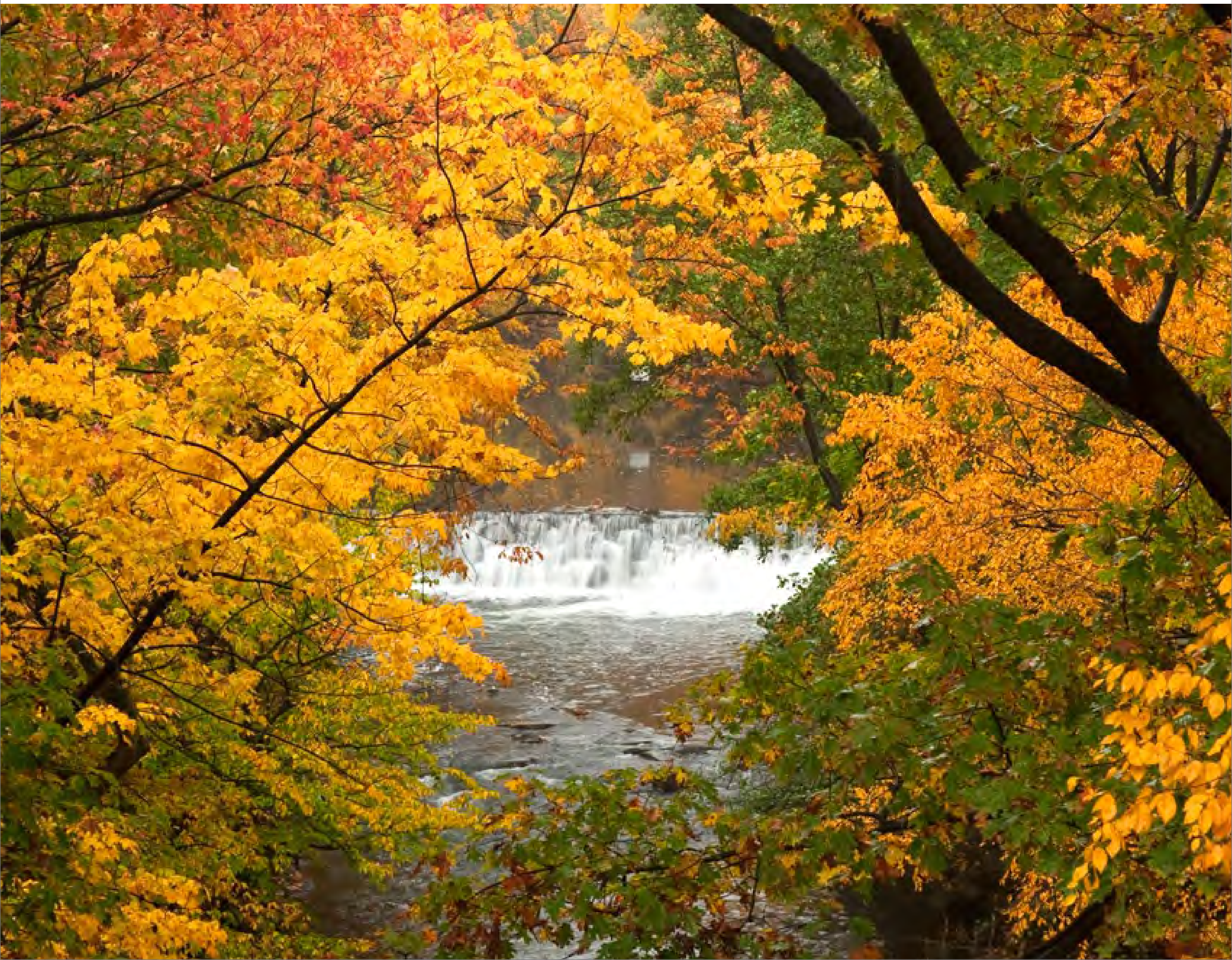
NYBG

THAIN FAMILY FOREST PROGRAM
2008–2025

New York Botanical Garden



Thain Family Forest Program 2008–2025

Jessica Arcate Schuler
Todd A. Forrest

New York Botanical Garden

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Previous page:
The Forest provides welcome shade in the heat of summer.

Opposite:
The Bronx River has cut a dramatic gorge through the bedrock of the Forest.

I. Introduction

The 20-hectare (50-acre) Thain Family Forest in the heart of The New York Botanical Garden is the largest remnant of the forest that once covered much of what is now New York City. A canopy of centuries-old oaks[1], tulip trees, sweetgums, maples, and other native hardwoods rises over dramatic terrain that includes the Bronx River floodplain and gorge, intermittent streams, ephemeral pools, and rocky ridges. The Forest has been an important research site, a favorite visitor destination, and an invaluable educational resource since the Botanical Garden became its steward in 1895. This unique urban woodland, which founding director Nathaniel Lord Britton referred to as "the most precious natural possession of the city of New York" (N.L. Britton, 1906), was the primary reason for the establishment of the Garden on its site. The New York Botanical Garden, recognizing the scientific, educational, and cultural value of the Forest, is committed to the continued preservation of this beautiful and important natural resource. [Map 1: Thain Family Forest in The New York Botanical Garden, page 2]

