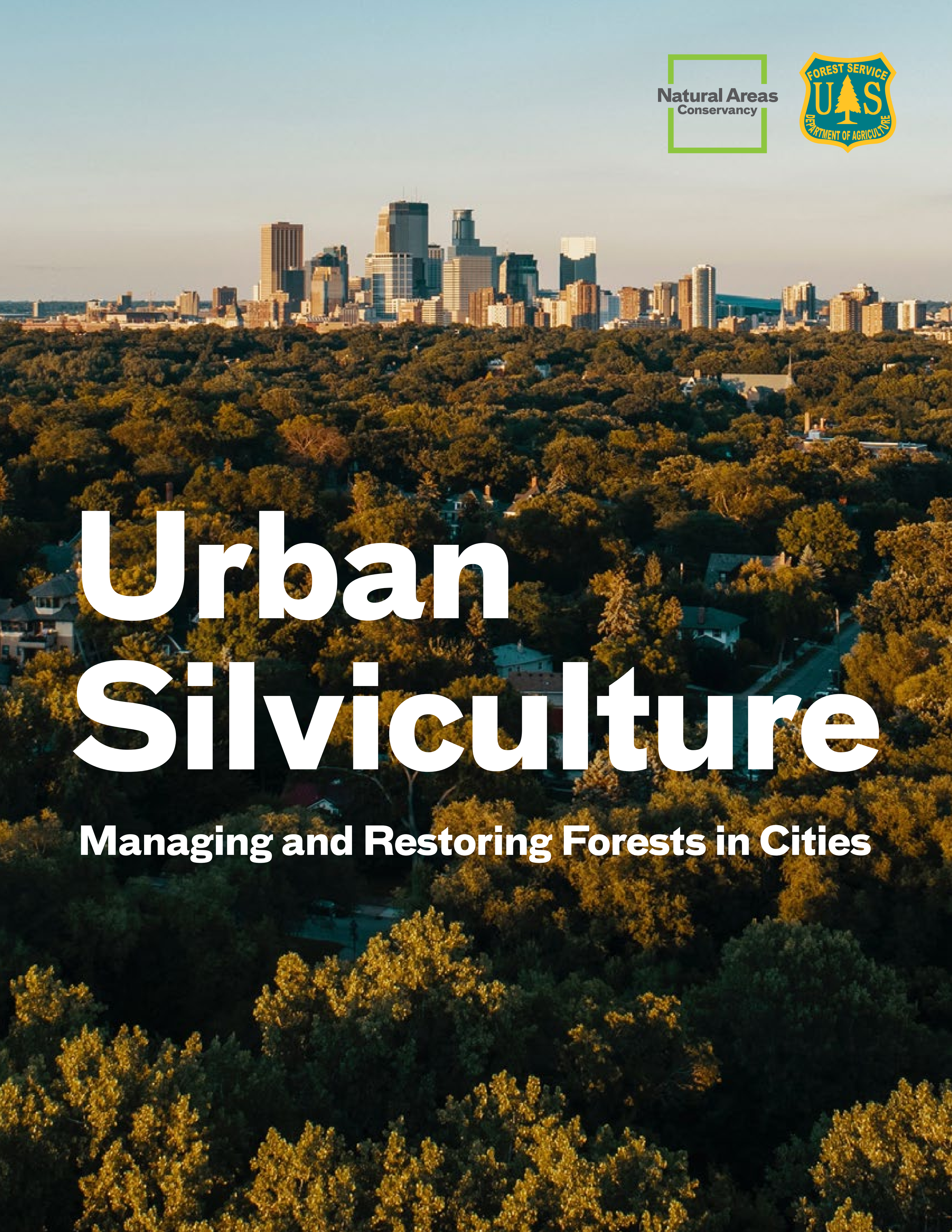
Natural Areas Conservancy

Forest Service U.S. Department of Agriculture



Urban Silviculture

Managing and Restoring Forests in Cities

Acknowledgments
This work was done in partnership with the United States Department of Agriculture Forest Service, the Natural Areas Conservancy, the Forests in Cities Network and partners.

Michael Andreu, *University of Florida*
Leslie Brandt, *USDA Forest Service*
Tony D'Amato, *University of Vermont*
Robert Fahey, *University of Connecticut*
Morgan Grove, *USDA Forest Service*
Constance Hausman, *Cleveland MetroParks*
James Duncan, *Miami-Dade County Environmentally Endangered Lands program*
Sarah Hines, *USDA Forest Service*
Brian Palik, *USDA Forest Service*
Nausheen Ipqual, *USDA Forest Service*
Kristen L. King, *New York City Department of Parks and Recreation*
Eliot Nagele, *New York Botanical Garden*
Linda Nagle, *Utah State University*
Joanne Rebbeck, *USDA Forest Service*
Todd Hutchinson, *USDA Forest Service*
Anna Waugh, *Mississippi River Park Connection*
Mary Hammes, *The Nature Conservancy*
Nicole Barbieri, *City of Gainesville*
Amy Witt, *Forest Park Forever*
Michael Yadrick, *City of Seattle Parks and Recreation*

Authors
Brittany M. Wienke, *Natural Areas Conservancy*
Clara C. Pregitzer, *Natural Areas Conservancy*
Helen M. Forgione, *Natural Areas Conservancy*
Sarah Charlop-Powers, *Natural Areas Conservancy*
Richard A. Hallett, *USDA Forest Service*
Max R. Piana, *USDA Forest Service*
Nancy Falxa Sonti, *USDA Forest Service*

Please cite this report as follows:
Wienke, B. M., Pregitzer, C. C., Charlop-Powers, S. A., Forgione, H. M., Hallett, R. A., Piana, M. R., Sonti, N. F. 2022. *Urban Silviculture: Managing and Restoring Forests in Cities*. Natural Areas Conservancy, New York, NY.

COVER
Minneapolis, by Robert Bye / Unsplash

BACK COVER
Gainesville, Florida by Brittany Wienke

All photos by NYC Parks or NAC unless otherwise credited.

Illustrations by Jen Shin.

Created in 2012, the Natural Areas Conservancy is a nonprofit organization devoted to restoring and conserving New York City's 20,000 acres of forests and wetlands in close partnership with the New York City Department of Parks and Recreation.

www.naturalareasnyc.org

Natural Areas Conservancy

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

Urban Silviculture

Managing and Restoring Forests in Cities

1234 Fifth Avenue | New York, NY 10029

September 2022

Dear Colleagues and Friends,

With more than half of the world's population living in urban areas, urban forests are widely recognized as essential to supporting healthy and vibrant cities. From mitigating extreme heat, to providing nature-based experiences for city residents; forests in cities provide ecological, social, and economic benefits that have become a cornerstone in city sustainability and planning. In order to ensure these benefits, it is critical to care for urban forests using approaches that are informed by their condition and context.The Natural Areas Conservancy is pleased to publish *Urban Silviculture: Managing and Restoring Forests in Cities*. This guide connects the dots between management practices in forests within cities and outside of cities. Forests across the urban/rural gradient are ecologically similar, and face similar challenges related to climate change and invasive species. These pressures increase the need for ongoing forest care and management. Silviculture, a holistic framework for managing forests, can provide a pathway for managers to keep forests healthy and resilient.

The guide provides an overview of how a silvicultural framework and practices can be applied to urban forested natural area management. The contents are informed by our work in New York City, as well as the work of partners across the nation including members of the Forest in Cities Network (naturalareasnyc.org/national). The *Urban Silviculture* guide comes at a time when interest in urban forestry is at an all-time high; it is our intention that the information included here can catalyze managers to leverage new public interest, existing science and research, and time-tested approaches to ensure the long-term health of urban forested natural areas.

As we look into the future and see a world that is becoming more urban, warmer, and more unpredictable, protecting and managing forests feels ever more urgent. Forests in cities may not rival the vast wilderness areas, or rural national forests in number of hectares, biomass, or timber products; but they do play an important role in contributing to our society and our understanding of forest ecosystems broadly. By working together we can continue to build a community of practice that meets the needs of the challenges faced in the forestry community within and across forests in all settings.

Sincerely,

Sarah Charlop-Powers
Executive Director, Natural Areas Conservancy

Clara Pregitzer
Deputy Director of Conservation Science, Natural Areas Conservancy

Brittany Wienke
Conservation Science Project Manager, Natural Areas Conservancy

United States Department of Agriculture

Forest Service

Research and Development

Sustainable Forest Management Research
Forest Service
201 14th Street SW
Washington, DC 20250

Natural Areas Conservancy
1234 Fifth Avenue
New York, NY 10029

In this changing and growing world, more people are living in urban areas than ever before. Green space in cities is critical to the health and wellbeing of the urban population, and forests in cities are woven in the urban landscape. We are learning that these urban forest patches are governed by many of the same patterns and processes as their rural cousins, and that these forests need similar care and attention, with specific adaptations for urban challenges.

This handbook provides a guide to that care, leaning on the expertise of the US Forest Service in both rural and urban silviculture. The US Forest Service provides leadership in the protection, management and use of the nation's forest, rangeland, and aquatic systems. The mission of the Forest Service is to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations. The long-term experiments of the USFS have informed forest management practice and environmental policy since 1908. Inspired in part by the experimental forests, a growing body of work examining specific dynamics of forests in urban settings provides the basis for urban silviculture. At a broader scale, frameworks are being developed for adapting urban forests to altered temperature and precipitation regimes, invasive flora and fauna, environmental contamination (both atmospheric and terrestrial; eg. elevated carbon dioxide, ozone, nitrogen deposition, heavy metal loads), and direct and indirect human activity.

Regardless of size, forests must remain healthy to fully realize their potential to provide a wide variety of socio-ecological benefits. Our research indicates that these urban forested natural areas or patches are distinct from street and park trees both in how they need to be managed and how they are perceived by the surrounding community.

This guide is an important step towards promoting a silvicultural systems approach to managing forests in cities by adapting traditional silvicultural approaches applied to our rural forests to the realities of the urban environment. In addition, this work has already fostered a dialogue between urban and rural forest managers focused on sustainable forest management in the face of anthropogenic forces which may not be unique to urban systems but co-occur and can be exacerbated in cities leading to altered forest function, composition, and structure. As we learn more about how to manage forests in cities where the climate and other stressors have already changed the forested environment, we are taking steps to build a community of forest managers in both urban and rural settings that will enhance our knowledge to manage all forests. And in so doing, we are honoring our mission to sustain all forests to meet the needs of present and future generations regardless of where they live.

Thomas M. Schuler
National Program Leader for Silviculture Research

Contents

Figures

Tables

Sidebars

Case Studies

Appendices

New York City

New York Botanical Garden

Executive Summary

In cities across the United States, forested natural areas account for the majority of urban greenspace. These forests in cities require care and management to stay healthy and provide ecosystem benefits. Silviculture, a holistic framework for managing forests that is widely used in rural areas, can also be used to manage forests in cities. This guide provides a brief introduction to silvicultural practice, and shows how it can be used to manage forests in cities for sustained and increased benefits through case studies and practical tools for urban forest managers.

For some, the concept of silviculture might evoke images of forest products, timber, and vast tracts of forest in rural settings. But increasingly, silviculture is used in forested natural areas within cities. Natural areas account for the majority of urban parkland (68%) in the United States, meaning that natural resource management practices, including silviculture, have a place in large metropolitan regions. Moreover, urban areas in the U.S. are expanding, meaning that more forest land is now found within or in close proximity to urban areas, and these techniques will become increasingly relevant.

This guide provides an introduction to silvicultural systems with particular emphasis on how they can be applied to and benefit urban forested natural areas. The guide also connects these concepts to silviculture in rural areas. With increasing urbanization outside of America's core metropolitan areas, lessons learned from working in an urban context could provide important information to forest managers outside of cities. Additionally, urban areas can serve as a bellwether for future climate changes in rural areas, and looking to urban forests may help suburban and rural forest managers incorporate management approaches that foster resilience to impacts from climate change, invasive species, and fragmentation (to name a few).

Organizations working in urban forestry and conservation have pioneered approaches to sustain and direct the growth of urban forested natural areas. Many of these groups have authored sophisticated management plans and have adapted silvicultural techniques to enhance the health, diversity, climate resilience, and longevity of urban forests. Case studies from this body of work, and references to their management plans, are included throughout this guide to ground the concepts in the real world.

Our goal is to show that silvicultural practices can be adapted to manage urban forested natural areas for the long term. We want to expand the toolbox for urban forest managers to include traditional silviculture strategies and tactics used outside of cities, and opportunities that exist between rural and urban practitioners. Ultimately, managing an urban forested natural area is about caring for and preserving the forest so it can continue to be a source of delight, wonder, and discovery for urban residents, and provide a raft of ecosystem benefits for cities.

Who is the Audience for this Guide?

The silvicultural framework presented in this guide translates to activities in urban forested natural areas in the United States, from publicly-funded and managed urban parks to private lands and everything in between. This guide is intended to help urban natural resource professionals, but is meant to be accessible to anyone interested in the management of forests in cities.

In addition to readers in urban areas, this guide strives to connect the dots between forest practices across the urban-rural gradient. Acknowledging the similarities between urban forested natural areas and rural forests, and exchanging case studies and techniques between both settings, can help inform a broader understanding and community of practice. Additionally, the impacts of climate change and multitude of other disturbances (pests, diseases, non-native invasive species) are often experienced first or more acutely in urban settings.[1] For this reason, urban-adapted silviculture practices may be able to help forest managers outside of city settings prepare for future and novel conditions.

How Can This Guide Be Used?

Approaches to managing forests in cities reflect the differences in climate, social and political context, and ecosystems of the cities they are within. A forest in Houston, Texas, may require a different management approach than a forest in Baltimore, Maryland, or Boise, Idaho. As such, this guide will not provide silvicultural prescriptions to urban forested natural area management. Specific management recommendations will need to be generated locally. However, since the underlying principles of silviculture are broadly applicable across forest types, this guide will help managers think through their forest management planning at a high level.

To that end, this guide offers a framework for conducting silviculture in urban or community settings, starting with assessment, to planning and goal-setting, operations, and monitoring. Throughout the guide are silviculture case studies from urban, suburban, and rural forests across the country. These examples show how silviculture has been used to deal with management challenges such as non-native invasive species and climate adaptation. They also show that more intensive management interventions, such as thinning or prescribed burning, are possible and even necessary in urban contexts. The examples contained in this guide can be used to explain and justify the need for such management to elected officials and other leadership positions. Additionally, terms are defined throughout the guide to explain silvicultural terminology and connect it to the realities of urban and community settings.

Readers will find some practical tools at the end of the guide such as a checklist outlining data, equipment, and skills needed to execute silviculture, and a silvicultural prescription template, ready to be adapted to individual urban contexts.

West Hollywood, California

Ariel Blanco / Unsplash

Fire maintained Sandhill Community in the Wildland Urban Interface at Julington-Durbin Preserve, Jacksonville, FL

Sarah Tobing

Introduction

What Are Urban Forested Natural Areas?

Urban forested natural areas look and feel like the woods: trees are the dominant form of vegetation, natural regeneration takes place and is often how dead trees are replaced, and there is no regular management to prevent regeneration from growing (e.g., mowing).[2] Forested natural areas are common in urban areas, ranging in size from less than 1 acre to several hundred acres, and account for over 1 million acres in U.S. cities alone.

Cities across the United States usually contain landscaped parks, street trees, and natural areas, often collectively referred to as "the urban forest." The trees in these various spaces are very different from each other. For example, street trees and trees in landscaped parks receive care on an individual basis using arboriculture practices and are generally replaced with planted trees when they die.

In contrast, the complex, multi-strata structure of urban forested natural areas is similar to rural forests and is governed by similar ecological processes.[3] Also like rural forests, urban forested natural areas provide a suite of important ecosystem services: carbon capture and storage; urban heat mitigation; removal of air pollution and particulates; stormwater capture; and habitat for biodiversity. Due to their proximity to many more people, urban forested natural areas offer disproportionally high benefits in comparison to rural forests areas; because of their complex structure, they also offer benefits at a higher rate than other types of urban forest.[4]

Urban forested natural areas are often mistakenly presumed to be small, degraded patches of vegetation, dominated by non-native invasive species. However, a 2021 survey of 12 cities across the United States showed that many natural areas are in fact dominated by native species and are in high ecological health. An in-depth ecosystem assessment of New York City's natural areas showed that the majority of the natural area canopy is composed of native species, and stores carbon at a rate comparable to rural forests.[5]

Urban forested natural areas are sites of respite and relaxation for urban residents; sources of "nearby nature" for people in dense cities; and opportunities to socialize, create, and explore through trails. Increasingly, policymakers and the public are recognizing the value of these spaces as critical infrastructure for a healthy, livable city.

