# Advancing management of urban forested natural areas: toward an urban silviculture?

**Max R Piana[1*], Clara C Pregitzer[2,3], and Richard A Hallett[4]**

**Cities worldwide are engaging in large-scale greening projects motivated by the wide range of documented ecological, economic, and social benefits of urban forests. Urban forested natural areas are a critical component of the total urban forest but are often overlooked and typically lack formal management frameworks. One approach to addressing this deficiency may be to borrow from traditional ecological management frameworks and practices (that is, silviculture). Although urban forested natural areas share similarities with rural forests, the impacts of urbanization on forest stand dynamics may require modification of these methods and in some cases development of novel silvicultural guidelines. We present an urban silviculture framework through which we synthesize emerging research and identify challenges and opportunities for advancing goal setting, assessments, and on-the-ground management strategies. Adapting silvicultural practices to cities can improve the long-term sustainability of urban forests and establish management approaches that address future conditions in forests across the urban–rural continuum.**

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Urban forests are commonly defined as "all trees in the city", a characterization that does not distinguish between site type and structure (NUCFAC 2015). We suggest that the urban forest can be broken down into subcategories of site types that differ in structure and management approach, including but not limited to street trees, landscaped park and yard trees, and urban natural areas (Figure 1). Distinguishing between urban forest types is important when defining management goals and strategies. Street and park trees are typically managed on an individual basis by arborists, often exist within a closed tree pit or mowed lawn, and are replaced when they die. Arborists have well-defined management guidelines that focus on safety and sustainability within the confines of the built environment (eg International Society of Arboriculture certification program), but there are no such guidelines or practitioner certifications for urban forested natural areas. Here, we examine the potential to apply the concepts of traditional ecological management and silviculture to urban forested natural areas, and the extent to which such approaches may need to be modified to accommodate the complex socioecological dynamics of urban systems.

## In a nutshell:

- The "urban forest" includes all trees within a city, from street trees to natural areas; these greenspace types are not the same and require distinct management strategies
- Because urban forested natural areas are more similar to rural forests than other urban greenspaces, traditional ecological management approaches may be suitable
- Given the socioecological dynamics of cities, traditional forest assessments, objectives, and management strategies may need to be modified and novel silvicultural tools created
- Urban adapted silvicultural practices can support greening goals in cities and may inform future management in nonurban forests confronted by human encroachment and disturbances

*[1]Department of Environmental Conservation, University of Massachusetts–Amherst, Amherst, MA [*](max.r.l.piana@gmail.com); [2]The Forest School, School of the Environment, Yale University, New Haven, CT; [3]Natural Areas Conservancy, New York, NY; [4]US Department of Agriculture Forest Service, Northern Research Station, New York City Urban Field Station, Bayside, NY*

Replete with dead wood, a regenerating understory, and structural complexity, urban forested natural areas differ ecologically from street and park trees and represent an important cultural and ecological component of cities in forested biomes (Panel 1; Figure 2). Defining what constitutes an urban forested natural area is therefore important to mapping and quantifying these areas, creating policies, and describing management options. For our purposes, we define urban forested natural areas as places where (1) trees are the dominant vegetation type, (2) natural regeneration and establishment of woody species can occur and is often the dominant form of woody plant recruitment, (3) there is no regular human-directed maintenance activity or disturbance that limits the establishment of woody species (eg mowing). These habitats are fundamentally similar to rural forest stands structurally (Pregitzer *et al.* 2019a), and plant health and productivity are driven by patterns and processes common to forest ecosystems.

Although akin to their rural analogs, urban forested natural areas are vulnerable to the many social and biophysical stressors of urban landscapes. Urban environments typically feature altered temperature and precipitation regimes, invasive flora and fauna, environmental contamination (both atmospheric and terrestrial; eg elevated carbon dioxide, ozone, nitrogen deposition, heavy