The Forest, originally known as the "Hemlock Grove," has changed considerably since 1895. The hemlocks that once dominated the canopy began to decline early in the 20th century and have been nearly decimated in the last 30 years by two invasive insects: hemlock woolly adelgid and elongate hemlock scale. Human-caused disturbances including soil compaction, over-collection of native plants, pollution, introduction of invasive species, fragmentation, loss of top predators, and climate change threaten the remaining native plant communities and habitats. Previous stewards, respectful of natural processes that created the Forest and informed by ecological theories of their times, preferred a "let alone" policy of limited human intervention (N.L. Britton, 1906; Irwin, 1979; Institute of Ecosystem Studies, 1988). After decades of this approach, it became clear that active management of the Forest would be necessary to mitigate the cumulative effects of anthropogenic disturbances. To address threats to the Forest's health, the Garden's Strategic Plan, *Into the 21st Century 2009–2015* (The New York Botanical Garden, 2008) proposed the creation of a comprehensive program of research, education, and ecological restoration.

The goals of the Thain Family Forest Program are to encourage natural ecosystem processes and mitigate anthropogenic disturbances; to promote the natural regeneration of native species with minimal human intervention; to study and understand the impacts of the urban environment on forest health; to connect people with nature; to communicate the importance of forest ecosystems and the significance of having an old-growth forest in New York City; to teach about conservation, including the impacts of invasive species and ecological restoration; and to engage volunteers, students, and interns in all aspects of research, stewardship, and education.

The Forest offers the opportunity to experience nature's beauty in all seasons.

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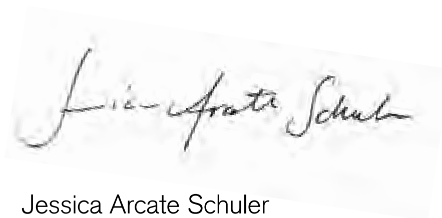
[1]See Appendix 1 for list of species cited

Map 1: Thain Family Forest in The New York Botanical Garden

Active management does not imply struggling to maintain the Forest in a static state. Forest ecosystems are characterized by constant change, therefore management protocols and practices must be constantly assessed and adapted to address new threats as they arise and take advantage of new tools and techniques as they become available. In the spirit of adaptive management, this document reviews forest restoration, public education, and research initiatives undertaken between 2008 and 2015 and establishes priorities and protocols for future restoration, education, and research. Ultimately, the primary goal of our work is to protect the Forest's unique flora, fauna, and ecosystem processes while ensuring that it continues to be safe, accessible, and inspiring to Garden visitors, researchers, and educators for generations to come.

With deep gratitude we acknowledge Carmen and John Thain for their generous support of and passionate interest in our work. Their belief in the importance of conserving nature in our own backyards has been an inspiration to all who value the Forest.



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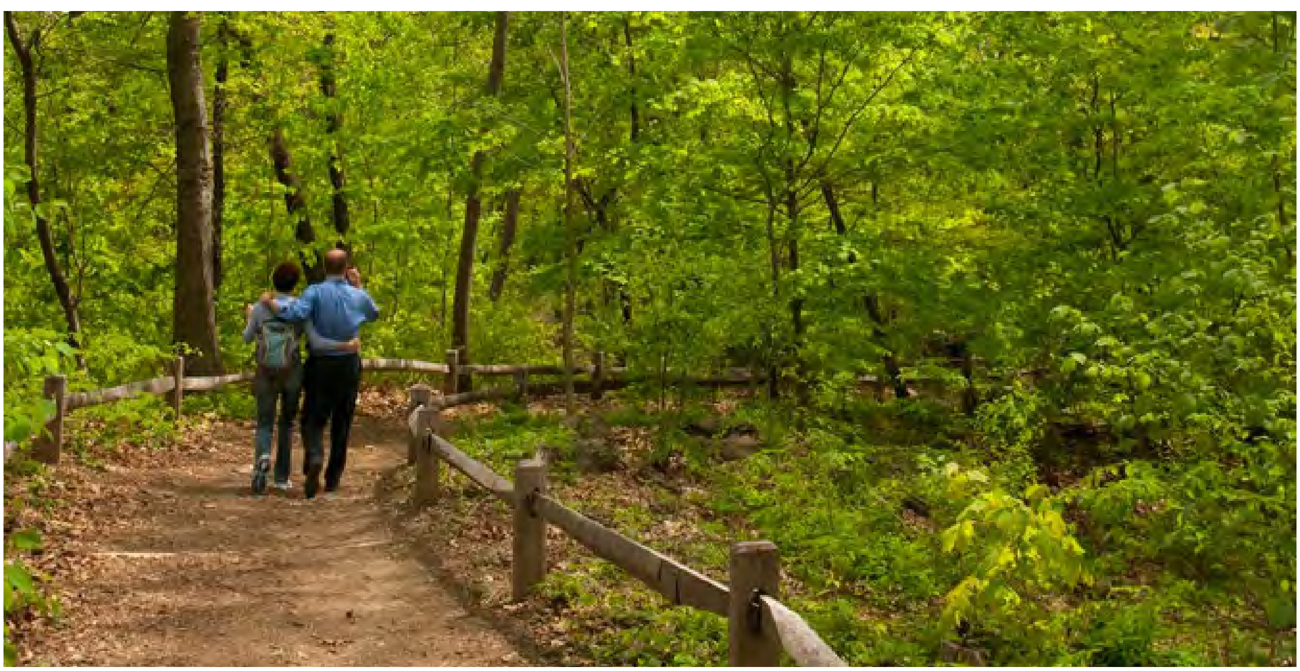