Another common misconception about forested natural areas in cities is that the forests will "take care of themselves." When faced with the challenge of prioritizing different municipal projects, officials often relegate forested natural areas to the bottom of the list, assuming that the trees will just keep growing another year. Though many forested natural areas are in good health, the pressures of the surrounding urban environment, magnified by the effects of climate change, mean that care and management must be ongoing. Without proactive, long-term management and care, the health of these natural areas may decline, along with the benefits they provide.

Fig 1. There are many types of tree canopy in an urban setting. Forested natural areas are different from other types of tree canopy, and require different care.
Jen Shin

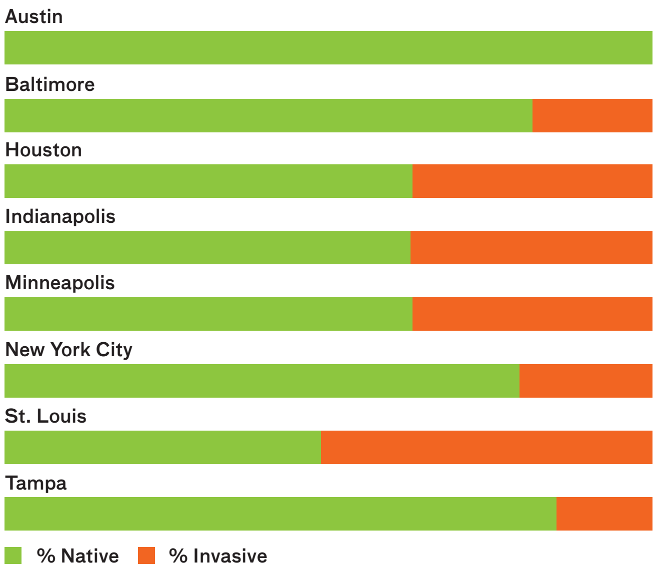
These photos illustrate the similarities in species composition and structure between urban and rural forested areas at a glance. Top, an young oak forest in Cuivre River State Park, Missouri; bottom, a vernal pool and oak forest in Forest Park, St. Louis.
Wikimedia Commons / Forest Park Forever

For example, without monitoring and management, urban forested natural areas may begin to host greater populations of non-native invasive plant species. These species prevent natural regeneration from growing into the mid-story and canopy, leading to eventual canopy loss and diminished ecosystem services. This scenario can create a feedback loop where one stressor or disturbance triggers another, and the essential character may be difficult and expensive to restore. Consistent management of urban forested natural areas is required to keep the forest healthy and visitors safe. We share real-life examples of this exact process from cities across the United States later in the guide.

Managing forests in cities is a complex task and requires a comprehensive approach. A significant proportion of cities with forested natural areas do not have plans to guide their management. In a survey of more than 100 urban natural area managers across the United States, only about half (55%) had a management plan in place to guide actions in urban forested natural areas. Unlike with street and other trees in developed landscapes where the field of arboriculture has developed standards and professional certifications for tree care, no such formal training exists for urban forested natural areas.

Forest management has enjoyed a long and rich history in the United States. Historical Indigenous management was practiced long before colonization and continues today. There is also a deep well of silvicultural knowledge informed by science and research. Given the similarities between urban forested natural areas and rural forests, there exists an opportunity for both to borrow from this lineage of practice, research, and evidence supporting silviculture.

Fig 2. A 2021 survey of cities across the U.S. shows that urban forested natural areas can be primarily dominated by native species.



Busting Common Myths About Urban Forested Natural Areas

Real forests are not common in cities. The "urban forest" is mostly just street trees and landscaped park trees.

The urban forest contains different types of tree canopy. Forested natural areas often contain most of the trees in cities, and most parkland in cities is comprised of natural areas.

When there are forests in cites, they are different from rural forests because they are small in area and of low quality.

Most forests in cites are dominated by native species, with large canopy trees established over 100 years ago. Some forests in cities are small, while some are hundreds of acres in size.

Forests in cities don't need management; they will take care of themselves.

Without management, protection, and monitoring, our forests will likely decline. The stressors of the urban environment and climate change impact the long-term health and viability of forests in cities. These impacts can be mitigated through proper management.

Silviculture is only used to harvest timber and is limited to rural areas.

Silviculture is a means to achieve specific goals for a forest, including goals related to wildlife habitat, recreation, forest health, and climate change adaptation. It can be practiced anywhere there is a forest, whether in cities or more remote areas.

The field of urban forestry is about tree planting and tree maintenance.

The urban forest includes many types of trees and tree canopy. Street trees, which are individually managed by arborists, are one type. By contrast, managing urban forested natural areas requires specialized training in ecology, conservation, restoration, and silviculture.

CASE STUDY

Non-Native Invasive Tree Removals in New York City

Climate Type
Humid continental hot summers with year-round Precipitation

Primary Natural Disturbances
Hurricanes, nor'easters, severe summer and winter storms, drought

Urban Disturbances
Fragmentation, littering, soil compaction, soil contamination of hydrocarbons and heavy metals, pests, pathogens, non-native invasive species, occasional understory fires

Past Condition
Mixed hardwood with co-dominant non-native invasive tree species

Desired Condition
Mixed hardwood, dominated by native species

Number of Acres
50 acres

Budget
Two permanent forest garden staff are dedicated to the site

Implementation Timeline
Tree removals over the course of 3 years

Case Study Contact
Eliot Nagele, New York Botanical Garden

High-Level Management Goals

The New York Botanical Garden is home to an old-growth forest fragment that was never cleared or altered. However, urban stressors and millions of visitors over the course of a century helped change the landscape from hemlock-dominated to a mixed hardwood forest with great numbers of large-diameter non-native *Phellodendron amurense* and *Aralia elata*, as well as many other non-native invasive species. The Garden manages for overall forest resilience and native species regeneration, drawing on data collected during forest inventories conducted every five years.

Silvicultural interventions

Garden arborists removed *Phellodendron amurense* across the forest. Following removals, Garden staff check to see how abundant non-native invasive species are and if native species are regenerating naturally. Depending on the state of the understory, Garden staff will either plant with native species that are propagated from seeds collected from the forest or permit the natural regeneration to flourish. Staff consistently monitor these plantings as well as investigate any new gaps created by tree blowdowns to assess if supplemental native species plantings are required.

Clockwise from Top Left: Garden arborists removed large-diameter invasive trees at night so as not to startle Garden visitors; Garden staff regularly monitor the results of the single-tree removals and conduct full forest inventories every five years; Using seeds collected from the forest, Garden staff created a small tree nursery to use in understory plantings; When natural regeneration doesn't fill in gaps, the Garden uses native tree seedlings from its nursery to enrich the understory.
New York Botanical Garden

CASE STUDY

Thinning for Forest Health in Seattle's Puget Park

Climate Type
Warm-summer Mediterranean

Population
724,305

Primary Natural Disturbances
Windthrow, landslides

Urban Disturbances
Non-native invasive species

Desired Condition
Transition the forest to be conifer dominated

Number of Acres
24 acres

Budget
Not Available

Implementation Timeline
2014–2019, including planning, public engagement, felling, replanting, and maintenance

Case Study Contact
Michael Yadrick, Seattle Parks and Recreation

High-Level Management Goals

The city of Seattle, via the Green Seattle Partnership, has a goal to restore and manage nearly 2,500 acres of forest within the city. After the original coniferous forests of the region were cut down, native deciduous trees grew and occupied about 95% of the canopy. Goals for management are focused on ecological restoration, reintroducing native conifers to the canopy, and enhancing forest health. In the 24-acre West Duwamish Greenspace: Puget Sound Park, the goal was to reestablish a mixed conifer-deciduous forest.

Silvicultural Interventions

In mid-August after the primary bird nesting season, contractors thinned about 600 stems of native red alder and bigleaf maple. The thinning and gap creation allowed more light to reach the forest floor, favoring light-demanding conifers which had been planted in the understory. Crews also planted 10,000 native trees and shrub seedlings to occupy newly-available ground after the thinning. Weedings controlled non-native invasive plants. Finer twigs and branches were left as wildlife habitat and will eventually decompose, adding organic matter to the soil; larger-diameter cut trees serve as nurse logs, where natural regeneration can grow. Crews created snags for habitat and retained other pre-existing snags.

This dense stand of native red alder shaded the forest floor and prevented the natural regeneration of light-demanding native conifer species. This had ripple effects through the forest, affecting plant and animal communities.
Michael Yadrick

Outcomes

Monitoring after the thinning showed a survival rate of 75% of seedlings planted in the understory, even in partial- and full-sun conditions after a hot and dry summer. The winter after, freezing conditions and a droughty early spring took another 35% of seedlings. These survival rates were still higher than in other sites in Seattle. Site selection explains some of this: this site had high soil moisture to begin with, and removing some of the canopy reduced competition for soil moisture.

This photo shows the same stand after the thinning. The forest is more open, allowing light to reach the forest floor, necessary for the native conifer species planted in gaps to thrive.
Michael Yadrick

What Is Silviculture and Why is it Needed in Cities?

Silviculture is defined by the U.S. Forest Service as the "art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis."[6] In other words, silvicultural practice can include growing, tending to, and removing trees in a thoughtful way with stated forest goals in mind. Typically, silviculture is framed as a series of interventions conducted in forests over time, often decades, to reach these goals.

In rural settings, common forest goals can include creating habitat for wildlife, increasing carbon sequestration and storage in trees, or timber extraction. In cities, common forest goals include increasing tree canopy and canopy closure, sustaining species diversity, and providing ecosystem services.[7] Silviculture can be used to achieve these goals and more. In the case studies that follow, examples will illustrate how silviculture has been used to reduce the prevalence of non-native invasive species, enhance a forest's climate resilience, and restore a native ecosystem type after decades of neglect.

Because of its ability to achieve a wide suite of goals, silviculture is already practiced in many cities across the United States. In some cases, the silviculture happening in cities is called "silviculture." But other practitioners may use different language to describe it, including "forest restoration," "forest management," "ecological restoration," or simply, "conservation." Silviculture provides a framework that may unify these activities.

Recognizing ongoing work as silviculture might reframe management activities into a comprehensive, long-term strategic plan. This can allow practitioners to think through what they're already doing and use silviculture as a framework to identify gaps in data or planning. Identifying management activities as silviculture could allow practitioners to access a very deep body of knowledge and scientific research. It can also help translate work in urban areas to language that is commonly used by rural foresters who are working in similar forest types. This can make learnings from rural forests more accessible to urban forest managers. In this way, silviculture can act as a bridge across siloed efforts. Using a common language can facilitate learning and sharing from urban to rural settings, especially as "urban" challenges (fragmentation, non-native and invasive species, and magnified effects of climate change) become more common in rural landscapes.

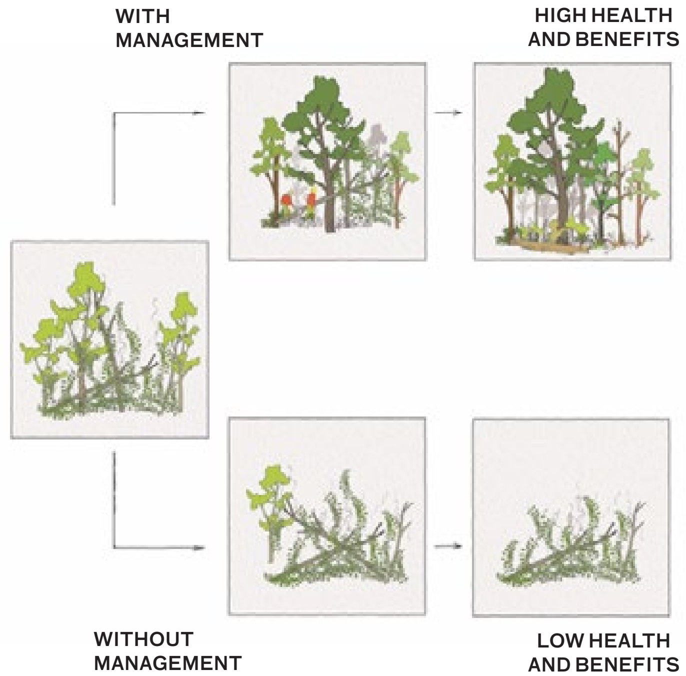


Fig 3. This diagram illustrates how a forest can improve with management or decline with neglect. The upper path depicts a forest in high health with high ecosystem service provision, while the lower path depicts a forest in low health with low ecosystem service provision.

Connecting Silviculture to Conservation and Ecological Restoration

With such a broad definition, silviculture can be used to achieve many diverse goals for forests, including those in cities. Though silviculture is used in conjunction with timber management and harvesting, the uses of silviculture extend far beyond forest products. In recent decades, have seen a sea change among forest management goals, with ecosystem services and social values coming to the forefront of priorities.[8] Silviculture is used for forest restoration projects; habitat creation and wildlife protection; watershed conservation and management; adaption to the expected effects of climate change; to create enjoyable and safe experiences in natural settings for visitors; and more. Many of these tested approaches align with typical goals for managing forests in close proximity to people, like those in cities.

Central Park in New York City
Chris Wilton / Unsplash

Silviculture and Urban Forest Restoration

In urban environments, where forest dynamics are similar to rural settings but differ in some important ways, there is a need to pair silviculture with other restoration activities.

For example, in a rural setting, the removal of trees from a site is often an opportunity for trees to regenerate, capitalizing on natural seed dispersal and the existing seed bank, and allowing advance regeneration to create a new stand of trees. In urban areas where invasive species are more prolific, creating gaps or removing trees in natural areas can provide space for undesirable plants, such as invasive vines and shrubs that grow rapidly and take up newly-available space, light, nutrients, and moisture before native tree species can establish. There is also evidence that advance regeneration is less abundant in urban settings,[15] compounding the issue and reducing the likelihood of stand regeneration.

Thus, in an urban system, silvicultural strategies for regenerating native trees or shifting the stand composition may need to be accompanied by both pre-treatment activities, such as non-native and invasive species removal and post-treatment activities, such as broadcast seeding, seedling plantings, continued non-native and invasive species removal, and prescribed burns.

Theodore Wirth Regional Park, Minneapolis, Minnesota
Minneapolis Park and Recreation Board

TABLE 1

Some Common Silvicultural Treatments, Uses in Forest Management, and Corresponding Natural Disturbances

Silvicultural Treatment	Description	Uses in Forest Management	Corresponding Natural Disturbance
Release	The removal of trees or branches that blocked light from a part of a desired tree. This “releases” the desired tree from being shaded out.	Release treatments improve conditions for the desired tree, allowing the desired tree to take up more space, sunlight, and resources. This is often the objective of a thinning. In urban settings, release happens with pruning, invasive species removal, or when a tree tips over after a storm.	Release treatments happen on a continuum from individual branches falling away, as in a windstorm, to entire trees or stands being removed, as in a hurricane or severe fire.
Single-Tree Removal	Individual trees of all size classes are removed more or less uniformly throughout the stand to achieve desired stand structural characteristics.	Single-tree removal is similar to the release treatment described above, improving conditions for a desired tree.	A single-tree removal can occur in cases of insect outbreaks, wind storms, senescence of old-age classes, or other similar disturbances.
Thinning	The removal of undesirable trees to adjust spacing between desired trees in a stand.	Thinnings are used as a type of release treatment to favor desired trees, especially in relation to species, size, and importance to wildlife. In urban areas, thinnings can help reset the trajectory of a forest stand toward a more climate-adapted future and encourage natural regeneration.	More intensive insect outbreaks, light ground story fire, natural death of some trees due to competition during forest succession, wind storms, tree loss due to drought.
Shelter Wood	The removal of most of the canopy to create a new stand under the shelter of some mature trees left standing (as seed sources and for wildlife habitat).	Shelterwoods are a release treatment used to encourage the natural regeneration of certain species (e.g., oak, hickory, white pines, maples). Remaining trees can be left in clumps or be evenly distributed, depending on the species regeneration desired.	Strong hurricanes, microbursts, ground story fires, ice storms, flooding, intense insect outbreaks.
Gap Creation (also known as Group Selection)	The removal of a small patch of trees (a group), typically at least ¼ of an acre in size.	Gap creations are a treatment to encourage establishment of a new cohort of trees. They can be used in combination with other site treatments, such as scarification or burning, to encourage light-demanding species. This is used to create age, species, and size diversity within a stand.	Group die-off due to root rot, insect damage, tornado or microbursts.