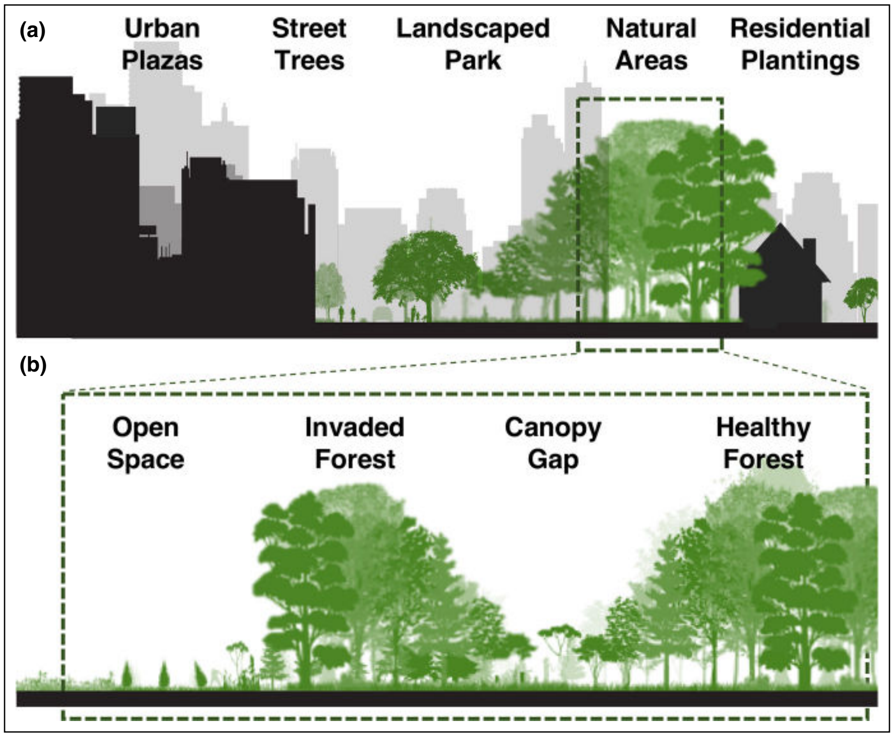


**Figure 1.** (a) In its broadest sense, the urban forest includes multiple greenspace types, from constructed sites with single plantings to natural areas and woodlands; (b) for cities in temperate and forested biomes (eg in the northeastern US), urban forested natural areas can be organized into subcategories related to forest condition and more appropriate for specific forest management prescriptions. We include areas targeted for afforestation, such as open space and abandoned parcels. Note that we use the term "healthy forest" to broadly characterize "a condition of forest ecosystems that sustains their complexity while providing for human needs" (Sampson *et al.* 1994). The characterization of urban forested natural areas will vary across biomes and sociopolitical contexts.

metal loads), and direct and indirect human activity (Pickett *et al.* 2011; Johnson *et al.* 2020). These anthropogenic forces are not unique to urban systems. However, they often co-occur and can be exacerbated in cities, leading to altered forest function, composition, and structure. Recent research suggests that urban conditions may impact plant populations throughout their life history, from seed production to dispersal to adult establishment, potentially shifting plant community dynamics and trajectories (Piana *et al.* 2019). These dynamic changes can result in a greater abundance of nonnative seedlings and dissimilarity between canopy and seedling layer composition and potential shifts in forest community trajectories as compared to nearby rural forest equivalents (eg Pregitzer *et al.* 2019a; Piana *et al.* 2021). Notably, the context of urban forested natural areas may vary, from a forest located in a dense urban core to a woodlot located at the urban–wildland boundary, and therefore the intensity and co-occurrence of urban stressors may also differ. Urban ecologists have only recently begun to examine how forest structure, diversity, and function may (or may not) vary in these different urban contexts and across the different gradients of anthropogenic influence.

Even with these potential differences, urban forested natural areas meet many of the criteria described by conventional definitions of

**Panel 1. Why do urban forested natural areas require special attention?**

Urban forested natural areas are a common and important contributor to the ecosystem services of cities located in forested biomes (Figure 2). Natural areas are a dominant form of urban parkland, accounting for 84% (~1.7 million acres) of parkland within the 100 most populous US cities (Harnik *et al.* 2017). Forests frequently dominate these natural areas; for example, forests compose more than 70% of the total natural area in New York City, representing 5.5% of the city's total land area and ~25% of all parkland (Pregitzer *et al.* 2018). Urban forested natural areas are important because they often provide a disproportionate amount of ecosystem services to cities (Mexia *et al.* 2018) and a unique set of benefits within the urban context, including support for local flora and fauna, opportunities for nature-based recreation, and specific human health benefits linked to spending time in nature. From a conservation perspective, these sites are known to harbor high native plant diversity and provide important wildlife habitat (Lepczyk *et al.* 2017). Indeed, the value of urban forested natural areas may extend beyond the boundaries of a city, contributing to broader regional biodiversity and conservation efforts.