The Forest feels far away from the encroachments of city life.

Map 2: Forest Trails and Highlighted Features

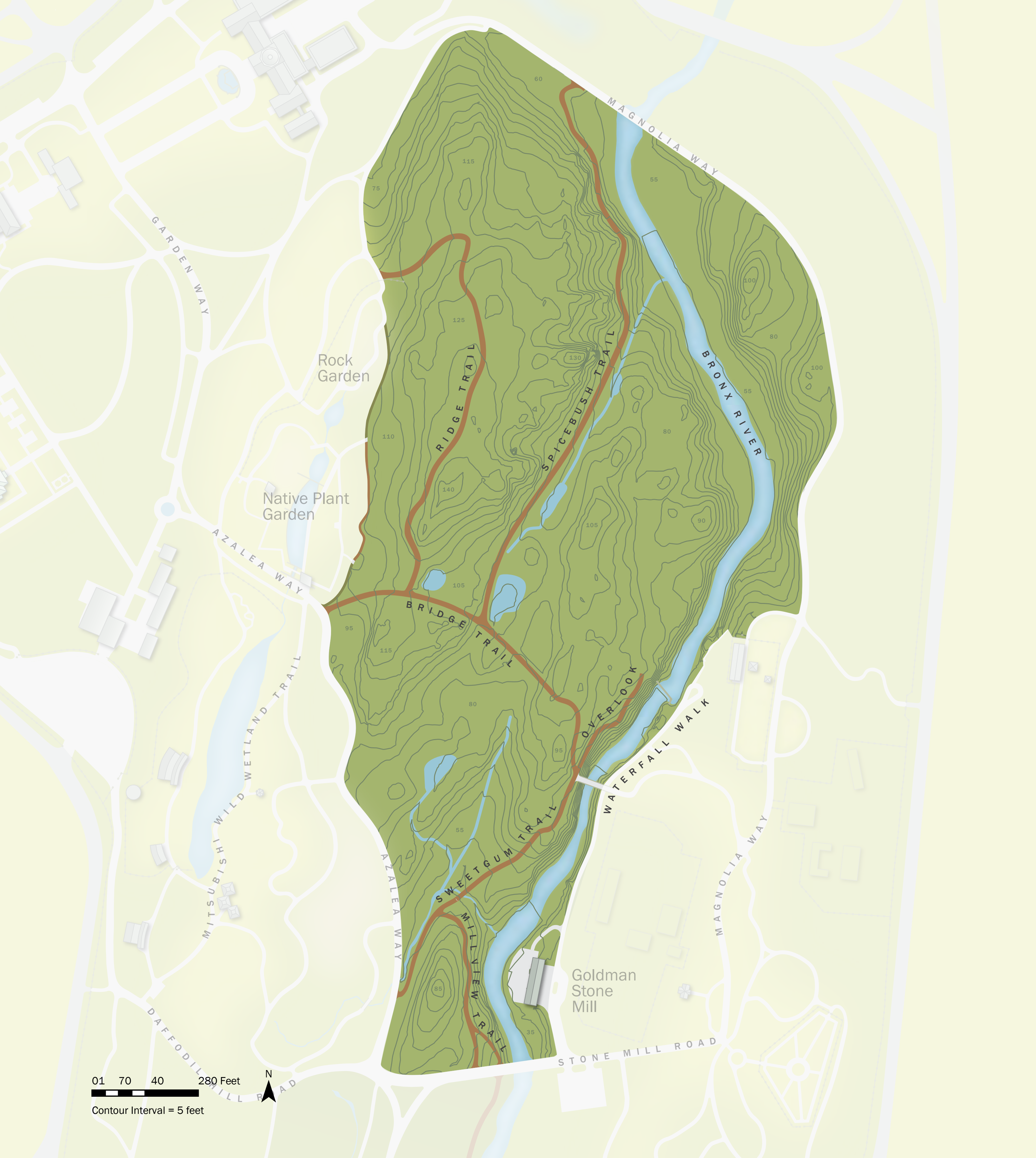
II. Natural History of the Thain Family Forest

Forest management practices can only be effective if they are based on a thorough understanding of the abiotic (environmental factors such as climate, bedrock, and soils) and biotic (living organisms including plants, animals, fungi, insects, and soil microfauna) elements that define the forest to be managed. It is equally important to understand the history of human impact on the forest, including intentional management practices and unintentional but significant human influences such as air and water pollution and soil compaction. The Garden is fortunate to have a long history of research and observation in the Forest to draw from in devising management strategies.