CASE STUDY

Climate-Adaptive Silviculture in St. Paul

Ash forests are suffering the deadly effects of emerald ash borer, a non-native insect. This case study shows that forests across the rural-urban gradient can face the same environmental pressures, and that practitioners can use similar silvicultural practices to manage for resilience.

Climate Type
Humid continental hot summers with year around precipitation

Population
304,547 (3.65 million in the metro area)

Primary Natural Disturbances
Flooding

Urban Disturbances
Non-native invasive species

Past Condition
Elm-ash-cottonwood floodplain forest

Desired Condition
Floodplain forest dominated by site-native species hardy to zone 4

Number of Acres
Twenty-four 0.1 acre plots (2.4 acres total) of treatments across 534 acres

Budget
Initial funding provided by the Wildlife Conservation Society Adaptation Fund in 2018 ($247,600). Ongoing funding from various sources supports conservation corps crews, a stewardship and volunteer coordinator, and research staff.

Implementation Timeline
2 years for ash removal and planting; maintenance and monitoring for 25 years.

Case Study Contact
Leslie Brandt USDA Forest Service & Mississippi River Park Connection

High-Level Management Goals

The Mississippi National River and Recreation Area flows through the center of the Minneapolis-St. Paul metropolitan area. The combination of non-native species (especially emerald ash borer) and climate change is leading to canopy losses that are not being replaced by natural regeneration. The National Park Service, the Northern Institute of Applied Climate Science, the University of Minnesota, City of Saint Paul Parks and Recreation, Mississippi Park Connection, and other partners are experimenting to find a species composition mix that is better adapted to the future projected conditions of the Mississippi floodplain. This project is part of the larger Adaptive Silviculture for Climate Change (ASCC) network of experiments coordinated by Colorado State University.

Silvicultural Interventions

The project makes use of existing gaps created by dead ash. Dead ash and other undesirable species were removed from 0.1-acre plots and planted with 2- to 6-foot tall bare root saplings spaced 7 feet apart. Site prep, including harvesting and fencing, was conducted the winter before planting. The project tests 3 alternative strategies for adapting the forest to climate change. The resistance strategy aims to restore the site to its previous condition, reintroducing American elm and other site-native species such as silver maple and

cottonwood. The resilience strategy aims to expand site biodiversity with a wide suite of native tree species, including some species native to southern Minnesota and northern Iowa but not currently found on the site, such as swamp white oak and sycamore. The transition treatment is planted with floodplain tree species that are native to more southern regions of the Upper Mississippi River Basin, such as Iowa, Illinois, and Missouri, including species such as southern pin oak, pecan, and tulip poplar.

Outcomes

These experimental silvicultural treatments will be monitored over the next 25 years. The results will help other floodplain forest managers in the Mississippi floodplain understand and manage their forests in a changing climate, whether in urban or rural regions.

Emerald ash borer has devastated patches of ash trees in the Mississippi National River and Recreation Area, adjacent to the St. Paul-Minneapolis metropolitan region. To address this, park managers and US Forest Service scientists cleared the dead ash gaps and worked with volunteers to plant new, climate-adapted trees (above).

CASE STUDY

Silvicultural Approaches for Managing Stands Facing Emerald Ash Borer Mortality in Minnesota

Location
Chippewa National Forest in northern Minnesota, rural counterpart to the St. Paul example (opposite)

Climate Type
Humid continental

Primary Natural Disturbances
Some light wind, flooding

Urban Disturbances
Emerald ash borer

Past Condition
Closed canopy black ash forested wetland

Desired Condition
Healthy, naturally-regenerating diverse forest

Number of Acres
126 acres

Budget
$10,000 for purchasing and planting seedlings

Implementation Timeline
Winter 2012–Fall 2013

Case Study Contact
Brian Palik, USDA Forest Service

Cities and rural landscapes alike are struggling to deal with ash die-off. Research outcomes from rural settings, such as in this case study, can help inform restoration strategies in urban settings.

High-Level Management Goals

Northern Minnesota wetland forests are dominated by black ash, Fraxinus nigra, tolerant of ponding and heavily saturated soils. In these forests, black ash lowers water tables in the summer through evapotranspiration, assisting the survival of other tree species, helping to support a summer herbaceous flora, mammals, birds, amphibians, reptiles, and arthropods. Black ash is also a culturally significant tree to northern Minnesota Native American tribes. However, emerald ash borer (EAB), a non-native insect, is a major threat to the health of black ash forests. Since its detection in southern Michigan in 2002, EAB has decimated urban and rural ash trees, with mortality rates greater than 99%. This experiment tested four different silvicultural approaches to replace black ash trees with other species in order to maintain ecological functions in wetland forests, with the goal of identifying the most promising combination of tree species and canopy treatments to maintain forest cover post-EAB mortality.

Silvicultural Interventions

Seedlings of different native and non-native tree species were planted in stands treated with clearcuts, group selection, and tree girdling, as well as untreated control sites. These treatments were selected to emulate possible adaptation approaches in the case of an EAB infestation. The clearcut treatment emulates preemptive salvage logging; the group selection represents partial logging prior to an EAB infestation, while also leaving some canopy trees to limit rising water tables; and the girdling treatment most closely emulates EAB-induced mortality, with trees dying over the course of several years.

Outcomes

Seedlings planted in the clearcut treatment did not fare well compared to the other treatments. After eight years, swamp white oak (Quercus bicolor), American elm (Ulmus americana) and hackberry (Celtus occidentalis) had high survival rates (+40-80%) in the group selection, girdle, and control sites, and low to medium rates in the clearcut sites (5 - 50%). Manchurian ash (Fraxinus mandshurica), a non-native ash resistant to EAB, had moderate survival (20-60%) in the group selection, girdle, and control sites, and a medium survival rate in the clearcut site (25%).

A 10-year-old swamp white oak (*Quercus bicolor*) planted in a gap.

Ecological Basis of Silviculture

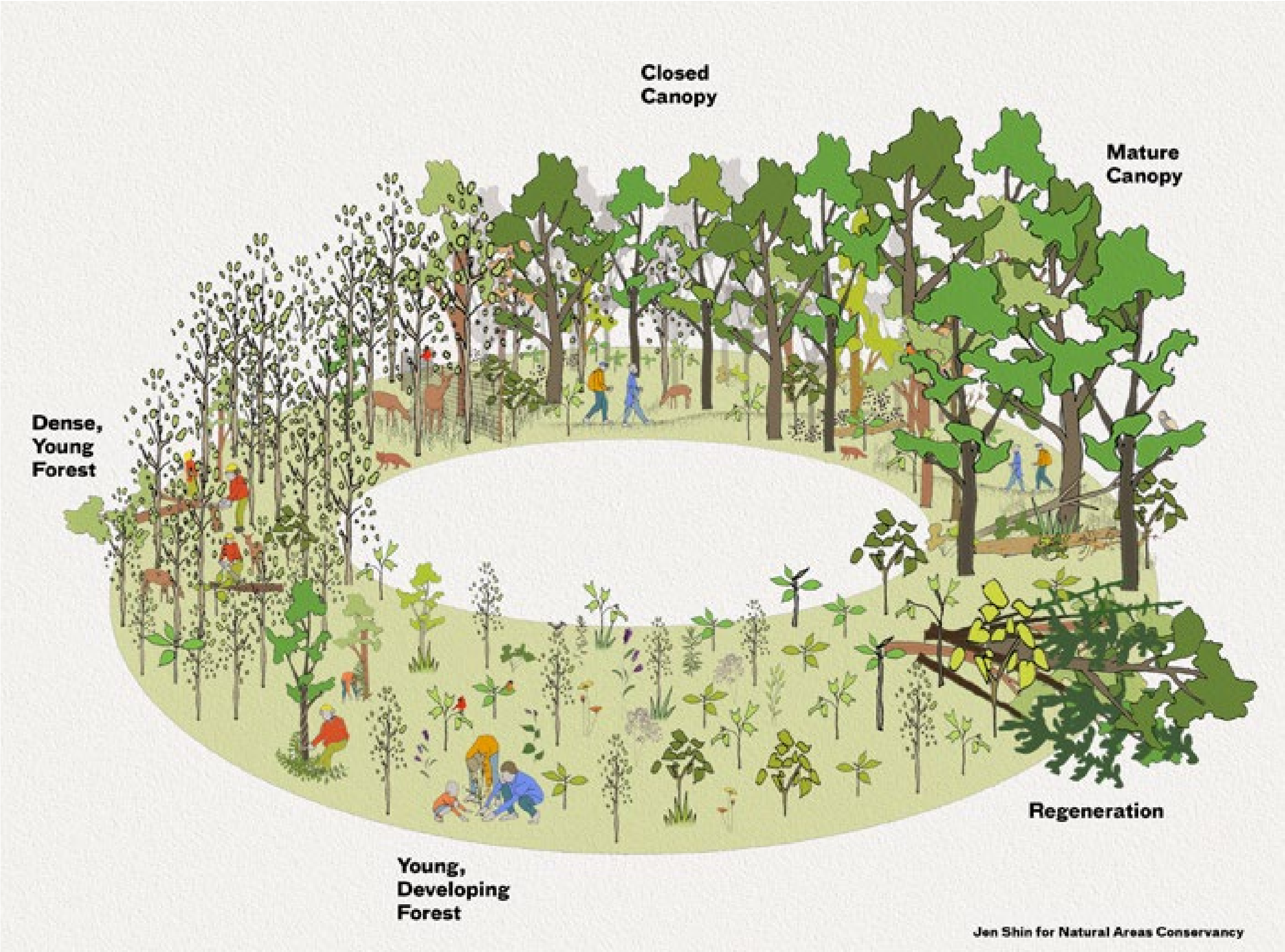


Fig 4. Silviculture at its best is a method of working with the natural ecology of forest systems to get desired results more quickly. Here, we see people performing management activities (planting, thinning) at different stages of forest development to shape the future forest. Planting, one of the most common urban forestry activities, is an exercise in choosing species that will one day become mature forest canopy. Thinning is an opportunity to remove unwanted trees, select for traits such as trunk straightness or climate-adaptive capacity, provide more light for understory growth, and prevent unsafe tree die-off. All of these activities happen in conjunction with ongoing natural processes, leading up to and including the death of mature trees, which provides the resources for new trees to grow—whether through the human intervention of planting or natural regeneration.

One key aspect of silviculture is the close mirroring or guidance of natural processes in order to create or shape a forest, often on an accelerated timeframe.

Silviculture emulates natural processes by way of three separate but related concepts. The first is understanding a tree species' ecology and life history. The second is understanding how individuals grow together in a community over time, known as *forest stand dynamics* or *forest succession*. Third is the disturbance regime. All three concepts roll up into an understanding of the forest landscape and ecology. Silviculture can be understood as the synthesis of these three concepts to achieve a forest composition and structure that meets human needs.

Individual species' ecology and life history are the foundations of silviculture. It is necessary to understand reproduction strategies, moisture needs, light/shade tolerance, and other needed habitat conditions, to determine which silvicultural interventions make sense.

Forest stand dynamics is a way to understand how multiple tree species function together as a community.[9] This includes the study of changes in forest stand structure over time and stand behavior after disturbances.[10] A "stand" is defined by managers

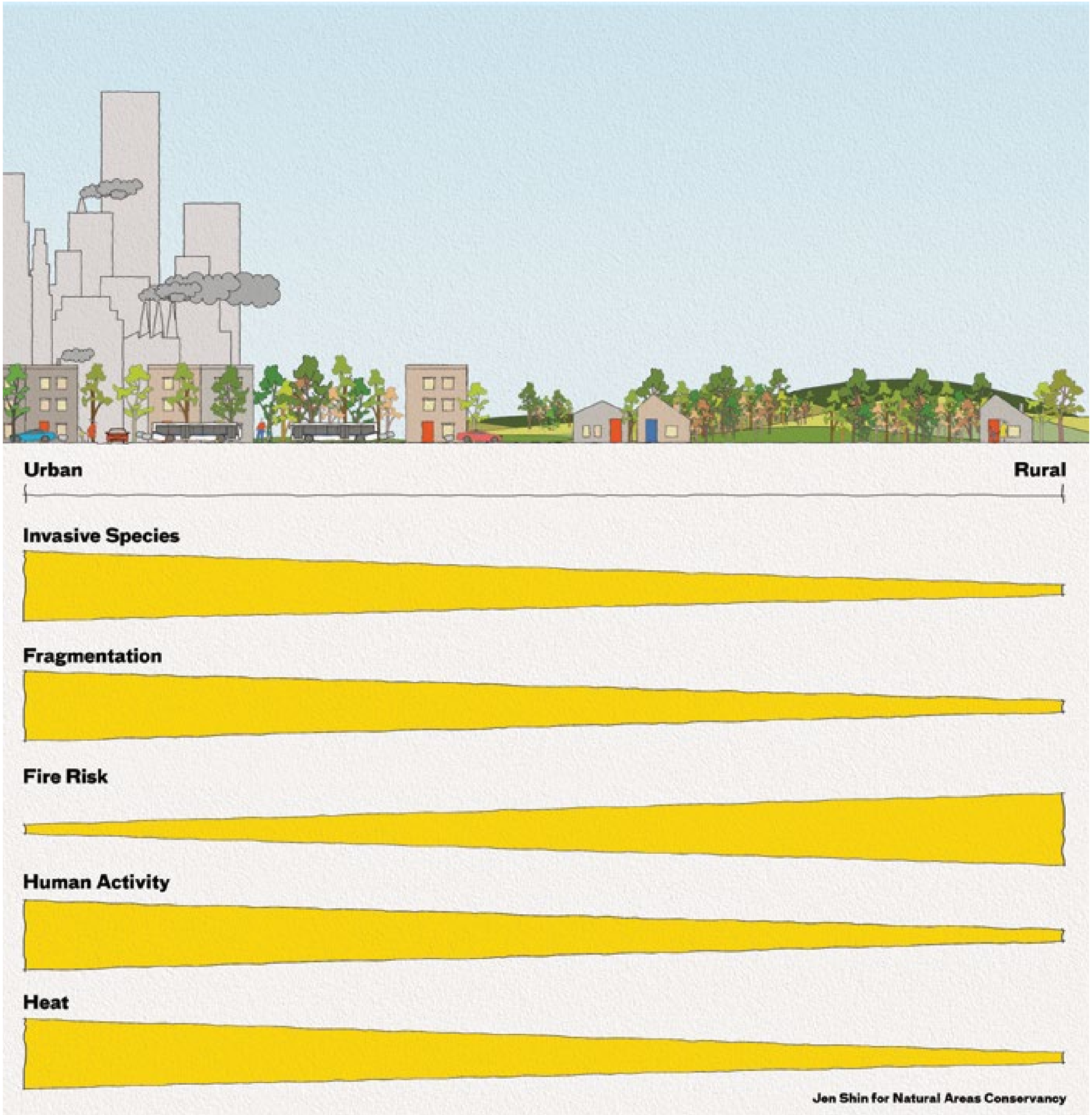


Fig 5. This diagram shows how the impact of disturbances change depending on the setting. In urban settings, disturbances such as intense storms, heat, soil contamination, invasive species, and human activity (heavy use, trampling, dumping, etc.) generally exercise greater pressure on forest systems, while disturbances like deer herbivory and fire can be greater in rural areas.

North Miami, Florida
Michel Reyes / Unsplash

History of Silviculture and Land Management

Though the name was invented in Western Europe and is derived from Latin, the practice of silviculture is ancient. It was practiced initially by indigenous peoples across the globe as a component of agriculture, in which patches of forest were cleared to make room for arable crops and eventually allowed to return to forest—known as swidden agriculture. This results in complex land use systems that are still in practice today, especially in tropical regions. Prior to European arrival and colonization of North America, Native American groups across the continent burned forests regularly to shape forest composition and structure, showing a preference for fire-tolerant, nut-producing species, such as oaks and hickories. The selected species provided food for people and for game.[12] North American landscapes prior to European colonization were the result of centuries of intentional forest management by native peoples. European settlement and forced removal of Native people—and the cessation of their purposeful forest manipulations—resulted in a wholesale change in forest structure and management.[13] This change is most notable in the form of fire suppression, resulting in a species shift from fire-tolerant to moisture-loving, mesic species and a thick herbaceous understory.

