatoren anregen.

Resumen. Los bosques urbanos proporcionan muchos beneficios a los residentes y también pueden mejorar la resiliencia de las ciudades, la capacidad general para recuperarse de las perturbaciones antropogénicas y naturales. La resiliencia se considera a menudo desde una perspectiva ecológica, social o social-ecológica. En esta revisión de la literatura, sintetizamos estudios anteriores (n = 31) para explorar la resiliencia en los bosques urbanos y los espacios verdes y para entender cómo se han considerado las perspectivas sociales o ecológicas. Encontramos que los estudios que combinan resiliencia y bosques urbanos han ido aumentando con el tiempo. Las definiciones de resiliencia y bosques urbanos son muy variables, pero generalmente los estudios se centran cada vez más en un enfoque de sistemas social-ecológicos. El marco teórico más común aplicado a la comprensión de los bosques urbanos y la resiliencia es un enfoque de evaluación de riesgos y vulnerabilidades. Los estudios se distribuyeron en todas las geografías, con cierta concentración cerca de las principales estaciones de investigación y universidades con científicos que se especializan en resiliencia y espacios verdes urbanos. A medida que se presta más atención al papel de la infraestructura verde en la contribución a la resiliencia urbana, alentamos la adopción de definiciones, teorías e indicadores coherentes.

Appendix Table 1. Full database of coded articles is available online. https://www.isa-arbor.com/Publications/Arboriculture-Urban-Forestry

Appendix Table 2. Codes used to analyze included studies.

Code	Type of code	Description of code
Authors	In vivo*	Last name, first name of all authors
Title	Text	Title of the article
Publisher/journal	In vivo	Full name
Month	Text	Month published
Year	Numeric	Year published
Full citation	Text formatted	Full citation in the ISA citation style—http://auf.isa-arbor.com/
Keywords	In vivo	Keywords from the article
Study location: city	Text	City or multiple cities studied
Study location: state	Text	State or multiple states studied
Study location: country	Text	Country or multiple countries studied
Site type	Categories	Urban forest, urban green space, trees—planted, trees—natural, gardens
Document type	Text	Article, gray literature, book, conference proceedings, manuscript, thesis
Report citations	Yes/no/NA	If the article is a report, has it been cited in the peer-reviewed literature?
Total citations	Numeric	How many times has the article been cited?
Journal impact factor	Numeric	What is the impact factor of the journal?
Search strategy	Text	How was the article discovered: database name, from another article (name of article), from a person (name of person), from an internet search?
Reviewer	Text	Name of project personnel that coded article
Theoretical framework	Text or NA	If a framework is used, description for framework; Otherwise, NA
Goals/objectives/research questions	In vivo	What are the stated goals or objectives of the study?
Hypotheses	In vivo	What are the stated hypotheses of the study?
Data collection method in vivo	In vivo	Text description of how the data was collected
Data collection method summary	Text	Summary/synthesis of data collection method in preset categories
Data analysis method in vivo	In vivo	Text description of data analysis technique(s), as copied from the article
Data analysis method summary	Text	Summary/synthesis of data analysis method in preset categories
Treatment of resilience	Text	How does the article define resilience?
Resilience indicators	Text	If they state what their indicators of resilience will be, copy that. Otherwise, leave this blank or write "no indicators used."
Resilience of what?	Text	What is described as being resilient (e.g., trees themselves, managers, communities)
Resilience of what?	Code	Ecological component, ecological system, social component, social system, social-ecological component, social-ecological system
Resilience to what?	Text	What the system is described as being resilient to (e.g., climate change, human disturbance)
Resilience to what?	Code	Pulse or press
Resilience for whom?	Text	To whom the system is resilient for (e.g., subpopulations of people, wildlife)
Resilience for whom?	Code	Actors or organizations
Resilience perspective	Text	The systems perspective of the study: social, ecological, social-ecological
Definition of urban forest	Text/in vivo	Coded from the study when possible, otherwise summarized; will include description of what is included in an urban forest (e.g., street trees, park trees, privately owned trees, etc.)
Additional notes	Text	Anything that will help co-authors keep track of salient information

*in vivo coding refers to codes that use the actual words within the text, as opposed to codes chosen by the reviewer to represent the text