The 20-hectare (50-acre) mixed hardwood Forest is a remnant urban old-growth forest: it has never been cleared for agriculture or significantly developed and remains as an effectively natural ecosystem within one of the largest metropolitan areas in the world (McDonnell, 1988; Loeb, 2001). Archaeological evidence shows that the Forest had been a hunting ground for Native Americans long before the first European settlers arrived (Kazimiroff, 1955). For more than two centuries after settlement, the Forest was part of large, actively farmed plantations, including the Delancey and Lorillard estates (Hermalyan,1982). Perhaps due to its shallow rocky soil, or early land disputes, or the sylvan beauty of its stands of mature trees, the Forest was never transformed into field or pasture. The City obtained the Forest in 1888 as part of a historic aquisition of nearly 4,000 acres of new parkland for "the sanitary welfare of our metropolis…an increase of its park area, commensurate not only with its present wants but with its future and rapidly increasing necessity" (Marsh, 1884; State of New York, 1888). In 1895 the Forest and its surroundings were chosen as the site for The New York Botanical Garden (N.L. Britton, 1926). [Map 2: Forest Trails and Highlighted Features, page 4]

Bedrock and soils are the foundation of any forest. The bedrock, predominantly schist and gneiss, formed during a series of mountain-building events in the Ordovician Period, about 450 million years ago (Isachen et al., 1991; Brock and Brock, 2011). Eons of erosion, punctuated by at least four glacial advances during the Pleistocene Epoch, ground the bedrock down into the low hills and shallow valleys that define the Forest's topography. When the last glacier melted approximately 14,000–20,000 years ago, it left a mantle of rocky debris, called glacial till, over the bedrock. Abundant evidence of glaciation can be observed throughout the Forest, including striations on a rock outcrop along the Bridge Trail, erratics in various locations, and a pothole at the Mill View Trail Overlook. The highest point is 43 meters (141 feet) at the top of a rock outcrop in the center of the Forest and the lowest point is 10 meters (32 feet) just south of the Forest, where the Bronx River exits the Garden beneath the Linnaean Bridge at Fordham Road (LaFave et al., 2003). [Map 3: Forest Topography, page 6]

Map 3: Forest Topography



A Forest visitor in 1909

Soils in the Forest are “predominantly fine sandy loams derived from glacial till” that are shallow to bedrock (White and McDonnell, 1988). Recent soil surveys indicate that soil series on slopes and upland areas are mostly Charlton, Chatfield, and Hollis acidic sandy loams (pH ranging from 3.5 to 5.5) with varying depths to bedrock (Shaw et al., 2007). In low areas adjacent to ephemeral streams and along the Bronx River floodplain, soil series consist of Canandaigua (fine-silty), Tonawanda (coarse-silty), and Natchaug (loamy) with pH values 5.6 to 6.5 (Shaw, 2010). Early research in the Forest indicated soil compaction, caused by the “indiscriminate trampling…of multitudes,” affected the Forest’s health by hindering hemlock regeneration (N.L. Britton, 1906). Recent studies have revealed that the Forest soils have a pH range of 5.4 to 7.4 with extreme cases of 3.9 and 8.0; have high heavy metal concentrations, including zinc, lead, and copper; are compacted due to excessive trampling; and exhibit hydrophobic properties due to long-term deposition of hydrocarbons from the burning of fossil fuels (Schuler, 2006 and 2011; White and McDonnell, 1988). [Map 4: Forest Soils, page 8]

When the Garden assumed stewardship of the Forest, it was defined by soaring stands of mature hemlocks (Britton, 1906). In 1937 hemlock was the dominant canopy species in 36% of the Forest (Rudnicky and McDonnell, 1989). By 1985 hemlock dominated only 17% of the Forest (Rudnicky and McDonnell, 1989). In 2011 the Forest canopy only consisted of 4% hemlock[1]. By 2015 only 102 living hemlocks remained (Schuler, 2015). The decline of hemlock has been caused by two introduced pests: hemlock woolly adelgid and elongate hemlock scale. The loss of most of the Forest’s hemlocks and the alarming rise of invasive species have resulted in a forest that looks quite different today than it did when the Garden first became its steward.