Traditional Ecological Knowledge

Given the long history of silviculture as a practice in North America, traditional ecological knowledge is a rich source of information for forest ecology and conservation. Groups with long-standing ties to land and forests, such as native peoples and other peoples who have lived in an area for generations, often have deep and unique knowledge about phenology, ecology, and relationships between species. Combined with scientific knowledge, traditional and local ecological perspectives can provide a well-rounded understanding of forest ecology and approaches for management.

and refers to an area of forest that is more or less homogenous in terms of the tree species and size, hydrology, topography, soil types, and social factors such as frequency of use or common human activities. A stand is the smallest management unit for applying a silvicultural treatment.[11] Disturbance is an ecosystem perturbation that causes a pronounced change in conditions. Common ecosystem disturbances in urban settings include floods, hurricanes, high winds, insects, diseases, and impacts from human activity. In natural settings, disturbances create conditions for forests to regrow and help diversify structure and species composition over time.[14] Disturbance can be partial, where only some trees or vegetation are killed or removed, or total, where an entire stand is killed or removed. Each forest species evolved and developed in conjunction with the disturbance regime, and have developed mechanisms to regrow through stages of forest succession in response. Because disturbance can cause impacts that are patchy across the landscape, a forest often looks like a mosaic of forest structures in different stages of development.

These disturbances are felt across the landscape and encompass both urban and rural forests. However, urban forested natural areas can be subject to multiple, co-occurring, and sometimes exacerbated disturbances that impact an urban forest's ability to recover and respond.

For example, a windstorm or insect outbreak in a city might cause a few trees in a forested natural area to topple, leaving a gap in the forest canopy. In this scenario, non-native or invasive species could take over the gap and prevent natural regeneration from growing, as seen in the example from St. Paul. The resulting effect could be arrested succession and a trajectory of degradation.

One approach in silviculture is to emulate naturally-occurring disturbances in order to achieve their management objectives; and mimicking natural disturbances might be just one step towards achieving the long-term goal. These methods can be tailored to the disturbance regime for the region and should be appropriate for the site. Correctly executed, these actions will speed up or change the trajectory of forest succession, changing forest structure or composition, and help achieve desired outcomes for the forest.

The James River in Richmond, Virginia
Elly Johnson / Unsplash

CASE STUDY

Prescribed Burning and Thinning in St. Louis for Forest Restoration

Climate Type
Humid subtropical

Population
308,174

Primary Natural Disturbances
Wildfire, tornadoes

Urban Disturbances
Soil disturbances, suppression of natural disturbance regime, fragmentation, invasive species, limited natural regeneration

Past Condition
Mesic, shade-tolerant understory coming up under an overly-mature oak-hickory

Desired Condition
Healthy, regenerating oak-hickory understory forest

Number of Acres
9 acres

Budget
Changes year to year, but cost is higher per acre than rural areas due to liability insurance, heavy equipment not allowed in the Park, have to remove a lot of downed wood and all brush piles

Implementation Timeline
Winter of 2014–2015, with prescribed burns two years after

Case Study Contact
Amy Witt, Forest Park Forever

High-Level Management Goals

Forest Park Forever, a private nonprofit conservancy that partners with the City of St. Louis, has been dedicated to the large urban forested natural area within Forest Park, working to improve and sustain long-term forest health. This has meant shifting the forest's trajectory from an unmanaged, widely invaded woodland. As part of this transition, resources also shifted from short-term and recurring invasive species management to managing the landscape as a natural system.

Silvicultural Interventions

Forest Park Forever staff used a combination of thinning in 2014–2015 and prescribed burns in 2016–2017 to restore the woodlands to a more open and stratified structure. Thinnings targeted mesic, shade-tolerant trees and non-native trees, and were conducted in winter when park usage was lower. Working in winter also meant that impact on flora and fauna was decreased. Contractors used reduced-impact methods to maintain soil and ground flora integrity. After the thinning, woody material was removed immediately so as not to alarm the public. Leaf litter was removed, and broadcast seeding and plantings of fast-flowering native plants, trees, grasses, and sedges followed the thinnings. Increased fuel loads of native grasses and sedges enabled controlled burns, managed by contractors and only permitted between October and April, from 8 am to 4 pm, to protect air quality.

Outcomes

Increased light to the forest floor after thinnings and burnings increased plant diversity, and grass and sedge plantings provided safe fuels for future prescribed burns. Restoring these plants immediately after the silvicultural treatments ensured growing space was occupied and non-native invasive plants were less competitive. The work is ongoing, with different stands targeted for thinnings and restoration each year, using an adaptive management approach. Total acreage for thinning and restoration each year varies from 1 to 7 acres, depending on available budget. The results of these efforts include a more complex forest structure, and the removal of mesic, shade-tolerant trees providing sufficient light for native oak and hickory species to grow from advanced regeneration to mid-story and eventually canopy species.

Above: A prescribed burn in St. Louis' Forest Park, paired with a thinning, helped restore the forest composition from shade-tolerant and moisture-loving to the sun-demanding, more open structured oak and hickory woodlands. Right: Progress photos show the change over time in Forest Park. Note the openness of the forest and clear sightlines, which enhance public safety.
Forest Park Forever

CASE STUDY

Silviculture for Sandhill-Pine Ecosystem Restoration in Gainesville

Climate Type
Temperate, humid subtropical

Population
132,127

Primary Natural Disturbances
Hurricanes, wildfire, drought, bark beetles, pine beetles, high temperatures, and high water tables

Urban Disturbances
frequent litter and construction/trash dumping, unintentional movement of non-native invasive species, plant poaching, and gopher tortoise poaching

Past Condition
Hardwood hammock due to fire suppression

Desired Condition
Sandhill-longleaf pine

Number of Acres
78.2

Budget
0; Contractor received all material and sold it to a biomass plant

Implementation Timeline
Winter 2015 and ongoing management efforts

Case Study Contact
Nicole Barbieri, City of Gainesville, and Michael Andreu, University of Florida

High-Level Management Goals

The City of Gainesville is restoring a sandhill-longleaf pine ecosystem from the water and laurel oak-dominated hardwood hammock ecosystem that sprang up in response to decades of fire suppression. The purpose of the restoration project is to provide increased habitat for native Florida plants and animals, such as the gopher tortoise, an important species whose burrow provides refuge for about 360 other animal species.[3]

Silvicultural Interventions

To accomplish this restoration project, the city collected desirable native grass and wildflower species seeds present onsite and in other nearby parks before hiring a contractor in the winter of 2014–2015 to harvest oaks. The contractor cleared the oaks in about a week and kept the timber, helping the city realize approximately $30,000 in cost savings. In the seasons that followed, city staff conducted follow-up monitoring, seed scattering, and planting of native wiregrass. They also treated hardwood sprouts with herbicides. In 2016, the first in-house prescribed burn was conducted, with the goal to burn every 2–3 years. Because of the site's proximity to residential areas, schools, and major roads, burning can only take place with a southerly wind, and occasionally, brush mowing stands in for fire. In the winter of 2021–2022, staff planted pine tubelings, and will continue planting pine for a few years to re-establish a low-density, uneven-age stand of longleaf pine.

Outcomes

While this restoration project is ongoing, the removal of oaks with some remnant trees has transformed the structure from a closed-canopy oak hammock to a spacious, low-density pine savanna structure. Herbaceous plants and hardwood sprouts crop up and are treated with herbicides. City staff constantly monitor for invasive species and conduct removals for herbaceous and grass species every two weeks, while woody species are treated every 2 years. Prescribed burns are planned for 2022.

Top: The dramatic sight of a post-clearance restoration project. The City of Gainesville hired contractors to remove native water and laurel oaks to restore this site to a sandhill longleaf pine ecosystem. The city traded the oak timber for the labor, and the contractors sold the oaks to a biomass plant. Middle: After removing the oaks, longleaf pine seedlings were planted on the site, along with broadcast seeds of native grasses. In time, this will create the ideal habitat for gopher tortoise. Bottom: Taken at another park in Gainesville, this photo shows the target ecosystem: a healthy, multi-aged canopy of longleaf pine, with a palmetto midstory and wiregrass.
Brittany Wienke

CASE STUDY

Silviculture for Slash Pine Restoration After Hurricane Andrew in Miami-Dade County

Climate Type
Subtropical

Population
2.7 million

Primary Natural Disturbances
Hurricanes

Urban Disturbances
Fragmentation, fertilizer leaching, conversion

Past Condition
Degraded and fragmented pine rockland with poorly-adapted endemic canopy subspecies, remaining habitat contained within an urban matrix

Desired Condition
Healthy pine rockland with appropriate subspecies

Number of Acres
~500–1500 acres

Budget
Ongoing

Implementation Timeline
1992–present

Case Study Contact
James Duncan, Miami-Dade County

This stand of slash pines represents the 20-year-long effort, still ongoing, to restore and protect a globally rare forest type, the pine rocklands. Miami-Dade County regularly thins and burns these forests to maintain the canopy.
Jame Duncan

High-Level Management Goals

In 1992, Hurricane Andrew swept through South Florida, causing approximately $25 billion in damage and severely damaging the canopy of the globally-rare pine-rockland habitat, characterized by southern Florida slash pine (*Pinus elloittii* var. *densa*) on thin-to-bedrock limerock soils. Approximately half the canopy was destroyed by direct impacts from the hurricane, and the remaining pine canopy was attacked by pine beetles. Within a year, mortality was as high as 98%, putting this endemic variety at risk of extirpation. The high-level management objective for Miami-Dade County staff and the Forest Service was to restore *Pinus elloittii* var. *densa* to the site at an unevenly-sized diameter distribution, with a mixed herbaceous understory to carry future prescribed fire.

Silvicultural Interventions

Restoration efforts in Miami-Dade County had been constrained by the available stock at local nurseries. To address this, County and Forest Service staff collected pine cones from the remaining *Pinus elloittii* var. *densa* in the fall, at the moment of peak cross-pollination to ensure the most robust genetic diversity. The pine cones were sent to a state nursery facility, located near a women's prison in north central Florida. The women germinated pine seedlings and returned them to Miami-Dade County for planting. The project was so successful that some sites were over-planted. Continued maintenance includes thinning in overstocked sites and prescribed burns.

Outcomes

The *Pinus elloittii* var. *densa seedling* production system has been very successful, providing hundreds of thousands of seedlings that the County uses in pine-rockland habitats and gives to private pine rockland landowners. Thanks to the seed collection efforts by County and Forest Service staff, the nursery trade has begun to carry *Pinus elloittii* var. *densa* as well. This silvicultural intervention is ongoing, even after nearly 30 years.

Pine seedlings, such as this one, are grown offsite and returned to Miami-Dade County for planting. Seedlings are used on public and private land to restore and conserve the pine rocklands.
Robert Grant

CASE STUDY

Low-Intensity Thinning for Oak Regeneration in the Chicago Metro Region

The experimental site before thinning.
Robert Fahey

The experimental site after thinning. Note the increased sunlight to the forest floor. White oak seedlings were planted in the gaps to grow into the future canopy.
Robert Fahey

Location
Lake County, Illinois, USA

Climate Type
Continental

Primary Natural Disturbances
Wind, fire

Urban Disturbances
Deer browse, development

Past Condition
Dense overstory canopy with little regeneration and invasive plant species in the shrub layer

Desired Condition
Open canopy with enough light to promote advance regeneration of mid-tolerant species such as oaks, more diverse native-dominated ground and shrub layers

Number of Acres
910 acres

Budget
Likely about $200,000 to date

Implementation Timeline
2011–2017, with two years of implementation and five years of monitoring, and adaptive management. Project is ongoing with additional phases of work slated for 10–20 years in the future.

Case Study Contact
Robert Fahey, University of Connecticut

High-Level Management Goals

Many regions in the eastern U.S. that were once oak-dominated forest systems have transitioned to more shade-tolerant, moisture-demanding systems over the past three hundred years. This change is related to European settlers, forced removal of Native peoples, subsequent fire exclusion, deer browse and acorn consumption, non-native invasive species, as well as urban, suburban, and exurban development. These altered oak systems have recently become a focus of restoration efforts, typically with use of prescribed burns and intensive canopy removals. In suburban and exurban areas, these intensive approaches are often prohibited or difficult to execute. Five alternative, low-intensity strategies were tested, paired with understory oak seedling plantings, to develop oak restoration methods for more heavily populated areas.

Silvicultural Interventions

Instead of the high-intensity clearcuts, shelterwoods, and prescribed burns that are often suggested for oak restoration, this project used a combination of sub-canopy thinning, invasive shrub removal, and canopy thinnings. All sites received sub-canopy thinnings and invasive shrub removals. Then, canopy thinnings were deployed at different intensities, from 0%, 10%, 17.5% as an aggregated group shelterwood, 20%, and 40% basal area removals. After thinnings in 2012 and 2013, 2-year-old white oak (*Quercus alba*) seedlings of local genetic provenance were planted in each plot. No prescribed burning was used. Seedling survival under the different canopy treatments was tracked over five years.

Outcomes

Seedling survival and average growth rates were not significantly different across the five different treatments. Seedling survival in general was about 45%, even without deer browse protection, weeding, or the concentrated non-native invasive removal right before the treatments were implemented. These lower-intensity canopy removals can, overall, provide conditions that are amenable to oak seedling plantings and survivals.

Silviculture as a Framework

As described above, silviculture is a holistic approach to managing a forest. In the sections that follow, we break down the practice of silviculture into a few key parts, summarize why these activities matter, and give recommendations and examples for each.

1. Assessments
2. Planning & Goal Setting
3. Implementation
4. Monitoring
5. Adaptative Management

Assessments

Before you make any changes to the forest, you need to know what you have: how much forest, where is it, what condition is it in, and who uses it? Working from data helps managers make informed decisions that are within the ecological parameters of their forest.

Natural Areas Mapping Assessments

Creating a map of forested natural areas is a critical first step in setting up a field-based assessment. This map will show where the forested natural areas are and their acreage. This can be accomplished with pre-existing maps and analysis in a geographic information system (GIS) or via remote sensing. Mapping can be done at the citywide level, park level, or any area of interest.

After gathering this high-level information, a more detailed assessment of the city's natural areas can begin, supplemented by field-collected data on metrics like species composition and forest structure. These more in-depth assessments help give finer-scale information that feeds into establishing goals, objectives, and recommendations.

In the following sections, we provide a few ways to collect this detailed data on forest composition and structure. More resources are available in Appendix A.

Biophysical Field Assessment

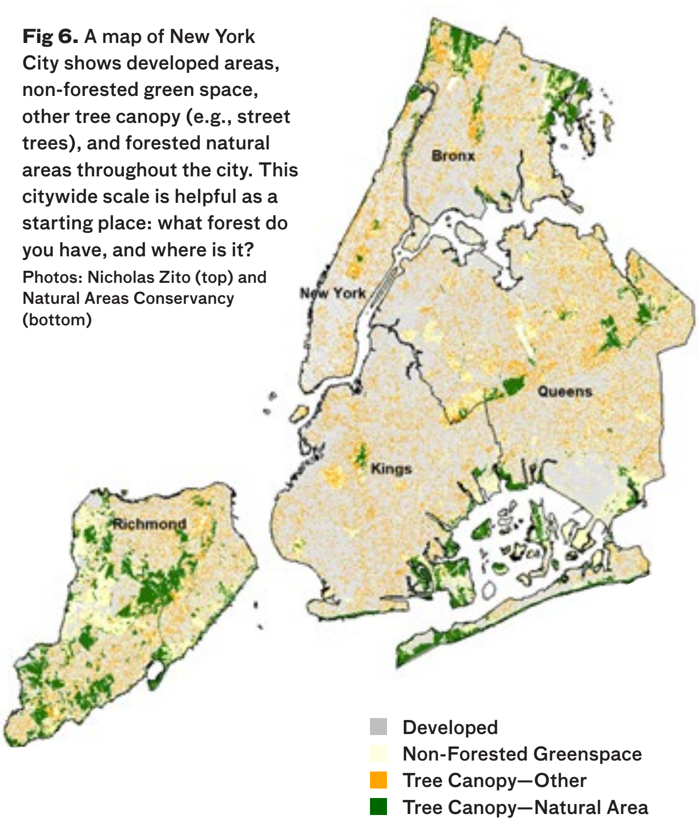
In rural silviculture systems, biophysical forest assessments are organized by stand, because silvicultural treatments are usually prescribed at the stand level. However, in a city setting there are a few different scales that may be of interest. Below we describe an assessment approach at two possible scales: a citywide assessment approach and a smaller, stand-level approach.