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**Figure 2.** Urban forested natural areas, like this one in Inwood Hill Park in New York City, provide multiple social and ecological services for city residents.

forests, and therefore opportunities exist to draw from traditional ecological forest management and silvicultural practices to reimagine best practices in these spaces. Recognized as the oldest conscious form of applied ecology to meet anthropocentric management goals, silviculture is informed by a deep understanding of forest silvics (eg the life history, growth, and ecology of a species), community dynamics (eg succession), and natural disturbance regimes (Ashton and Kelty 2018). Through this ecological understanding, prescriptions and operational treatments are developed that manipulate site conditions and forest community dynamics to promote a desired forest structure and composition. Applied to forests of different types and confronted by natural and human driven disturbances (eg fire, harvesting, wind throw), silviculture is a paradigm grounded in a data-driven and long-term understanding of ecosystem function and management performance that may be easily transferred among similar forest systems and contexts. Despite the clear need and opportunity to apply silvicultural principles to urban forests, a comprehensive silvicultural framework has yet to be formally proposed for or applied to urban forested natural areas.

In the US, there has been a reliance on planting and techniques associated with arboriculture or restoration ecology, thereby representing a limited number of treatment options available to foresters. In other parts of the world, especially Europe, there is a long history of applying traditional silvicultural methods in urban contexts, particularly in periurban woodlots, which may have had decades of formal forestry management (von Gadow 2002; Konijnendijk *et al*. 2006; Duinker *et al*. 2017; Gundersen *et al*. 2019). Still, even in these cases there is a lack of operational-scale experiments that allow for robust evaluation of management methods (von Gadow 2002) and in turn, effective knowledge transfer of best management practices as is observed in other silvicultural systems. Furthermore, differences in the urban environment may be found to influence forest dynamics such that common forest practices associated with regional, nonurban forests may be inadequate. In such instances, novel management approaches may be required to maximize the resilience, health, and productivity of these forests. Whether a distinct urban silviculture is needed is therefore a valid and important question.

Recognizing this, we present a conceptual framework for incorporating traditional ecological forest management, adaptative management, and silvicultural practice (Figure 3) into urban settings, including (1) forest assessment methods, (2) management objectives and goal setting, (3) vegetation management practices, and (4) monitoring and evaluation. Through this framework, we synthesize emerging research and practice of urban silviculture, identify critical knowledge gaps, and highlight opportunities for adopting or adapting traditional forest management methods and applying them to urban forested natural areas. Our main concept – applying silviculture to urban forested natural areas – has universal relevance, but how this framework is implemented will differ across biomes and socioecological contexts. While we present examples from across geographies and forest systems, this is not intended to be an exhaustive review and specific examples often focus on temperate forests of the US.

## What do you have? Urban forest assessment

Forest assessments, which may occur at multiple spatial and temporal scales, are the foundation upon which all ecological management needs are understood. Well-established approaches for forest assessment include type mapping, forest inventories, and even projective modeling (Ashton and Kelty 2018; Janowiak *et al*. 2018). Traditionally, forest mensuration or inventory focuses on determining such attributes of logs, trees, and stands as abundance, volume, and/or condition (eg sawtimber quality; Graves 1906). Graves (1906) did not overstate when he wrote that the science of forest mensuration "lies at the foundation for all practical work in the woods". Indeed, the primary objective of forest mensuration at any scale is to provide quantitative information for decision making. Furthermore, as the scope of forestry widens and its horizons grow, new measurement problems emerge (Husch *et al*. 1972). This is particularly relevant when one considers management strategies for urban forested natural areas.

To date, the "measurement problem" of inventorying urban forested natural areas has been influenced by the general definition of "all the trees in the city". Many cities have begun to use i-Tree Eco and urban Forest Inventory and Analysis (FIA), two plot-based sampling methods, to assess the urban forest at the city scale and provide information about trees across all urban cover types. Although useful for raising public awareness about trees in the city, these sampling approaches are not necessarily effective for characterizing forested natural areas (Pregitzer *et al*. 2019b), or prescribing community- or stand-specific management strategies. Traditional forest inventory sampling strategies often focus on stratifying areas of interest by forest type, stand age, and size class, providing quantitative information for targeted forest management strategies. This is relevant to the urban forest, as managers and policy makers are now recognizing the value of urban forested natural areas, prompting a discussion about best inventory strategies to determine the location, extent, and composition of this often-overlooked greenspace (Gulsrud *et al*. 2018). Emerging approaches use land-cover data, LIDAR, and multispectral imagery data to create urban tree canopy maps and delineate forested natural areas (eg Li *et al*. 2019). These techniques have made it possible to create ecological community type maps and modified dichotomous keys that include both regionally common and novel forest types, as well as information on stand condition and a city-wide inventory of all forested natural areas (eg Edinger *et al*. 2016; Forgione *et al*. 2016). This work supports stand assessments oriented toward designing management strategies, such as stocking indices and potential for advance regeneration (eg Piana *et al*. 2021).