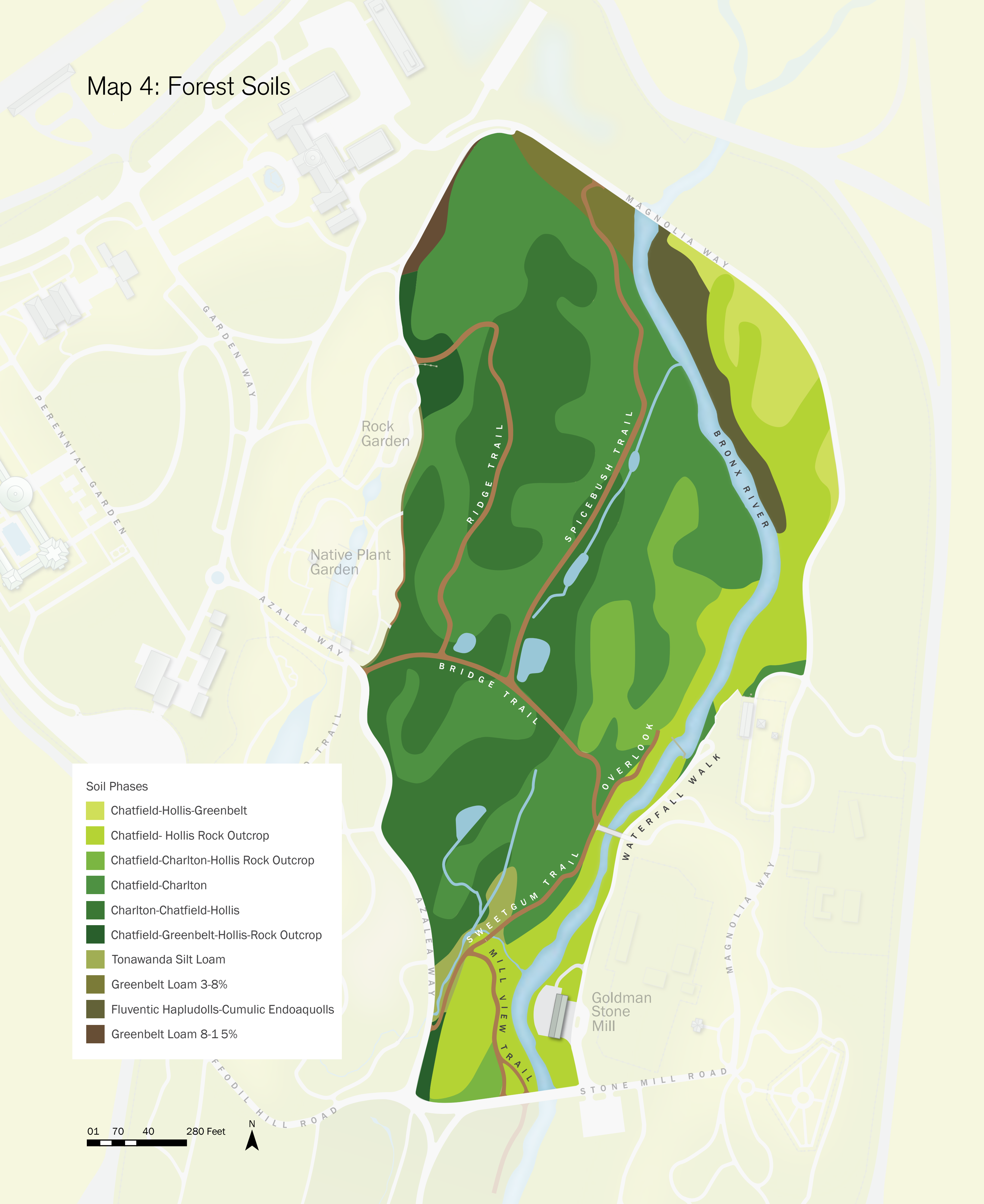
In 1985 researchers in The New York Botanical Garden Forest Project defined eight canopy vegetation clusters or types within the Forest based on a 15% sample (Rudnicky and McDonnell, 1989). Of these eight, four were considered dominant:

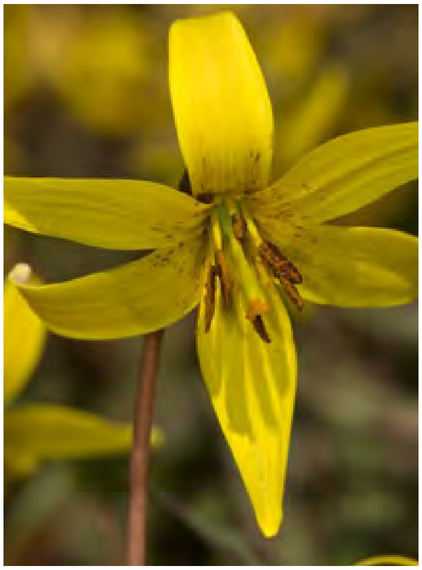
1) hemlock
2) maple, black cherry, and sweet birch
3) red oak
4) American beech

Sampling also identified secondary canopy vegetation types, including sweetgum, tulip tree, white oak, and white ash. The forest sampling protocols used to determine canopy vegetation types in 1985 were reapplied in 2002, 2006, and 2011. Managers use these datasets to analyze the impacts of management activities, environmental change, and major disturbances on Forest vegetation. Recent sampling indicates that the Forest has a mixed hardwood canopy dominated by black cherry, red maple, American beech, various oaks, sweetgum, and hickories. [Map 5: Dominant Canopy Trees, page 10]. Invasive plant species present in substantial numbers include Japanese angelica tree, Norway maple, Amur corktree, Japanese honeysuckle, English

[1]See Appendix 4 Table 1

Map 4: Forest Soils




Trout-lily thrives in the Forest.

ivy, Amur honeysuckle, linden viburnum, lesser celandine, Japanese and hybrid knotweeds, and five different ornamental flowering cherries.