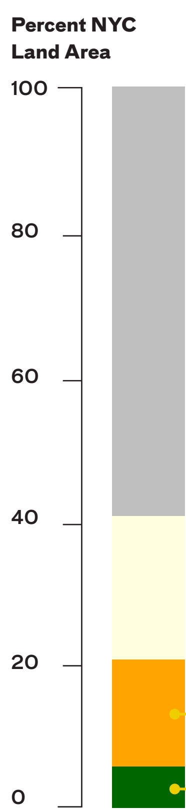
Citywide Assessment

A citywide forested natural areas assessment will take the entire city jurisdiction as the management unit. Understanding the conditions of the forest at the city scale will help give a snapshot of the forest's condition and help inform forest management goals going forward.

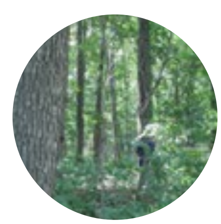
To assess the forest at the city scale, managers will create plots across all the forested natural areas, using the maps and acres described in the paragraphs above. The number of plots will be related to the total amount of forested natural area in order to collect enough data to provide a representative, realistic view of the forest. After plots are established across the city's forested natural areas, managers usually take a few basic measurements, described below. Additionally, managers might establish smaller subplots within the larger plot to record species found in the forest understory, documenting any advanced regeneration.

Fig 6. A map of New York City shows developed areas, non-forested green space, other tree canopy (e.g., street trees), and forested natural areas throughout the city. This citywide scale is helpful as a starting place: what forest do you have, and where is it?
Photos: Nicholas Zito (top) and Natural Areas Conservancy (bottom)





Tree Canopy—Other
Open grown trees planted or growing in close proximity to buildings, in rights of way, residential areas or in landscaped parkland. Trees in such locations are often planted and managed on an individual basis. Opportunities to increase tree cover of species diversity can be directly manipulated through planting trees.



Tree Canopy—Natural Area
Trees growing in forest stands. In cities these can occur in areas such as remnant parkland, vacant lots, privately owned woodlands, or along highway medians. Forest stands primarily rely on natural regeneration and management is conducted in more similar methods as rural forests. Such areas can contain high concentrations of native species and diversity.

Fig 7. A close-up of Van Cortlandt Park, a 1,146-acre park in the Bronx borough of New York City, with the light green trees representing park and landscape trees, and the dark green representing the forested natural area. This kind of mapping enables a forest manager to know where to direct their efforts for a forest assessment.

Stand Assessment

While a citywide assessment gives a high-level picture of forest conditions across the city, a stand assessment is a way to get more granular information about a part of the forest. While the process to create plots is the same — establishing a number of plots that is statistically representative of the size of the stand — managers can collect more detailed data at this smaller scale. For example, this could be an opportunity to take note of signs of human use, such as dumping, vandalism, or presence of people on trails. This data can inform management actions more specifically.

Putting it All Together

Taken together, these measures provide a starting point to understanding forest structure, composition, and condition; help inform high-level goals; and give clues about what silvicultural treatments might be appropriate in particular stands. This process is most effective when repeated, since multiple measures over time can help decipher the trajectory of the forest as the city, forest, and climate changes.

Conducting a forested natural areas assessment could be a large undertaking , and may require resources such as field staff, equipment, and funding. For some cities, there may also be an opportunity cost in directing staff time away from pressing daily work. But with data in hand, managers can identify and prioritize projects, and utilize the most appropriate silvicultural interventions to maintain and protect forested natural areas.

Stratifying for Natural Areas in Commonly Used Assessments

There are existing tools that can be used for citywide tree canopy and forest structure. Urban tree canopy (UTC) analysis and i-Tree Canopy, which are remote sensing methods, provide insight into forest cover. The i-Tree suite of tools provides information about the dollar value of urban forest benefits, and the associated field-based sampling method gives practitioners a framework to capture information about forest composition and structure. These are used by many cities across the country to assess the urban forest at the citywide scale, but with the exception of the i-Tree field-based sampling method which could place plots in forested areas, they do not stratify the urban forest into different cover types; therefore, forested natural areas are measured in the same way as street trees. The resulting information does not provide enough detail to inform forested natural areas management.[16]

Social Assessment

One critical aspect of an urban forested natural, and one that makes it different than a more rural forest, is the number of people who visit it. By virtue of their proximity to thousands, in some cases millions, of people, forests in cities are generally more heavily used and offer recreational value to more people than rural forests.

Moreover, green spaces in cities, including forested natural areas, have historically been shaped and controlled by elite actors, often directly excluding or disadvantaging people along racial and class lines. Understanding who uses the forested natural area, who does not, and why or why not, is key to addressing longstanding inequities in urban green spaces and providing an urban nature experience that is accessible, safe, and enjoyable to all city residents.

A social assessment can also tell us how forested natural areas are currently being used. Compacted soil under a big tree, litter or trash in a concentrated area, platforms installed between big branches, signs of camping, broken branches along trails, and more can show managers where natural area visitors hang out and how they spend time there. It can also show managers where it might be appropriate to practice silviculture and where it would be disruptive to do so. For example, in a thick, overgrown stand where illegal dumping takes place, a thinning could open sightlines and discourage illegal dumping. This observational data can be gathered while performing the stand assessment, mentioned above.

More direct surveys or interviews can help you understand what local community members want from their forested natural areas as well. Questions about common activities, frequency of visitation, feelings of safety, desires for future forest conditions, and perceptions about silvicultural treatments can inform management activities.

For these reasons, including a social component to your assessment is recommended . Gathered via structured observation, in-person user interviews, telephone or online surveys, focus groups, or social media data, this information should also feed into goal-setting, described in greater detail below. Though it may be challenging, it is critically important to collect data that reflects your city's demographics and residents to make sure voices of historically excluded groups are heard.

TABLE 2

Putting It All Together

How do you actually conduct an assessment? This table summarizes the types of data you need, how to collect the data, and what questions the data is trying to answer. Examples and resources follow, showing real-world examples of urban natural areas assessments from around the country with methods for data collection and analysis.

Type of Assessment	Data to Collect	How to Collect	How to Use Data	Examples and Resources
Desktop Analysis	Acres of natural areas Where natural areas are in the city Topographical features How many plots needed to collect a representative sample	Remotely-sensed imagery interpretation, thematic data layers, GIS	Initial understanding of how much forest there is and where it is in the city. Use to determine where to collect biophysical and social data, and how much.	*Ecological Cover type map from NYC* *Assessing Houston's Forested Habitat*
Biophysical Assessment (Citywide & Stand)	Density of trees (trees per acre) Species of trees Size of trees Natural regeneration Non-native species A contiguous group of trees sufficiently uniform in age class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, to be a considered a unit. A stand is the fundamental unit of silviculture reporting and record-keeping.	Forest plots Species identification Measure dbh with dbh tape Subplots A stand's size is determined by the manager and generally scales up or down in relation to the size of the forest property. In an urban forested natural area, a stand may be quite small or defined by how an area is used (e.g., the forest surrounding a hiking trail could be a long, linear stand).	Clearer picture of forest type, condition, and potential health risks.	City-wide example: *A City-wide Assessment of New York City's Forests* Site/stand-level example: *Plant Community Assessment and Management Recommendations for Minneapolis Park Natural Areas* *Assessing Forest Health Patch: A Protocol from Baltimore* *Upland and Forest Ecological Assessment for New York City* *Baltimore's Forest Patches: Emerald Assets for Ecosystem Services*
Social Assessment	Who uses the forest? Who does not? Why do they visit? What do they want from their forested natural areas?	In-person surveys or interviews, analysis of census block data, telephone surveys, analysis of social media data, structured observation.	Understand what residents want from their forested natural areas and inform ecological goals.	*Citywide Social Assessment of New York City Parks and Natural Areas in 2013–2014* *Conceptualizing Social-Ecological Drivers of Change in Urban Forest Patches*

TABLE 3

Some Silviculture Terms Related to Conducting Assessments, Planning, Goal-Setting, with Definitions and Some Urban Considerations

Below are some silvicultural terms that may come up in discussion and research while planning silvicultural interventions.

Term	Definition	Considerations in Urban Areas
Natural Regeneration	The establishment of a plant or plant age class from natural seeding, sprouting, or suckering. Natural regeneration is a broad term that includes advanced regeneration (as defined below) and other forms of plant establishment.	In urban settings, natural regeneration experiences different pressures, such as altered seed predation dynamics, deer browse, competition with invasive species, changes in soil chemistry, and altered disturbance regimes. This can affect the abundance of natural regeneration, species that regenerate, and more. **NOTE:** Natural regeneration is foundational to many silvicultural treatments. However, emerging research shows that natural regeneration dynamics are different in urban forested natural areas and can result in less natural regeneration. It is critical that natural regeneration presence is confirmed and quantified before silvicultural treatments that rely on natural regeneration are performed.
Advanced Regeneration	Seedlings or saplings that develop or are present in the understory.	**NOTE:** See above for concerns regarding natural and advance regeneration. These terms are sometimes used interchangeably.
Stand Density	A quantitative measure of trees per unit of land area, usually measured in number of trees, basal area, or volume per acre.	
Age Class	One of the intervals into which the age range of trees is divided for classification or use. An age class is a distinct aggregation of trees originating from a single natural event or regeneration activity, or a grouping of trees, such as a 10-year age class, as used in inventory or management. Also known as a cohort.	In urban settings, age classes could be created from a tree-planting event, or from seedlings growing in a gap formed during a wind storm.
Cohort	One of the intervals into which the age range of trees is divided for classification or use. A distinct aggregation of trees originating from a single natural event or regeneration activity, or a grouping of trees, such as a 10-year age class, as used in inventory or management. Also known as an age class.	
Site Indicators	A collection of clues (e.g., species composition, buttressed roots, etc.) that indicate site quality in the absence of a site index or in a more natural setting.	In an urban context, you might want to look for social site indicators (e.g., presence of trash, vandalism, ground cover erosion, etc.), as well as things like buttressed roots, indicator species, species composition. and more.
Basal Area	The cross-sectional area of a tree or stand, used to determine stand density.	

Term	Definition	Considerations in Urban Areas
Silvicultural System	A planned process whereby a stand is tended, harvested, and re-established. The system name is based on the number of age classes (see Even-Aged, Two-Aged, Uneven-Aged), and/or the regeneration method used (see Clearcutting, Seed Tree, Shelterwood, Selection, Coppice, Coppice with Reserves). Usually a long-term plan that incorporates multiple treatments.	Silvicultural systems often span decades. In urban settings, managers might need to consider how to align this long-term approach with other urban systems and decision-making that operate on shorter time horizons.
Silvicultural Prescription	A silvicultural prescription is a document which has a planned series of treatments designed to change current stand structure and composition of a stand to one that meets management goals.	Prescriptions normally consider ecological, economic, and social objectives and constraints. In an urban setting, a greater emphasis may be placed on social objectives.
Leave Trees	Trees specially marked to be left untouched during a silvicultural treatment.	In an urban setting, a leave tree could be a tree that is expected to do well in future climate scenarios, provides habitat for wildlife, or is beloved by the community.
Stand Initiation	A stage that assumes a major disturbance has just wiped out a stand, and all the plants are now growing with limited competition for growing space, resulting in an open structure with lots of herbaceous plants and some trees that are short in stature.	Stand Initiation could also be caused by the cessation of disturbance, if the disturbance is something like mowing a lawn or weeding out tree seedlings.
Stem Exclusion	A stage following stand initiation, in which trees start to grow thickly in a single layer but eventually differentiate into crown classes and create multiple strata. Some trees start to die as a result of being overtopped and shaded.	This stage of forest development looks messy and can be dangerous if standing dead trees are not removed. Additionally, this stage of forest development is characterized by very thick growth, reducing sightlines.
Understory Reinitiation	As trees in the upper strata begin to stabilize, plants in the understory begin to grow, though the amount of shade from the overstory keeps the understory somewhat short.	In urban settings, understory re-initiation may include non-native invasive species.
Old-Growth/ Mature Forest	A stage in forest development where the oldest trees (part of the cohort present at stand initiation) reach the end of their lifespan and begin to die.	
Forest Type and Type Mapping	A group of forested areas or stands of similar composition (species, age, height, and stocking) which differentiates it from other such groups. Type mapping refers to the assessment process, whereby these areas are delineated.	Prior understanding of land use history or site history.
Strata	Groups of forest types with the same or similar species composition, age, and height class. These strata may be defined as overstory, midstory, and understory. Other classification systems that are tree-specific refer to crown class, which is an evaluation of an individual tree's crown in relation to its position in the canopy and the amount of full sunlight it receives. The four recognized categories are: dominant (D), codominant (C), intermediate (I), and overtopped or suppressed.	

Planning and Goal Setting

Though silviculture is focused on manipulating vegetation within ecological constraints, people's values dictate why manipulations are made in the first place, and what goals those manipulations are meant to achieve. If the first step is knowing what your city has (assessment), the next step is knowing what your city wants from its forests.

There are many ways to answer the question, "what do you want?" when it comes to forest management. Here, we have described just three of the various ways to think about goals and outcomes of forest management: community input and equity, climate vulnerability, and ecological and forest health. These three related, complementary lenses can help jumpstart planning and goal-setting conversations in your city. There are more resources to help advance goal-setting and planning included in Appendix A.

In the assessment section above, we establish the importance and value of assessments at different scales. Scale also plays a role in planning and goal-setting, two closely related concepts. Citywide assessment data will inform high-level goals and provide a framework for stand-level goals. For example, with a citywide goal to manage a forest for climate resilience, the nested stand-level goal could be to ensure a diversity of species and structures through planting and thinnings. Whatever the goal, progress towards the goal should be measurable, specific, and associated with current and desired forest conditions.[17, 18]

Where there is difficulty in reconciling silvicultural practices and goals in urban settings, managers can draw from a suite of examples in both urban and rural settings. Doing so can assuage community members or officials and show that a silvicultural approach can be appropriate, has been field tested in other settings, and can address "root" problems. In cases where the idea of silviculture faces resistance from stakeholders, drawing on other management paradigms more common in urban settings, such as landscape design or arboriculture, might be beneficial.

High Prarie, near Billings Montana
Steve McConnell

CASE STUDY

Community-Led Silviculture in Baltimore

Location
Baltimore, MD

Climate Type
Humid subtropical

Primary Natural Disturbances
Storms, wind, hurricanes, emerald ash borer

Urban Disturbances
Deer browse, development, chronic city disinvestment, invasive vines, extreme heat, flooding

Past Condition
Standing dead ash trees, heavily invaded, limited regeneration

Desired Condition
A healthy, forested space for multiple uses, focused on community agriculture and light recreation

Number of acres
10 acres

Budget
3800 volunteer hours in 2021, plus Forest Service and church staff time

Implementation timeline
September 2020 to July 2023

Case Study Contact
Nancy Sonti, USDA Forest Service

High-level Management Goals

Stillmeadow Community Fellowship Church owns 10 acres of ecologically degraded forest land in the predominantly Black neighborhoods of Beechfield and Irvington in southwest Baltimore. Stillmeadow Community PeacePark and Forest had many standing dead ash trees, invasive vines, and lacks a robust understory due to deer browse. However, it is also increasingly used and loved by church and community members, and boasts an organic apiary, community garden, orchard, creek, trails, and meditation areas that run through the property. Residents care for the forest through stewardship activities, as well as community science and research, but without more serious intervention, the forest was unlikely to naturally return to a healthy state. Therefore, the church's management goals included removing the hazardous ash trees, restoring the site through careful planting to facilitate natural forest succession, and enhancing climate resilience, with the ultimate goal of creating a space that provides shade, recreation, and spiritual space for the community. The U.S. Forest Service Urban Field Station in Baltimore recognized an opportunity to provide funding and technical assistance to help the church realize its goals, while also conducting valuable research about urban silviculture and forest restoration.