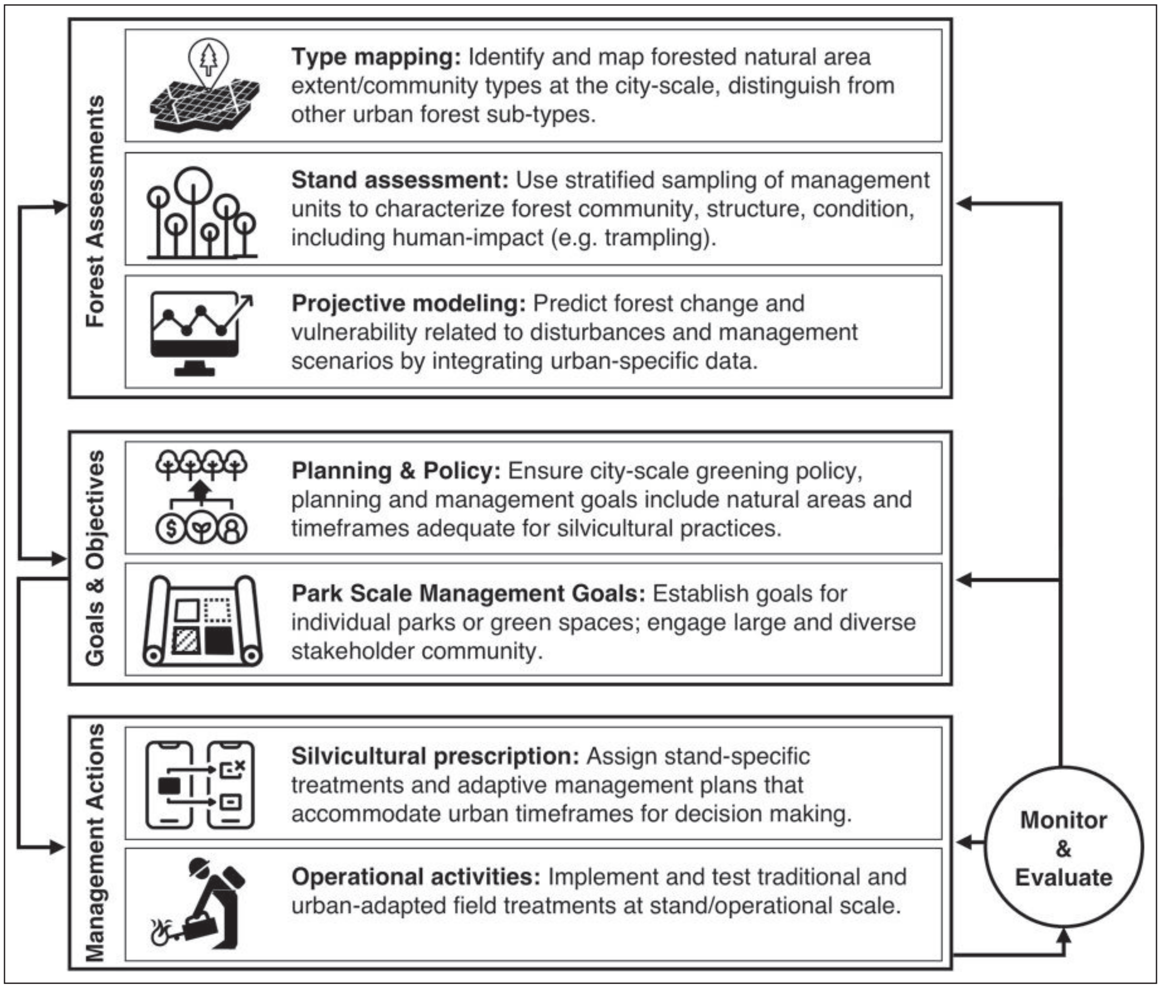


**Figure 3.** A silviculture framework adapted to urban forested natural areas. Clearly articulated goals, assessments of current and future conditions, and resources for implementation of management strategies are all important for sustaining urban forested natural areas and achieving greening objectives.

In addition to these inventory methods, there are urban-based vulnerability assessments that look toward future threats (Brandt *et al*. 2016; Steenberg *et al*. 2017). Such assessments use distribution models to identify species vulnerable to, resilient to, or present due to climate change (Brandt *et al*. 2016). These efforts provide important baseline information that can guide species selection for managers. However, cities could benefit from process-based models commonly used in nonurban systems to assess how forest composition and structure might shift in response to disturbance, climate change, and management strategies (eg Janowiak *et al*. 2018). Parameterizing urban process-based models will require improved understanding of urban forest composition, structure, and community dynamics at the landscape and local scale.