Understory native woody plants in the Forest include hop-hornbeam, hornbeam, flowering dogwood, arrowwood, witch-hazel, and spicebush. While some native wildflowers, including trout-lily, Canada mayflower, false Solomon's seal, hairy Solomon's seal, and white wood aster, thrive in the understory, there have been many changes to the spontaneous flora of the Forest since the late 19th century when botanists published the first formal inventory of the native and naturalized plants of the Garden (Atha et al., 2016). More than 100 species of native wildflowers, ferns, and fern-allies documented in an 1896 inventory have been extirpated from the Garden, with the greatest loss of diversity in the Forest (N.L. Britton, 1899; Pace, 2010; Pace, 2011)[2]. A variety of factors led to the loss of native plants: the over-collection of native wildflowers (N.L. Britton, 1902; Copp, 1904; E.G. Britton, 1912a and b; E.G. Britton, 1913); the trampling of soil by crowds of visitors (N.L. Britton, 1904), changes in soil chemistry (White and McDonnell, 1991); and increasing populations of invasive plants, many of which were introduced from the Garden's Living Collections (McLean, 1935; Rudnicky and McDonnell, 1989).

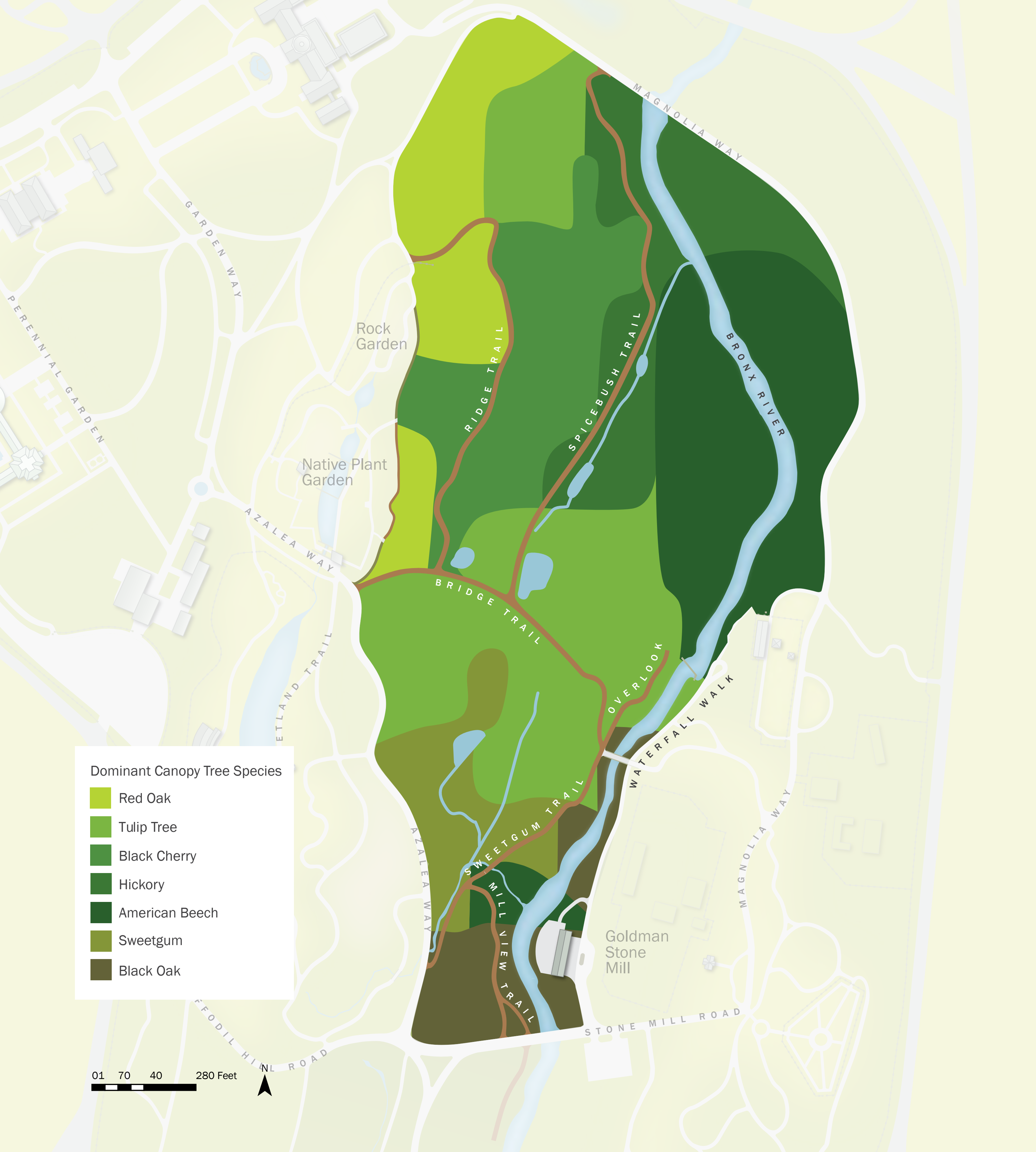
Hurricanes, nor'easters, droughts, and summer thunderstorms are all a natural part of the disturbance regime of northeastern forests. On August 8, 1913, an intense summer storm with high winds resulted in the loss of "4 oaks, 7 hickories, and 5 hemlocks in the Hemlock Grove on the west side of river (Britton, 1913)." The hurricanes of 1938 and 1944 caused substantial damage to the Forest. An ice storm on March 4 and 5, 1940, destroyed a total of "200 good-sized trees" (Journal of The NYBG, 1940; Journal of The NYBG, 1938; Journal of The NYBG, 1944; Graves, 1944). Hurricane Gloria on September 27, 1985, is believed to have introduced the hemlock woolly adelgid from Long Island to mainland New York, the Forest, and the rest of New England.