Silvicultural Interventions

In September 2020, U.S. Forest Service staff traveled from the George Washington and Jefferson National Forest to Baltimore to train local staff in removing dead and invasive trees from the PeacePark. Following site clearance, community members and Forest Service scientists planted thousands of fast-growing willow and poplar, and built deer fences to prevent excessive browsing. Lastly, community volunteers worked with the church and Forest Service to remove invasive plants and used wood chips to suppress growth of invasive species.

Outcomes

Teams of community members have already removed much of the standing dead ash, making the forest less hazardous for visitors and increasing light to the forest floor. Willow and poplar seedlings have been planted in these new gaps to test if these fast-growing early-successional species can achieve canopy closure quickly and accelerate forest succession. A "Canopy Crew" of local high school and college students cared for the trees during the first growing season after planting, including deer fence maintenance, hand-weeding of invasives, and watering as needed in drought conditions. Non-silvicultural outcomes included increased local engagement with the forest, developing a shared stewardship model for co-designing interdisciplinary research and co-producing knowledge, and finally, a collaboratively designed model "healing forest," intended to provide space for people who have experienced trauma.

Top: Hazardous ash trees killed by emerald ash borer were removed before restoration work could begin at Stillmeadow PeacePark. Bottom Left: Pastor Michael Martin and church staff open the Stillmeadow nursery, which will provide trees for the silviculture experiment. Bottom Right: Local community members restore the forest with native tree species.
Morgan Grove, USDA Forest Service

Community Input and Equity

The sheer volume of visitors to urban natural areas is one key way that they differ from rural forests. This is a critical consideration when setting goals and planning for the future of the forest. What do the residents of your city need and want from their forested natural space? Do citizens care about trail accessibility? Views? Bird habitat? These insights will be invaluable in determining goals and should inform/be combined with other input to create forest management plans.

There will likely be a variety of desires that come forward. Some might conflict with each other or with ecological goals. Some citizens might love and value non-native trees or plants, at odds with a native-forest goal. Birders may want additional trails through sensitive habitat, compromising regeneration or compacting soil. Conflicts like this are unavoidable and highlight the need to understand community desires from the beginning in order to mitigate greater conflicts later on.

Many groups, particularly Black, Indigenous, and people of color, and low-income people have been purposefully excluded from goal-setting and planning conversations in urban green spaces, the negative effects of which continue to this day. Efforts to include these perspectives from the beginning—to find compromise and problem-solve in partnership with community members—is an essential aspect of planning with equity in mind.

Depending on the outcomes of community meetings or the social assessment methods described in the previous section, community-based goals may or may not call for silvicultural approaches. Some goals, such as improved access from multiple entry points, will probably not draw on silviculture; whereas a desire for a safer trail system and a long-lived forest would call for silvicultural practices. Ultimately, community desires play a critical role in shaping goals and should help shape a resulting forest management plan.

Climate Vulnerability Planning

People within urban areas can be especially vulnerable to the effects of climate change. A high concentration of buildings and impervious surfaces intensify heat and extreme weather, making dense populations more susceptible to extreme impacts. Through the many ecosystem services forests provide (e.g., carbon sequestration and storage, stormwater absorption, heat mitigation, and more), urban forested natural areas can help cities mitigate some of these effects but are themselves vulnerable to the impacts of climate change.[19, 20]

Generally, two approaches to forest management are suggested for climate change mitigation and adaptation, respectively. The first seeks to maximize carbon storage in live trees; the second, to manage forests for a diversity of forest structures and species, as a strategy to enhance resilience to unpredictable, extreme climate events.[21] A balance between the two is suggested for a well-rounded, robust forest that accomplishes the goals of both carbon mitigation and resilience to climate change. Common city-scale management initiatives that promote increased urban tree canopy, species diversity, and tree sizes[22] draw from both approaches. Silviculture is a compatible framework to help achieve these municipal climate goals. Manipulating stand density and managing for diversity are goals supported by many silvicultural strategies, such as thinning, regeneration treatments, and episodic entries into stands.

Ecological and Forest Health Planning

Ecological and forest health can encompass a wide array of biophysical factors including but not limited to: disease and pest incidence, natural regeneration, water quality and provision, non-native and invasive species prevalence, and biodiversity and wildlife.

Cities often establish goals related to urban tree cover, species diversity, and tree size,[23] as well as goals related to native species conservation, public safety, and trails.[24] All of these goals can be achieved within a silvicultural system; however, goals set by a diverse group of stakeholders may clash with ecological goals. For example, clearing the mid-story to improve sightlines and public safety might clash with an ecological goal to maintain or improve native vegetation cover, biodiversity, and forest health. The role of the urban forested natural area manager is to help find compromises and communicate between groups to arrive at a solution.

TABLE 4

The Three Planning Lenses Described Above are Summarized and Put into Context with Some Examples from U.S. Cities

Planning and goal-setting for urban forest natural areas can benefit from the use of different lenses. Below are three examples that can help managers think about activities and outcomes in different lights.

Planning Lens	Short Description	Putting It Into Action	Example
Community Input and Equity	Shaping a forest that serves the needs of as many urban residents as possible requires listening to the community and including their goals in an official plan. There must also be an understanding that past planning decisions reverberate in the present day, disproportionately affecting low-income people and people of color. An equity lens recognizes that green spaces and natural areas are both a source of and solution to problems of inequity in cities.	Asking questions (of yourself, your colleagues, and community residents) about who benefits, who doesn't, and why is a good starting place. Engage with community leaders, conduct focus groups, or integrate any social assessment data into goal-setting and throughout the planning process.	*Austin's Climate Equity Plan* *Baltimore's 2019 Sustainability Plan*
Climate	A climate planning lens takes the projected climate changes in a region as the starting point. What is predicted to change? How can your forests be prepared to handle the projected changes? This requires a vulnerability and adaptation assessment that helps managers identify potential climate threats, risks, and adaptive capacity.	The Climate Change Response Framework offers an *Adaptation workbook*, developed by the Northern Institute of Applied Climate Science, to facilitate climate vulnerability planning, with specific suggested forest management actions.	*Adaptive Silviculture for Climate Change in the Mississippi National River Recreation Area* *Climate Adaptation Actions for Urban Forests and Human Health* *Climate Change Vulnerability and Response in Seattle's Urban Natural Areas* provides an example of a climate planning lens, including approach and recommendations.
Forest Health	A forest health lens sets goals according to current and desired measures of many factors, such as native species, prevalence of pests or pathogens, natural regeneration, biodiversity, and more. Requires a basic understanding of forest condition and structure.	The Forest Landscape Assessment Tool (FLAT) developed by urban forest managers and the USDA Forest Service provides a methodology to assess the condition and structure of any type of forest. It includes a case study detailing the implementation of FLAT in the highly urbanized King County, Washington.	*Forest Management Framework* from New York City, NY *City of Boise Reserves Management Plan* documents the health of each open space reserve within the city and articulates the connection between high-level forest health goals and specific management actions.

CASE STUDY

Single-Tree and Group Selection for Forest Restoration in Cleveland

Climate Type
Humid continental

Population
1.76 million in the metro area

Primary Natural Disturbances
Pest outbreaks

Urban Disturbances
Non-native invasive species

Number of acres
16 acres

Budget
Break-even between timber income and expenses

Implementation timeline
Inventory winter 2018, stand marking in early winter 2019, harvest in August 2019

Case Study Contact
Constance Hausman, Cleveland MetroParks

Top: After conducting a forest inventory, staff marked trees to remove in a single-tree selection and group selection silvicultural treatment.

High-level Management Goals

Located across Cuyahoga County, Ohio, the Cleveland Metroparks system rings the city and metro area, encompassing more than 24,000 acres of land. The park system acquires new properties regularly with mixed land use histories, such as old tree plantations and fallow farmland. In one 16-acre stand which was likely an old pasture abandoned in the 1930s, multi-stemmed, small-diameter red maples had densely colonized the site, with little to no mid- or understory, though some other tree species were present. Managers wanted to reset the trajectory of the site by reducing density to open up light and stimulate new regeneration with structural and species diversity, thus enhancing the climate resilience of the stand.

Silvicultural Interventions

A forest inventory, in partnership with the Ohio Department of Natural Resources, helped Metroparks staff calculate various stand attributes and develop management prescription options. The stand was marked as a single tree selection and focused on removing poorly formed, damaged, and multi-stemmed trees. Three group openings were also marked to enhance larger light gaps. Prior to harvest, buckthorn and other aggressive non-native invasive species were removed from the understory. In late summer of 2019, during the dry season, loggers used an existing gravel trail to enter the stand. Tree density was reduced from 135 square feet of basal area to 80–100 square feet of basal area per acre, mostly removing poor conditioned red maples. Black cherry and red oaks, two light-demanding species, were left behind as seed sources to catalyze a new flush of diversity. These species were left behind also because they are projected to be resilient to future climate conditions. Managers did not plant the site, relying instead on natural regeneration. A large deer fence exclosure was established around a 4-acre area to protect future regeneration.

Outcomes

The harvest was completed in August 2019, with monitoring planned in 2021. Anecdotally, managers have noticed increased regeneration within the deer fencing, including species that had not been present on the site or were scarce before harvest, such as cucumber magnolia and serviceberry. The revenue generated from the timber harvest provided funds to pay a consulting forester and to cover a portion of the deer fence. Managers were concerned about public response to a timber harvest on a very visible and accessible part of the park and carefully prepared staff to answer questions from the public. The harvest plan was presented at a public board of commissioners meeting, and materials explaining the purpose of the harvest were written up, anticipating questions from the public. The site now serves as a destination to demonstrate sound forest management practices, and Cleveland Metroparks staff provide public programming, tours, and special field trip workshops onsite.

An overstocked stand of multi-stemmed red maples cast dense shade and prevented a new cohort of tree seedlings from establishing.
Constance Hausman, Cleveland Metroparks

Removing parts of the canopy allowed sunlight to hit the forest floor and encourage natural regeneration of species other than red maples. Leaving behind black cherry and red oak as seed sources was a strategic choice, since these species are predicted to be well-adapted to future climate change conditions.
Constance Hausman, Cleveland Metroparks

Implementation and Operations

Silviculturists draw on a wide range of tactics that span a gradient from very intensive to light-touch manipulations. Knowing which one to use requires a deep understanding of the forest you have (assessments), how the species within react to environmental changes ("forest stand dynamics," described above), and where you want to end up (community input and goal-setting).

After all of the factors above are considered and addressed, the question still remains: How can a city adapt silviculture, operationally and practically, to urban conditions? The answer will depend on the forest type, the city's circumstances, and the many factors described above (policies, community goals, funding, etc.). However, there are a few suggestions for rural-to-urban adaptations that may help urban forested natural area managers take advantage of the wide suite of tools offered in the silvicultural toolbox. This section refers to the examples throughout the guide. The real-world adaptation of silviculture to urban settings is happening right now in cities, and those examples provide the best suggestions for translating rural practices to urban settings.

Public Communication

Cities are accountable to a broad public, and urban forested natural areas are well-used and frequently visited by urban residents. It is necessary to communicate the purpose, duration, and follow-up actions of any silviculture that may take place in an urban forested natural area, ideally with an explanation of how the silvicultural action works towards achieving a public goal.

Communication with the public can and should happen over a wide variety of platforms. Proactive outreach via press releases to local media, public meetings, flyers, door knocking, and social media are all encouraged. Outreach to any organized user groups such as hiking clubs or mountain biking organizations is advised. Staff who work in the natural area should receive training and talking points, so they are prepared to answer questions from visitors. Finally, signage can aid in explaining why and how silviculture is taking place, especially if it addresses some of the most frequently asked questions.

Urban forested natural area managers in the examples below (notably St. Louis, MO, and Cleveland, OH) took time to explain to the public, organized user groups, and officials why they were removing trees. They were pleasantly surprised by the wide breadth of understanding and approval their work received. This is a best practice and necessary step for the successful use of silviculture in cities.

Strategic and Opportunistic Action

Forest management can be difficult to execute in cities for reasons related to inconsistent funding for management, public visibility and perception, and logistics. Some cities across the United States have found ways around these difficulties.

Expenses for implementing silvicultural practices can be offset by timber exchange or sales if enough trees are removed, as in the case studies from Gainesville and Cleveland. Engaging volunteers, as in Baltimore, can also reduce costs, especially during site prep, planting, or seeding events. Spacing forest management activities out over time can reduce immediate costs, as in Forest Park in St. Louis, where thinnings and burnings take place in small areas (sometimes as little as one acre) each year as annual funding permits.

Given the spatial constraints and operational challenges of moving large equipment and machinery through a public park or natural area, compounded by possible misperceptions by the public (even with proactive communication), managers in urban settings may choose to use lower-intensity silvicultural treatments. The examples of lower-intensity silvicultural interventions from Chicago show that using chainsaws to remove fewer trees, paired with underplanting of tree species, can have the same effect as a more intense canopy removal. Thinnings in Seattle also show that selective removal with chainsaws, combined with plantings of desired tree species, can achieve the target forest structure and composition. The New York Botanical Garden removed non-native invasive tree species that had grown too large, again with chainsaws in a single-tree removal approach.

In settings where more intensive interventions are needed to adjust the forest trajectory, thoughtful use of heavy machinery, strategic timing, and special attention to the optics of the treatment can go a long way. Forest Park in St. Louis, MO used large machinery to remove large unwanted native tree species but did so in the middle of winter. Winter is the best time to remove trees to protect soil and ground cover and the time with the fewest people in the park. Quick removal of logs reduced inquiry, and ample communication helped explain to curious park visitors what was happening, and why.

TABLE 5

Urban Silviculture Goals, Natural Disturbances Emulated, Strategies, and Challenges Organized by Forest Condition and Structure

The table above shows some common urban forest goals, such as sustaining native forest communities and restoring degraded sites. It connects these goals with silvicultural treatments that can help realize the desired outcomes. Adapted from Piana et al 2021.

Management Unit	Goal	Challenges	Opportunities	Potential Silviculture Treatment	Natural Process or Distrubance Emulated
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 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	Seed rain, seed bank, animal dispersal
Canopy Gap	Canopy closure, promote natural regeneration of native species	Invasive plan speices, locating gaps and acting expeditiously, multiple treatments needed over long time frames	Low cost interventions to maintain connected healthy forests	Direct planting and seeding, passive restoration via seed bank, weeding, minimizing invasion risk	Seed rain, seed bank, animal dispersal, adventitious sprouting
Invaded Forest	Shift community trajectory towards target forest type, promote natural regeneration of native species	Legacy site effects, multiple treatements needed over long time frames, costly, social perceptions, uncertain results	Increased social and ecological benefits, reduce seed source and spread of invasion	Selective thinning/ harvesting, direct planting and seeding, reliance on natural regeneration	Wind storms, seed rain, animal dispersal, stump sprouts
Healthy Forest	Sustain native forest communities and promote 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, promote continued forest diversity in terms of species, age class, and forest structure	Thinning, seeding, monitoring, shelter wood	Wind storms, hurricanes, light to moderate fires, light insect damage

CASE STUDY

Herbicides and Prescribed Burning for *Ailanthus altissima* Management in Ohio

Location
Tar Hollow State Forest, Ohio

Climate Type
Humid continental

Primary Natural Disturbances
High winds

Urban Disturbances
Prevalence of non-native invasive species and diseases, climate change

Past Condition
Heavily invaded oak-hickory-yellow poplar forest

Desired Condition
Healthy oak-hickory-yellow poplar forest dominated by native species

Number of Acres
Not available

Budget
Not available

Implementation Timeline
2009–2014

Case Study Contact
Todd Hutchinson, USDA Forest Service

High-Level Management Goals

Throughout the eastern U.S., non-native invasive tree-of-heaven (*Ailanthus altissima*) proliferates in urban settings and increasingly in rural forests. In Tar Hollow State Forest in southeastern Ohio, researchers decided to reduce the prevalence of tree-of-heaven using herbicide, herbicide and fire, and fire treatments, along with a control. Anecdotally, fire was thought to have a positive effect for tree-of-heaven spread. The goal was to better understand the effects of fire on tree-of-heaven, and post-treatment outcomes. Experimental plots were established where tree-of-heaven represented 28% of the basal area.