### Future directions for research and practice

- Develop high-resolution mapping techniques that delineate forested natural areas and community types in cities.
- Develop rapid stand assessment and classification systems for urban areas.
- Parameterize or modify process-based forest ecosystem models for urban sites to project future forest structure, composition, and species vulnerability.

## What do you want? Urban forest goal setting and objectives

Clearly defining management goals and objectives that range from forest-wide to individual stand or management units is critical to designing effective management frameworks and silvicultural prescriptions. Silvicultural practices are varied and focus on improving or maintaining the health and productivity of forest stands over time. While traditional silviculture is primarily associated with growing trees for timber management and harvesting, in reality silvicultural objectives are limited only by the goals and associated values of stakeholders and society. Prescriptions may therefore be designed to manage for any number of ecosystem services, from maintenance of critical wildlife habitat, drinking water supplies, timber, and non-timber products, to remediating contaminated sites (Ashton and Kelty 2018). Goals and objectives that are measurable, specific, and associated with current conditions, desired future conditions, and realistic targets will be the most effective (https://conservationstandards.org/about).

In North America, urban forest programs typically have three main goals: increasing (1) urban tree canopy (UTC) cover, (2) species diversity, and (3) tree sizes (Ordóñez and Duinker 2013). These goals emphasize ecosystem services generated by urban forest canopy. For forest managers, goals and objectives may focus on maintaining or expanding UTC cover and the number of acres managed and maintained. In addition to these vegetation-specific goals, social themes relating to community partnerships and education are also common in municipal plans. For example, public access to greenspace (not just natural areas) has become an environmental justice issue, and citywide objectives now often focus on establishing minimum distances to greenspaces for all residents (Mekala and Hatton MacDonald 2018).

Increasingly, cities are moving beyond UTC cover and setting more ecologically framed goals, although they remain operationally vague. A review of more than 135 city plans found that municipalities worldwide have established broad ecological and sustainability-based goals that relate to biodiversity conservation (such as habitat conservation and ecological connectivity) but that most lacked quantitative targets (Nilon *et al*. 2017). Urban forested natural areas are critical for achieving such goals, and the classic conservation questions of "how much", "where", and "what" are being applied increasingly to urban greenspaces (eg Beninde *et al*. 2015). Another critical challenge for urban forest managers is how to frame objectives in the face of climate change and uncertainty. There are similar frameworks that consider three broad management goals, each of which may be valid in an urban context, including restoration to reference communities, promoting resilience or resistance to environmental changes, and adaptive goals that focus on transitioning forest communities to projected conditions (Rissman *et al*. 2018). Originally designed for different forest systems in nonurban settings, adaptive frameworks have begun to be applied to urban forests to define operational objectives (Brandt *et al*. 2016). Moving forward, the goal for urban forested natural areas may be to increase species diversity and structural complexity. This may require tree removal to establish multi-aged stands and increase heterogeneity, which could conflict with current city-scale UTC cover goals.

Approaches to sustaining native and ecologically robust urban forests are mired in the idiosyncrasy of complex urban systems and limited data (Cortinovis and Geneletti 2018). This complexity generates gaps in knowledge and planning that must be filled to inform the setting of effective urban conservation policy and goals, at both citywide and operational scales. Defining forest- and stand-specific goals will benefit from advances in assessment described previously. In nonurban forests, management objectives operate on relatively long time scales (50–100 years) and are often driven by return on investment, harvesting cycles, and/or tree species longevity. In contrast, urban land-use change and decision making occur rapidly, which restricts the time frame or expectations for achieving goals. An important question is whether the disconnect in time frames for urban decision making and ecology of trees and forest communities (eg time from growth to maturity and succession) present a fundamental barrier to applying silviculture in urban forests; this highlights how urban silviculture may need to draw from multiple paradigms (eg adaptive management, arboriculture) and distinguish itself from traditional practice.

### Future directions for research and practice

- Define distinct goals and objectives for urban forested natural areas that operate at multiple scales, including citywide, forest site, and stands.
- Define objectives for forests and stands that are measurable, specific, and associated with current conditions and realistic targets.
- Define short- and long-term goals accounting for current and future needs, environmental conditions, and urban time frames.