Over the past decade, the Forest has been greatly impacted by drought. Drought conditions were reported in Bronx County in 2002, 2004, 2005, 2009, 2010, 2013, and 2014 (US Drought Monitor, 2015). The drought of 2001 to 2002 is the last reported official Drought Emergency on record (NOAA, 2002; Cooper, 2002). October 29 proved to be an inauspicious date on two consecutive years in 2011 and 2012. On October 29, 2011, a nor'easter coated the Garden with wet, heavy snow that damaged thousands of trees in the Forest and throughout the landscape. On October 29, 2012, Hurricane Sandy brought the most devastating storm in recent history. More than 300 trees across the Garden were destroyed, including 167 trees in the Forest with a diameter at breast height (dbh) of 15 centimeters (6 inches) or greater. These significant disturbances have exacerbated the long-term impacts of human activities on the health of the Forest and underscored the necessity of active management.

Non-native species have had arguably the most dramatic effect on the health of the Forest. In the early 1900s chestnut blight led to the demise

[2]See Appendix 2 for list of extirpated species

Map 5: Dominant Canopy Trees



Red foxes feast on mice and other small mammals in the Forest.

Great horned owls nest in the Forest in winter.

of 1,500 American chestnuts (*Washington Post*, 1911). The introductions of elongate hemlock scale in the early 1900s and hemlock woolly adelgid in 1985 have led to the dramatic decline of hemlock. Flowering dogwood, once common throughout the Forest understory (City of New York Department of Parks, 1902) has been nearly extirpated by dogwood anthracnose. Arrowwood, one of the Forest's most abundant native shrubs, is threatened by viburnum leaf beetle, which was first discovered in 2008. In spite of all of these significant biological disturbances, the Forest still fulfills Britton's vision as a refuge for wild plants in New York City (E.G. Britton, 1916a and b).

The Forest, home to robust populations of birds, mammals, reptiles, amphibians, fish, and insects, is a preserve of genetic diversity (Munshi-South and Kharchenko, 2010). In some cases, animals have had a significant impact on the health of the Forest. Abnormally high eastern gray squirrel populations might be responsible for the poor regeneration of oaks and hickories (Honkala and McAninch, 1981). Cottontail rabbits have been observed browsing on seedlings and other understory vegetation in the Forest (Schuler, 2015). Non-native earthworms have been observed in the Forest since the late 1980s (Pouyat, 1992; Pouyat and Carreiro, 2003). Although their long-term impacts in the Forest have not been directly studied, earthworms are known to impact vegetation dynamics in northern forests (Hale et al., 2006; Nuzzo et al., 2009).

Many of the more than 200 resident and migratory bird species recorded at the Garden are observed during weekly bird walks that occur in the Forest throughout the year. In 1982 naturalist John Kiernan called the Forest "favorite owl country" for birdwatchers, who gather each spring to photograph nesting great horned owls and their owlets. Ample prey attracts Cooper's hawks, northern goshawks, and red-tailed hawks, which can be seen hunting among the Forest's trees. Diverse populations of plants and insects sustain warblers and other songbirds during their spring and fall migrations.

Research has documented the Forest's diversity and the great changes it has undergone over the past century (Gager, 1907; Honkala and McAninch, 1981; Rudnicky and McDonnell, 1989). Despite these changes, the Forest is a unique natural area that has persisted in the face of ever-increasing anthropogenic disturbances. The Forest's diversity, age, and urban location provide an excellent opportunity for conservation of native species and habitats, floristic and ecological research, and education about the importance of forested ecosystems. However, there are also significant challenges to preserving the Forest as a functioning natural ecosystem within one of the world's largest cities.