Silvicultural Interventions

Tree-of-heaven stems greater than or equal to 3 centimeters at dbh in the herbicide treatment plots, and herbicide and fire treatment plots received a dose of imazapyr via stem injection (hack and squirt) prior to any burning. Burn crews then set prescribed burns in the herbicide and fire and fire-only plots. Monitoring took place every other year for four years, in 2010, 2012, and 2014.

Outcomes

Herbicide and fire treatments were very effective at reducing tree-of-heaven prevalence, with 98.8% of trees and 99.4% of saplings dead in the first post-treatment growing season (2010). Herbicide-only was the next most effective treatment, killing 72.4% of trees and 85.7% of saplings. Fire-only treatments resulted in 29.5% mortality for the smallest trees (smaller than 10 cm dbh), and no mortality for larger trees, though there was some top-kill and resprouting. Each of the treatments were more effective than the control. Natural regeneration following the experiment showed native tree species returning, though the desired oak-hickory regeneration was lower than other native species. Four years after treatment in the fire-only plots, tree-of-heaven densities were beginning to recover, though they were still lower than pre-treatment densities.

Top to Bottom: Before prescribed fire, scientists treated some *Ailanthus altissima* with herbicide; Scientists used controlled burns as an experimental treatment for reducing the prevalence and spread of *Ailanthus altissima*. This invasive tree, also known as tree-of-heaven, is widespread in U.S. cities; The silvicultural treatment of combining herbicide and fire was most effective for removing the invasive *Ailanthus* from the forest, though some still grew back after the treatments.
Todd Hutchinson, USDA Forest Service; Joanne Rebbe (middle)

CASE STUDY

Silviculture for Climate Resilience in Ex-Urban Southern New England

Location
Connecticut and Rhode Island, USA

Climate Type
Humid temperate

Primary Natural Disturbances
Wind, fire, hurricane

Urban Disturbances
Pests, invasive plants, deer

Past Condition
Oak-hickory closed-canopy forest with beech-maple subcanopy

Desired Condition
Multiple conditions — but diverse, climate-resilient forest in general

Number of Acres
At least 3 sites, each 40–50 acres

Budget
Research budget ~$120,000

Implementation Timeline
Co-development workshop in 2020, Management implementation 2021–2022 across 3 sites, Monitoring for at least 20 years

Case Study Contact
Todd Hutchinson, USDA Forest Service

High-Level Management Goals

The forests of southern New England, broadly categorized as oak-hickory forests, are slowly transitioning to a more mesic and shade-demanding suite of species, notably maples, birches, and beeches. This transition may make the forest more susceptible to the projected effects of climate change in the region, such as warmer temperatures and longer growing seasons; changes in precipitation patterns, with more frequent and intense storms, less snow and more drought in the late growing season; and increased threats from pests, invasive plants, deer, and diseases. Through a suite of management and silvicultural activities, a collective of forest managers and researchers are planning to test resistance, resilience, and transition strategies. The main goals are to understand what silvicultural approaches will help maintain forest health in southern New England despite climate change impacts and to identify silviculture practices that are amenable on private lands in exurban or suburban areas. This project is a part of the Adaptive Silviculture for Climate Change (ASCC) Network of experiments.

Silvicultural Interventions

Like other projects within the ASCC Network, such as the St. Paul example, the forest sites in New England will test different strategies related to climate resistance, resilience, and transition. Resistance strategies aim to maintain the current composition and structure of the forest and will use a 3-stage shelterwood over the course of 20-30 years to that end. Reserves within the shelterwood will preserve pockets of legacy structures, create areas less vulnerable to windthrow, and provide habitat for rare species. Resilience strategies seek to alter current conditions primarily through species and structural diversification. Implementing patch cuts of at least ½ acres to permit more light-demanding species to regenerate, centering on areas where mortalities from gypsy moth (Lymantria dispar) create the opportunity is one example. Another resilience strategy is to underplant trees that are expected to be adapted to future climate conditions, including the reintroduction of American chestnut (*Castanea dentata*). Managers will also reintroduce fire to the landscape when possible. Transition strategies actively facilitate forest change. In southern New England, managers and researchers will look to create novel species assemblages through large patches or clear cuts, with future-climate-adapted plantings underneath and a "feathering" effect on the edges of the cuts to create a gradient of light conditions. Reserves will be maintained to vary in structure and species composition.

Outcomes

This project is still in development with initial implementation in late 2021. Managers are developing site-specific plans for implementation while also identifying additional sites to test the resistance, resilience, and transition approaches. Forest ownership in southern New England is a mosaic of small parcels under different management regimes. Project partners seek to mimic that social dynamic by replicating treatments across multiple ownerships.

TABLE 6

Some Silvicultural Terms Relevant to Implementation and Operations, with Definitions and Urban Considerations

Term	Definition	Considerations in Urban Areas
Artificial Regeneration	Human-directed planting of trees through direct seeding, cuttings, bare-root plantings, or enrichment plantings.	Often seen in urban areas through tree-planting programs or forest restoration efforts.
Regeneration Cut	A category of relatively intense silvicultural treatments that serve to help the stand regenerate. Examples include clear-cuts, seed-tree cuts, and shelterwood cuts.	These treatments emulate big, stand-replacing disturbances like fires and hurricanes. They are unlikely to be practiced in urban areas, but are included here for context (however, see example from Gainesville.)
Seed-Tree Cut	A regeneration cut that removes the majority of the stand, with the exception of a few trees that will provide seed source for the next cohort, producing an even-aged stand of new trees. Seed trees are removed after the new cohort establishes from seed.	
Clear Cut	A regeneration cut that clears all vegetation from the stand. Tends to favor wind-dispersed species and pioneer species, often paired with site treatments such as burning.	
Shelterwood	A regeneration cut that favors shade-intolerant to mid-shade-tolerant tree species, during which much of the existing basal area of the stand is removed but certain trees are left standing to provide seed source and shade to the new cohort of trees. Also favors advanced regeneration.	
Overstory Removal	A cut made after a shelterwood cut, in which the canopy trees left in the previous shelterwood are removed to release the advanced regeneration.	
Single Tree Selection	A method of creating new age classes in uneven-aged stands in which individual trees of all size classes are removed more or less uniformly throughout the stand to achieve desired stand structural characteristics. Used to achieve an uneven aged stand, or within an uneven aged stand.	Single-tree selection can be used to improve sight lines or to remove invasive trees, but may encourage other invasive species or nuisance vines in the gap that is formed. **NOTE:** Depending on the management goals of different cities, this method can lead to a slow degradation. For example, single-tree selection does not favor shade-intolerant species like oak and would be incompatible with a goal to encourage and oak-dominated canopy.
Low Thinning	The removal of trees in lower crown classes (intermediate, overtopped) to favor those in the upper crown classes.	In urban settings, this could be used to improve sight lines, to remove invasive trees, or to remove native trees that are not expected to be adapted to future climate conditions.
Crown Thinning	The removal of trees in the upper crown classes (dominant and co-dominant) to favor the best trees of those same crown classes.	
Group Selection	The removal of a small patch of trees (a group), typically at least ¼ of an acre in size. Used to create a multi-aged stand.	See examples from Cleveland, St. Paul, and northern Minnesota.

Cypress dome ecotone pine flatwoods at Julington-Durbin Preserve, Jacksonville FL

Sarah Tobing

Monitoring and Adaptive Management

Monitoring is defined as capturing data over time to assess the status or change of site conditions after a silvicultural intervention. It can provide managers with important information about treatment outcomes in comparison to the desired results. It can also help managers decide what to do next to achieve the goals in their management plans. Monitoring is a way to protect the investment made by conducting silviculture, allowing managers to answer the following questions:

- Was the silvicultural treatment successfully implemented?
- Did the silvicultural treatment actually achieve the goal(s) set forth?
- Was silviculture the most effective way to achieve the goal(s)?[25]

Answering these questions encourages the managers to collect data, assess, and reflect, steps that are part of an approach to natural resource management called *adaptive management*.

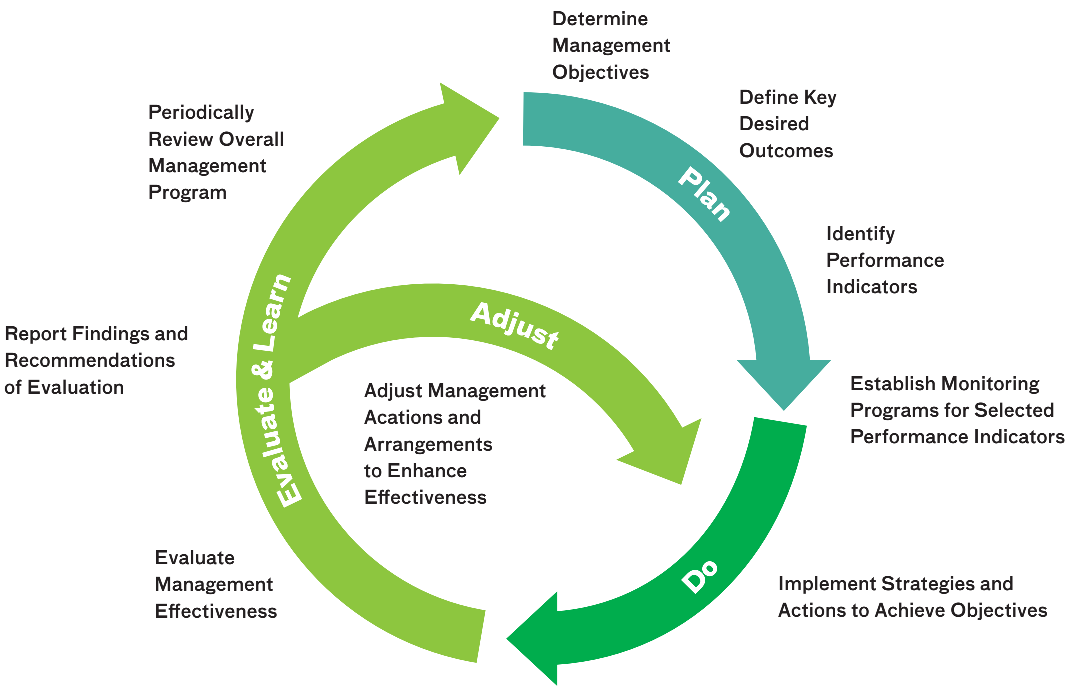
Adaptive management is a formalized framework that enables managers to learn from outcomes of silvicultural or other management interventions, making room for adjustments to a plan.[26] Essentially, adaptive management is a set of formalized, rigorous steps that guide the manager through experimentation, implementation, and evaluation with the intention of learning and using those findings to determine next steps. Adaptive management is also a way to help managers make decisions even when there are high levels of uncertainty, such as in the case of a new, untested management action.

For example, imagine a thinning project in an urban forested natural area. Managers would decide what outcomes they hoped to achieve with a thinning and determine what metrics would indicate if the thinning helped achieve those outcomes. In the case of a thinning, managers would want to have a clear picture of the composition and structure of the forest. This could be

FIGURE 8

The Adaptive Management Cycle

The Adaptive Management Cycle (DPIPWE 2014; Jones 2005, 2009). Reprinted with kind permission of Glenys Jones and the Tasmania Parks and Wildlife Service (Department of Primary Industries, Parks, Wildlife and Heritage-DPIPWE).



achieved through a fine-scale inventory that captures the size and species of all or most trees in the forest, or through a sampling approach that measures only some trees. This data would provide a comparative baseline for measurements taken after the thinning. It would tell the manager whether or not the thinning was successful according to their predetermined metrics and provide a clearer picture of what interventions might be needed next.

Using an adaptive management framework is an ongoing process that touches on each of the sections described in this guide. For example, problem identification and clarification will change depending on which perspectives are represented in the room (discussed in the "Community outreach and goal-setting" section). The design of the intervention will change depending on how the problem is defined, what goals are established, and what managers have to work with ("Biophysical assessment").

This flexible approach enables managers to learn as they go and make decisions using the most up-to-date data and best practices. That said, an adaptive management approach to urban forested natural areas must be balanced with a long-term vision and stable management objectives. While adaptive management uses current data to make necessary and immediate decisions, climate change projections must also be considered for long-term planning.

Below, a table demonstrates how a forest manager could measure progress made towards example goals, representing a sampling of metrics and measurements to track.

TABLE 7

Example Forest Goals and Metrics, with a Resource Protocol to Demonstrate its Use in Real City Settings

Below are some example goals that an urban forested natural area manager might want to achieve, using silvicultural techniques as a way to reach the goal. The "Pathway" describes what would need to change in a forest to achieve the goal — the "how." The "Measurements" describe how a manager can measure the changes in a forest and know if the intervention is working. "Resource protocols" are real-life examples that cities are already using to help them asses progress towards such goals.

Goal	Pathway	Measurement	Resource Protocol
Increase Carbon Sequestration and Storage	Increase growth rates of trees	Diameter of the tree is measured at 4.5 feet off the ground (diameter at breast height, abbreviated to dbh) over time	*Monitoring Data Collection Methods in the Urbanized Pacific Northwest*
Increase Habitat for Native Flora and Fauna	Decrease abundance of invasive species	Percent coverage of invasive species	*Monitoring Data Collection Methods in the Urbanized Pacific Northwest*
Encourage Natural Regeneration	Establish new cohort of seedlings	Percent coverage or count of seedlings	*Green Seattle Partnership Inventory Protocol*
Long-Term Forest Health	Monitor tree mortality rate	Percent dieback of live crown area	*Upland and Forest Ecological Assessment for New York City*

Management and Funding Cycles

Paul Ruster Park, Indianapolis, Indiana
Indianapolis Department of Public Works, Engineering, and Land Stewardship

Forests take a long time to mature, and silvicultural prescriptions reflect that reality, sometimes spanning 25 years or longer — much longer, in some cases. For optimal forest health, cities need to be ready and able to support management actions for the long-term, through consistent funding and policy that facilitates protection and care.

While the forest provides many benefits for urban residents, funding often falls short of what is needed. 94% of urban forested natural areas managers from across the United States describe limited funding or staff as a challenge, according to a 2019 survey.[27] Additionally, annual city budgets and grants provide funding on a relatively short (one-to-three-year) timescale. This is an abbreviated timeframe compared to the lifetime of a forest. Urban land use change and decision-making happen quickly in comparison to more rural areas. Having to spend funds over this short time period can force managers to make management decisions based on the funding timeframe, rather than more ecologically-appropriate timeframe.

Tying urban forested natural area management to city or grant funding renders these areas vulnerable to the ups and downs of municipal or organizational budgets.[28] This happened in 2020 when the COVID-19 pandemic affected budgets for 12 cities' natural areas management, in the form of hiring freezes, seasonal staff cuts, and contract work reduction.[29] The short-term impacts were evident: urban residents continued to use natural areas,[30] and fewer people and resources for restoration and management resulted in forest degradation, and in many cases set work back. For many cities, the COVID-19 pandemic highlighted that insufficient and irregular funding patterns had been a problem for a long time; a 2019 survey showed that 82% of cities already suffered from limited funding and staff.[31]

Despite the challenges posed by typical funding timeframes and ecological timeframes, cities do manage to conduct silviculture with the resources available to them. Positioning natural area goals and plans in a silvicultural framework can help show the need for long-term management, and could unlock funding and new partnerships. Examples from other cities show that proactive management using silvicultural approaches can address "root" causes of ecological problems, making the argument that more funding will reduce costs for restoration or management in the long run.

Conclusion

Though most commonly practiced in rural forests, silviculture has a place in urban forested natural areas and, indeed, is a current practice in many cities. In its essential form, silviculture is a long-term systemic framework based on proven approaches to achieve specific goals in any forest setting, whether rural, urban, or in between.

We have provided a high-level overview of the main components of silviculture, described how those components are realized, and suggested sways to adapt them to urban settings. The real-world case studies in a variety of settings ground the theory in practice. Between the information contained in this guide and the practical resources that follow, we aim to provide a starting point for urban forest managers to use the time-tested and scientifically vetted suite of silvicultural tools to enhance the health of their urban forested natural areas.

Taken together, we hope these resources provide tools to sustainably manage urban forested natural areas. As forest managers know well, the benefits urban forested natural areas provide are expansive, and without care and protection, they are subject to degradation. Viewing these urban forested natural areas as *forests*, with similar ecosystem benefits and ecological processes as forests found in rural settings, can encourage management. Using silviculture can help aid this shift in perspective.