## How do you get what you want? Urban forest management treatments

Silviculturists draw from a suite of treatment options that range in intensity with respect to site and stand manipulation to achieve their management goals and objectives (Ashton and Kelty 2018). Treatments are determined from an understanding of forest population and community dynamics, referred to as "stand dynamics" (Oliver and Larson 1996). Natural regeneration can be promoted by creating favorable site conditions for establishment; alternatively, sites may be artificially seeded or planted. Designed disturbances that emulate natural perturbations (eg fire, windthrow) are often used to mimic natural disturbance and manipulate biophysical conditions to promote or inhibit select species and communities (Kern *et al*. 2017; Ashton and Kelty 2018). For example, single trees may be removed to create forest gaps, or larger patch cuts or clear cuts implemented to support species that thrive in open conditions. Each of these approaches is informed by an understanding of individual site conditions, as well as the population and community dynamics of the desired species (Oliver and Larson 1996; Ashton and Kelty 2018).

A survey of over 100 cities across the US revealed that the most common on-the-ground management activities for forested natural areas consist of reestablishing native trees through planting and removing invasive species (Pregitzer *et al*. 2019c). Planting trees and invasive species removal can be expensive and resource intensive; for example, planting an acre of trees in New York City costs between $75,000 and $162,000 (Pregitzer *et al*. 2018). Studies examining the long-term effectiveness of these management strategies are relatively new, and suggest that such interventions improve forest structure and composition (eg Simmons *et al.* 2016; Sasaki *et al.* 2018; Wallace and Clarkson 2019). Less common are controlled comparisons and monitoring of different management approaches, although there is a recognized need for strategic and long-term monitoring to advance evidence-based management and assess forest change over time (Ordóñez and Duinker 2013). In one such instance, researchers determined that the level of intervention is important and that planting alone might not achieve restoration objectives unless paired with ongoing upkeep and invasive plant removal (Simmons *et al.* 2016).

A fundamental question in urban forest management is what alternatives to planting can be most effective at establishing desired forest structure and composition. Silviculturists rely on a base of knowledge informed by long-term scientific studies to inform prescriptions and management decisions (Oliver and Larson 1996; Ashton and Kelty 2018). Similar understanding of urban forest stand dynamics (such as the potential for natural regeneration or the response to management prescriptions) is emerging but remains limited (eg Piana *et al.* 2021; Witt *et al.* 2020). In cities, species-specific responses and the ecological thresholds to the multitude of socioecological stressors need to be determined (ie urban forest stand dynamics). In turn, we may better understand if alternative management approaches are needed to accommodate both the ecological (Panel 2; Figure 4) and social (Panel 3) contexts of urban forests. Emerging applied research and municipal activities formally (and informally) advance ecological knowledge and management options, borrowing from established methods of forest management in existing stands (such as thinning, urban-adapted burn treatments, and broadcast seeding), as well as novel strategies for creating forest on degraded land (Table 1; Oldfield *et al.* 2015; Pregitzer *et al.* 2019c). In Chicago, Illinois, researchers have developed the Urban Forestry Climate Change Response Framework, which is designed to bridge the gap

**Panel 2. How might silviculture treatments be modified to suit the context of urban forests?**

The appropriateness of different silviculture treatments in urban settings may vary, and given the complex socioecological context of these areas, may require modification. In temperate forests of the Northeast US, gap-based silviculture treatments (eg group selection, irregular shelterwood; Figure 4a) are common forest management approaches (Kern *et al.* 2017; Ashton and Kelty 2018). These techniques establish small gap clearings that create microsite conditions for establishment of desired species, and therefore rely on natural regeneration. Implemented across a landscape, these strategies can enhance the structural, compositional, and functional diversity of the forest. If the goal is to increase resilience within urban forests, such an approach may be appropriate, but ecological barriers (eg rapid invasion by herbaceous and liana species) may limit success and inhibit new tree establishment (Figure 4b). As a result, urban group selection or shelterwood may need to occur with secondary plantings and treatments. For example, could rapid growing pioneer trees be planted to accelerate canopy closure, suppress the establishment of invasives, and act as nurse crops for desired later-successional trees? As an alternative to planting large caliper trees, might managers supplement clearings with broadcast seeding or seedling planting? In this example, operational-scale research is required to understand performance of different gap sizes, establishment strategies, and species performance.

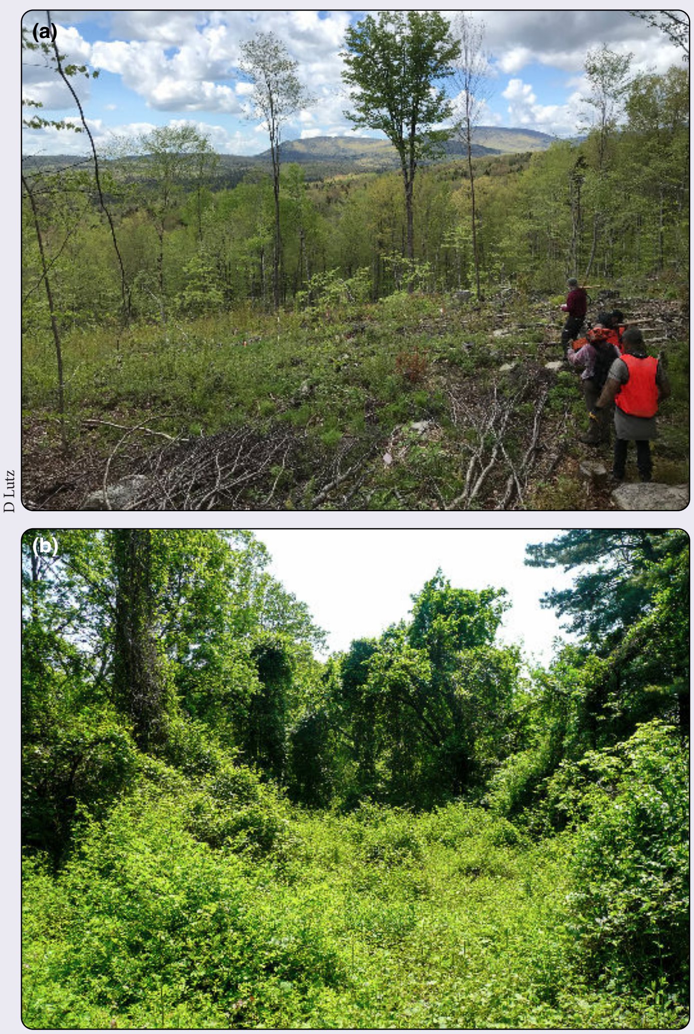


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**Figure 4.** (a) Gap-based treatments – such as those tested at the Adaptive Silviculture for Climate Change (ASCC) demonstration study at the Dartmouth College Second College Grant, New Hampshire – are a common approach for temperate forest silviculture in the US Northeast. (b) Gaps in urban forests are often rapidly invaded by plants (eg vines) that persist and may suppress natural regeneration of trees and forest succession; as a result, traditional prescriptions may need to be modified to support canopy closure and tree establishment.

**Panel 3. How must urban silviculture engage and respond to urban communities and social systems?**

Public perception and communication of ecological management strategies is an inherent challenge to forestry and land stewardship. The response from people to management actions in urban forested natural areas may be magnified, as these sites are embedded within human-dominated landscapes. This phenomenon was realized soon after the creation of many urban forest parks in the US. The famous landscape architect Frederick Law Olmsted recognized both the need to study and develop science-based management within designed and urban forest spaces, as well as the resistance of the general public – even when environmentally motivated – to active forest management in large forest parks in cities (Thoren 2014). Similar public responses were observed in Chicago, Illinois, and the surrounding county in the 1990s in response to proposed forest restoration activities, and as a result a moratorium was placed on tree removals (Gobster and Hull 2000). The need for active forest management in urban forested natural areas is heightened, but how this work is achieved in the public realm remains a critical management hurdle. Managers may benefit by drawing from community forestry methods commonly used in public spaces, such as streets and vacant lots. Based on the concepts of community development and planning, these approaches rely on stakeholder engagement methods to help define management goals and educate residents on the ecological principles driving these actions (Ordóñez *et al*. 2019). In addition to residents, urban silviculture will also benefit from integrating the expertise of other urban practitioners, such as planners, designers, and engineers. For example, what is the role of a landscape architect in large-scale forest practice in urban parkland? Can design mask management and communicate intent? If we look back at Olmsted, as a designer he clearly identified the critical need for long-term research to be integrated into these sites in order to develop knowledge-based management and treatments. We might also ask, what is the impact of forest management on people? Today, such thinking may be found in the concept of designed experiments, which have to date been most successfully integrated into large-scale urban afforestation experiments (Felson *et al*. 2013). Similarly, ecological managers may benefit from the input of designers and planners.

between assessment and action and focuses on vulnerability to climate change (Brandt *et al*. 2016). Nevertheless, there is a fundamental gap in applied research in urban forests and a need for operational-scale tests of traditional and novel silviculture treatments.