Seward Park,
Seattle, Washington
Audobon Society

Appendix A

Below is a list of more detailed lists of requirements to carry out silviculture in a city. This list is meant as a starting point and will vary depending on your city and the extent of your assessment, planning, and operations. Following this list is a collection of resources that provide examples of protocols that can be directly borrowed or modified to implement your silvicultural project.

Before You Start

- Have a plan that includes your goals and desired outcomes
- Access to the land and permission to collect data
- Time dedicated to data collection, analysis, and planning
- Staff with training in forest mensuration methods
- Staff to analyze and summarize the information you collect

Skills

- Ideally, ability to use GIS and download files related to soil types, hydrology, and topography
- Plant identification, especially with trees in many stages of development and non-native invasive species
- Familiarity with and ability to use forestry inventory tools, such as an angle gauge or dbh tape
- Ability to use Excel or another similar program to analyze data.

Equipment
(some of these items will be optional, or dependent on the approach taken)

- Data sheets
- Diameter tape to measure tree diameter at breast height (dbh)
- Measuring tape to measure plots
- Quadrat to assess understory and advanced regeneration
- Handheld GPS device or smartphone
- Computer with Excel or other data-entry and -analysis software
- (If you decide to remove trees) Paint and paint guns for marking and any saws or equipment needed to remove trees
- First aid kit

Plans and Data

- Maps of forested natural areas in your city
- Stands delineated within the forested natural areas
- Appropriate number of plots identified across the forested natural areas to collect representative data
- Data collected related to:
- Species composition on a per-stand basis
- Basal area on a per-stand basis
- Size class distribution by species on a per-stand basis
- Percent cover and composition of understory species on a per-stand basis
- Nonnative and invasive species percent cover and composition on a per-stand basis
- Natural regeneration presence/absence, species, and density

Planning

- Forest management goals
- Community and resident desires for forested natural areas
- Site level prescriptions to meet desired goals
- Field schedule

Implementation

- Appropriate permits and communication with partners
- Staff or volunteers trained to complete the work

Monitoring

- Follow-up data sheets to assess how management interventions are tracking with desired outcomes

Protocols for Urban Forested Natural Areas Biophysical Assessments

- *The Natural Areas Conservancy Upland and Forest Ecological Assessment*, developed for use in New York City, New York. Contains data sheets, a list of metrics to collect and why, steps for taking measurements, and sampling designs.
- *Green Seattle Partnership Forest Inventory Protocol*, developed for use in Seattle, Washington. Contains data sheets, a list of metrics to collect and why, and sampling designs.
- *Assessing Urban Forest Patch Health: A Protocol*, developed for use in Baltimore, Maryland. Contains a tutorial on using Google Earth to find forest patches, using Excel to determine sampling plots, a description of what field you need to collect data, a soil assessment guide, and sample data sheets.
- *Assessing Houston's Forested Habitat*, developed for use in Houston, Texas. Contains methods for using GIS and remote sensing to assess an urban forest landscape and suggestions for the number of plots per acre for assessment.
- *USDA Natural Resources Conservation Service Forest Inventory Methods*, developed for general use in the United States. Describes the rationale for taking a forest inventory, methods for taking forest inventory data, directions on how to use tools such as an angle gauge, equations for calculating and scaling basal area, and sample data sheets.

Protocols to Assist with Urban Forested Natural Areas Social Assessments

- *How to Engage Diverse Communities: A Tool Box*, developed by the University of Kentucky. An in-depth collection of 46 step-by-step guides to conducting community outreach and building community relationships.
- *Inclusive outreach and public engagement guide*, developed by the Seattle Race and Social Justice Initiative. Contains concrete steps to help make outreach and public engagement more inclusive in city settings.
- *Racial Equity Toolkit to Assess Policies, Initiatives, Programs and Budget Issues*, developed by the Seattle Race and Social Justice Initiative. Contains guidance to make sure racial equity is taken into account when making plans and policies, a step-by-step process for considering racial equity, and a glossary for understanding what racial equity means and why it matters.
- *Baltimore's Forest Patches: Emerald Assets for Ecosystem Services*, developed for use in Baltimore, Maryland. Contains a spatial analysis of Baltimore's forest patches in relation to transit, property values, and water bodies; as well as policy recommendations for forest management.

Examples of Urban Forested Natural Areas Social Assessments

- *Reading the Landscape: Citywide Social Assessment of New York City Parks and Natural Areas in 2013–2014*. Contains a methodology for conducting a social assessment of urban natural areas, as well as outcomes from a social assessment in New York City.
- *The Stewardship Mapping and Assessment Project* (STEW-MAP) is a research methodology, community organizing approach, and partnership mapping tool that can be used to identify new and existing organizations working across a landscape and depicts strategic networks, stewardship gaps, and overlaps in activity.

Resources for Urban Forested Natural Areas Climate Vulnerability Assessments

- *Climate Adaptation Actions for Urban Forests and Human Health* from the Northern Institute of Applied Climate Science. Contains guidance on forest management actions and connects their outcomes to human health in a "menu" format.
- *Adaptation Workbook*, developed by the Northern Institute of Applied Climate Science that walks you through potential climate change impacts on a specific parcel of land, and helps piece together adaptation actions to address those impacts.

Monitoring Protocols

- Rapid Site Assessment (RSA), found on page 38 of the *Forest Management Framework*, is meant to be a quick way to evaluate success before and after forest management interventions.
- *Natural Area Monitoring in Indianapolis* describes an approach to always-on monitoring in urban forested natural areas.
- *Monitoring Data Collection Methods in the Urbanized Pacific Northwest* provides concrete methods for collecting monitoring data. Written specifically for the urbanized Pacific Northwest, the methods can be adapted to any urban location.

Appendix B

A silvicultural prescription outlines a series of treatments that may be enacted over time to achieve the management goals in a forest site/stand. It may include multiple treatments. A silvicultural prescription draws upon data from a forest inventory and site assessment, and will be incomplete without that information. It is used to guide contractors, staff, and future managers. It's also a document to keep everyone on the same page as the implementation progresses, sometimes over decades.

This template, below, is meant to provide a starting place for urban forest managers that want to conduct silviculture in their cities. Adapted from many silviculture prescriptions from rural areas, this template reflects the unique aspects of urban forests. Use and change this template to suit the circumstances of your forest and your city.

Stand Name and Type of Silviculture Prescription

(Ex: Stand 4, Canopy thinning)

- Date the prescription was posted
- Date the trees were marked
- Total area marked (ac):
- Date the trees will be removed:
- Volume of marked timber
- Standing basal area (ft2/ac)
- Total board feet per acre:
- Total number of trees per acre:

Introduction and forest/site description:

Include a brief description of the forest:

- Dominant species composition
- Herbaceous layer and any advanced regeneration
- Average structure
- Any water features
- Roads, trails or infrastructure
- Topography, soils, general geology (rocky, sandy, etc)
- Ownership and land use history
- Any prior silviculture or forest management and those outcomes
- Future stand conditions if left untreated
- Desired future conditions

Management Unit/Stand Description

Build on the site description with more specific qualitative information about the stand

- Disturbance history and regime
- Forest structure, species and age classes
- Wildlife Habitat conditions
- Include attributes such as snag density and condition and the presence of down
- woody material
- Specific information on endangered species that exist within the stand
- Water resources
- Recreational and aesthetic resources
- Trails
- Amenities (comfort stations, benches)
- Physical or biological agents observed or of concern
- Common use of the stand (hiking, running, etc.)
- Times of day with heaviest use/visitation

Current Management Unit/Stand Data

- Average basal area per acre
- Average stem density per acre (trees per acre)
- Quadratic mean stand diameter
- Relative density per acre

Silvicultural Goals

Give bullet points of your silvicultural treatment and objectives. What are you doing to the forest, and why?

- Expand on desired future conditions
- Describe the precise silvicultural system you intend to use
    - What is the immediate action?
    - Describe the current stand condition in quantitative terms, and how you want it to change in quantitative terms (e.g., currently 118 average trees per acre, with a goal to reach average 90 trees per acre)
    - What is the follow-up action? How long before the follow-up action takes place?
    - Is there a third entry or action?
- With these in mind, describe how the silviculture system prescribed will address the primary goal.
    - The secondary goal
    - The tertiary goal
    - The wildlife goal
    - The climate adaptation goal

Public Outreach and Access
Describe how you have communicated with the public about the planned silvicultural treatment. Were relevant community groups consulted prior to writing this prescription? Will the public be able to see the stand during implementation? What signage will be in place?

Management Unit/Stand Marking System
Describe how trees will be marked for removal, cull, or snag creation. What color paint? Are there reserves? How will you make note of those?

Operational Considerations
What equipment is needed? What paths through the forest have been marked out for machinery or vehicles to move around? What will be done with excess material that should not be left in the forest? What permits are required, and have they been granted? Where will cut trees be placed (areas known as landings)? How have wetlands and streams been delineated so contractors can avoid them?

Wildlife Considerations
How will your prescription affect wildlife? What structures will be created for which species? From the ground story to riparian buffers to the canopy, describe what impacts the treatment might have.

Invasive Species, Pests, and Pathogens
What non-native invasive species are present in the stand? How will increased light, moisture, or change in nutrients affect non-native invasive species? What will you do to address it? Think about pests and pathogens. Are you cutting at the right time of year to avoid airborne pathogens? What are best management practices in your state or city for avoiding pests? Access to the stand during the intervention? What notice have you given to park or forest users to alert them to the planned activity?

Cultural Considerations
Are there areas of special use or history that should be protected? Examples could include: remnants of historical land use, like walls, burial grounds, cellar holes; areas of cultural importance to Native groups; or areas especially beloved by the public.

Legal Considerations
How does your treatment square with local and state law?

Notes

1. Lahr, E. C.; Dunn, R .R.; and Frank, S. D. 2018. "Getting ahead of the curve: cities as surrogates for global change." *Proceedings of the Royal Society of Biological Science*. Vol 285: 20180643. https://doi.org/10.1098/rspb.2018.0643
2. Piana, M. R., Pregitzer, C. C., Hallett, R. A. 2021. "Advancing management of urban forested natural areas: toward an urban silviculture?" *Frontiers in Ecology and the Environment*. 1–10.
3. Pregitzer, C.C., Charlop-Powers, S., Bibbo, S., Forgione, H. M., Gunther, B., Hallett, R. A., Bradford, M. A. 2018. "A city-scale assessment reveals that native forest types and overstory species dominate New York City forests." *Ecological Applications*. pp 1–11.
4. Vieira, J., Matos, P., Mexia, T., Silva, P., Lopes, N. Freitas, C., Correia, O., Santos-Reis, M., Branquinho, C., Pinho, P. 2018. "Green spaces are not all the same for the provision of air purification and climate regulation services: The case for urban parks." *Environmental Research*. Pp 306-313.
5. C. C. Pregitzer, Hanna, C., Charlop-Powers, S., and Bradford, M. A. 2021. "Estimating carbon storage in urban forests of New York City." *Urban Ecosystems*.
6. Forest Service Manual National Headquarters. 2014. "FSM 2400 Forest Management; Chapter 2470 Silvicultural Practices."
7. Pregitzer, C.C., Charlop-Powers, S., McCabe, C., Hiple, A., Gunther, B., Bradford, M.A. 2019 "Untapped Common Ground: The Care of Forested Natural Areas in American Cities." 46pp. Published by: Natural Areas Conservancy.
8. D'Amato, A. W., Jokela, E. J., O'Hara, K. L., Long, J. N. 2017. "Silviculture in the United States: An Amazing Period of Change Over the Last 30 Years." *Journal of Forestry*. 116(1). pp 55-67.
9. Oliver, C. D., Larson, B. C. 1996. "Forest stand dynamics: updated edition." New York, NY: John Wiley & Sons.
10. Ashton, P. M. S., Kelty, M. J. 2018. "The practice of silviculture: applied forest ecology." Hoboken, NJ: John Wiley & Sons.
11. Ibid 8
12. Delcourt, H.R. and P.A. Delcourt. 1997. "Pre-Columbian Native American use of fire on southern Appalachian landscapes." *Conservation Biology*. Vol 11, 1010–1014.
13. Mann, C. C. 2011. "Landscape with Figures: Artificial Wilderness." 1491: New Revelations of the Americas before Columbus. Vintage Books, pp 360–375.
14. Oliver, C.D. 1981. "Forest development in North America following major disturbances." *Forest Ecology and Management*. Vol. 3, 153-168.
15. Piana, M. R., R. A. Hallett, M. F. J. Aronson, E. Conway, and S. N. Handel. 2021. "Natural regeneration in urban forests is limited by early-establishment dynamics: implications for management." *Ecological Application*s 31(2):e02255. 10.1002/eap.2255
16. Pregitzer, C. C.; Ashton, M. S.; Charlop-Powers, S. A.; D'Amato, A. W.; Frey B. R.; Gunther, B.; Hallett, R. A.; Pregitzer, K. S.; Woodall, C. W.; Bradford, M. A. 2019. Defining and assessing urban forests to inform management and policy. *Environmental Restoration Letters*. Vol 14.
17. Piana, M. R., Pregitzer, C. C., Hallett, R. A. 2021. "Advancing management of urban forested natural areas: toward an urban silviculture?" *Frontiers in Ecology and the Environment*. 1–10.
18. Open Standards for the Practice of Conservation, https://conservationstandards.org/about/.
19. Brandt, L., Lewis, A. D., Fahey, R., Scott, L., Darling, L., Swanston, C. 2016. "A framework for adapting urban forests to climate change." *Environmental Science & Policy*. Volume 66, pp 393-402.
20. Ordóñez, C. and Duinker, P. N. 2014. "Assessing the vulnerability of urban forests to climate change." *Environmental Reviews*. 22(3), pp 311–321.
21. D'Amato, A. W., Bradford, J. B., Fraver, S., Palik, B. J. 2011. "Forest Management for mitigation and adaptation to climate change: Insights from long-term silviculture experiments." *Forest Ecology and Management*. Vol 262, pp 803-816.
22. Ordóñez, C. and Duinker, P. N. 2013." An analysis of urban forest management plans in Canada: implications for urban forest management." *Landscape Urban Planning*. 116: 36–47.
23. Ordóñez, C., and Duinker, P. N. 2013. "An analysis of urban forest management plans in Canada: Implications for urban forest management." *Landscape and Urban Planning*. Vol 116 pp 36–47.
24. Pregitzer, C.C., Charlop-Powers, S., McCabe, C., Hiple, A., Gunther, B., Bradford, M.A. 2019 "Untapped Common Ground: The Care of Forested Natural Areas in American Cities." 46pp. Published by: Natural Areas Conservancy.

25. Bounds, K., Feller, M. J., Greenfeld, J., Heaviland, M., Pregitzer, C., Wenskus, T., Gunther, B., Johnson, L., King, K., Lu, J., Naidich, M., Pehek, E., Simmons, B., Stanley, S. & Toth, E. (2014). Guidelines for Urban Forest Restoration.

26. Craig R. Allen, Joseph J. Fontaine, Kevin L. Pope, Ahjond S. Garmestani. 2011. “Adaptive management for a turbulent future.” *Journal of Environmental Management*. Volume 92, Issue 5, p. 1339–1345.

27. Pregitzer, C.C., Charlop-Powers, S., McCabe, C., Hiple, A., Gunther, B., Bradford, M.A. 2019 “Untapped Common Ground: The Care of Forested Natural Areas in American Cities.” 46pp. Published by: Natural Areas Conservancy.

28. The Nature Conservancy. *The NYC Urban Forest Agenda: Towards a Healthy, Resilient, and Just New York City*. (2021). pp. 108.

29. Plitt, S., Pregitzer, C. C., & Charlop-Powers, S. (2021). “Brief Research Report: Case Study on the Early Impacts of COVID-19 on Urban Natural Areas Across 12 American Cities.” *Frontiers in Sustainable Cities*, 3.

30. Grima, N., Corcoran, W., Hill-James, C., Langton, B., Sommer, H., & Fisher, B. 2020. “The importance of urban natural areas and urban ecosystem services during the COVID-19 pandemic.” *PLOS ONE*, 15(12), e0243344. https://doi.org/10.1371/journal.pone.0243344

31. Pregitzer, C.C., Charlop-Powers, S., McCabe, C., Hiple, A., Gunther, B., Bradford, M.A. 2019 “Untapped Common Ground: The Care of Forested Natural Areas in American Cities.” 46pp. Published by: Natural Areas Conservancy.