This work will benefit from collaboration and engagement with practitioners and scientists operating outside of the city. Silviculture is shifting to incorporate concepts of resilience and adaptation (Puettmann *et al*. 2012; Fahey *et al*. 2018) and modify traditional approaches to address complex human modified disturbance regimes, climate change, and biotic invasion (eg Kern *et al*. 2017; Janowiak *et al*. 2018). However, these new concepts have not been widely adopted into research (Fahey *et al*. 2018). There

**Table 1. Urban silviculture goals, strategies, and challenges organized by forest condition and structure**

| Management unit | Goal | Challenges | Opportunities | Potential silviculture treatment |
|---|---|---|---|---|
| Open space and nonforest landscapes | Establish new forest, expand existing forest, restore degraded sites without canopy | Tree establishment and survival, risk of invasion, degraded site conditions due to past land use (eg contaminated soil), existing informal social uses, high treatment costs | Increase forest cover in cities, connect existing forest stands, locate forests in areas of high need | Establishment treatments: direct seeding and planting, soil treatment (eg amendment), scarification (eg Oldfield *et al.* 2015) |
| Canopy gap | Canopy closure, promote natural regeneration of native species | Invasive plant species, locating gaps and acting expeditiously, multiple treatments needed over long time frames | Low cost interventions to maintain connected healthy forests | Establishment and regeneration treatments: direct planting and seeding, passive restoration via seed bank, weeding, minimizing invasion risk (eg Simmons *et al.* 2016; Wallace and Clarkson 2019) |
| Invaded forest | Shift community trajectory toward target forest type, promote natural regeneration of native species | Legacy site effects, multiple treatments needed over long time frames, costly, social perceptions, uncertain results | Increased social and ecological benefits, reduce seed source and spread of invasion | Intermediate and regeneration treatments: selective thinning/harvesting, direct planting and seeding, reliance on natural regeneration (eg Wallace and Clarkson 2019) |
| Healthy forest | Sustain native forest communities and promote future resilience | Prioritizing these sites when invaded forests seem like a greater threat, risk of biotic invasion | Protect healthy forests, ensure forest canopy into the future | Intermediate treatments: thinning, seeding, monitoring, shelter wood (eg Wallace and Clarkson 2019) |

**Notes:** examples of applied research are from temperate forest ecoregions in North America and New Zealand. At an operational scale, challenges, opportunities, and relative treatments will vary with region and will be coupled with practices common to nonurban equivalents.


**Figure 5.** Urban silviculture may not only draw from established forest management strategies, but may also serve as a model system for understanding different global change factors, and in turn inform more effective management of forests across the urban–rural continuum.

is an opportunity for research to span the urban–rural continuum, thereby supporting silvicultural treatments that address the challenges of multiple anthropogenic disturbances and a range of disturbance intensity. Indeed, there is an emerging perspective that supports the ecological study of cities as a bellwether for future conditions in nonurban ecosystems (Lahr *et al.* 2018). Applied research in the context of urban ecosystems may equip conservationists and practitioners beyond city limits.

### Future directions for research and practice

- Create replicable studies that investigate forest responses to urban conditions including novel disturbance regimes and urban-adapted silvicultural treatments, and the unique social and biophysical outcomes of forest management under these conditions.
- Explore the development of training and certification programs for urban silviculturists.
- Integrate adaptive management plans that address current and future climatic conditions and/or urban context and conditions.
- Develop effective monitoring plans for assessing long-term management performance and forest change.

## Conclusions

Although the tangible and intangible benefits that trees provide to the urban environment are now widely acknowledged, and despite the growing recognition that urban forested natural areas can make up a substantial proportion of the trees in a city, the management of this public resource remains limited and their long-term sustainability may therefore be at risk. Silviculture is not new, just new to cities. At the most basic level, we suggest that cities can benefit from the existing body of knowledge established for nonurban forested ecosystems; put more simply, forestry has a place in the management of urban forests. However, given the complex set of drivers that are either unique to or exacerbated in urban systems, we take this argument a step further and suggest that managing forests in the city demands innovative strategies be added to the silviculturists' toolbox. By rigorously applying silviculture science within cities, we advance applied ecological knowledge that may extend beyond cities and inform forest management across the urban–rural continuum. From climate change to invasion of exotic species, urban ecosystems provide a window into conditions that nonurban ecosystems will face in the future (Figure 5). Advancing an urban silviculture may therefore not only help to conserve ecologically and culturally valuable habitats in cities, but may also serve as a proactive step in advancing nonurban forest conservation practices in an increasingly human-impacted and uncertain future.

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