III. Forest Management and Research 1895–2008

When N.L. Britton first became the Forest's steward, he believed that a "let alone" management policy was the only way to preserve the Forest's primeval character (N.L. Britton, 1906). However, Britton's perspective gradually changed. After early research indicated that the hemlocks that defined the Forest were not regenerating due to "trampling of the thin soil by crowds of people," the Garden installed wood and iron fencing along the Forest's trails (N.L. Britton, 1904a; City of New York Department of Parks, 1914). After the blight decimated chestnuts in 1904, Britton ordered the removal of infected trees from the Forest (N.L. Britton, 1904a). By the mid-1920s it was clear that the cumulative effects of soil compaction caused by visitors wandering off Forest trails were hindering hemlock regeneration in the understory and threatening the Forest's future. Britton concluded that in order to keep the Forest a "Hemlock Grove" permanently it would be necessary to plant hemlock seedlings (N.L. Britton, 1926). In just 20 years, Britton's management policy evolved from a hands-off approach to active intervention.

There is little information in the Garden's archives about the management of the Forest between 1930 and 1980. Most information pertains to frequent fires that burned through the understory (Everett, 1965). Garden horticulturists recall planting hemlocks and ornamental shrubs in the section of the Forest facing the Lillian and Amy Goldman Stone Mill. Trails were maintained, although the iron rails that lined some of them were removed for scrap metal during World War II. In the 1930s, Garden horticulturists removed hundreds of non-native double-file viburnum from the Forest understory (McLean, 1935).

By the late 1970s it had become clear that in spite of these management activities, the health of the Forest was declining. Decades of air pollution, invasion of exotic species, unrestricted travel through the Forest, and fires started by vandals had taken their toll. Garden President Howard Irwin recognized that "our mode of management must now change or the hemlocks will gradually be replaced by other species of trees and the Forest will cease to exist" (Irwin, 1979). Irwin initiated an ecological study of the Forest to determine if its historical character as a "Hemlock Grove" could be preserved.

In 1979 and 1980, ecologists Dee Ann Honkala and Jay McAninch installed research plots in the Forest and gathered data on vegetation, hemlock regeneration, mammal populations, and soil characteristics. Their 1981 report on the Forest concluded that:

> *The place of the hemlock in the Forest has been seriously challenged by many well-adapted invaders. The character of the site has changed significantly due in part to many years of human use and abuse as well as the harsh realities of the surrounding urban environment* (Honkala and McAninch, 1981).

Hemlocks were abundant along the Bronx River until they were decimated by the hemlock woolly adelgid.

Honkala and McAninch documented abnormally high eastern gray squirrel populations, severe soil compaction, and well-established populations of invasive plants. Yet they were the first to suggest that the Forest, long known as the “Hemlock Grove,” could (and probably would) lose its hemlocks and still remain a valuable and viable natural area. They recommended that the Forest be managed for “native northeastern forest species” (not exclusively for hemlock) and that visitor access be tightly controlled through improvements in security and in the trail system, including the installation of boardwalks to alleviate soil compaction (Honkala and McAninch, 1981).

The most intensive period of study and management in the Forest before the present day began in 1984 when the Garden teamed with the Institute of Ecosystem Studies (IES) to establish the Forest Project, a long-term ecological research program led by ecologist Mark McDonnell with the goal of documenting the impacts of the urban environment on forest health. McDonnell and his staff established permanent plots in the Forest to provide baseline data on soils, vegetation, and general ecology. These data demonstrated the effects of urban environment on forest processes and provided a foundation for future management decisions. One of McDonnell’s early actions was to remove the word hemlock from the official name of the Forest. He recognized that redefining the Forest was the first step in creating a viable management policy and that the traditional narrow definition of the “Hemlock Grove” would influence both public perception and management strategy.

A 1988 plan prepared by McDonnell broadly outlined management objectives for the Forest. The plan argued that “a small forest in the midst of a large city can survive and remain natural only if it is managed in accordance with ecological principles and long-term goals” (IES, 1988). The goals of the management plan were to continue research and “promote the reproduction and growth of native species while minimizing changes caused by human activity” (IES, 1988). Few specific management practices were outlined in this plan, and all management activity was left to the discretion of the Forest Ecologist and Forest Manager. During the late 1980s and early 1990s, McDonnell and his colleagues rehabilitated the Forest’s trails, reduced the number of trails, installed 16 permanent research plots, wrote and installed interpretive signage, and performed in-depth studies of ecosystem processes within the Forest (McDonnell, 1985; White and McDonnell, 1988; Rudnicky and McDonnell, 1989; Pouyat and McDonnell, 1991).

After McDonnell left the Garden in 1993, Janet Morrison continued ecological research in the Forest. She and Forest Supervisor Rob Cardeiro drafted a management plan that addressed some issues facing the Forest, including trail maintenance, safety pruning, invasive plants, and maintenance of the grid system installed by the Forest Project (Morrison and Cardeiro, 1994). Their plan also suggested that restoration plantings along trails closed in the 1980s should be a management priority and be supported with appropriate resources; that the existing trail system was in need of repair and continued maintenance; and that a number of invasive plants required monitoring and potential management. Again, few specific management practices were prescribed and the day-to-day management of the Forest was left to the discretion of its horticultural stewards, who recorded very little data on what was accomplished. A notebook with management notes from April and May 1996 records “exotic removals” and highlights the location of this work. The priority species at that time were Amur corktree, Chinese aralia, and tree-of-heaven (Cardeiro, 1996). Prior to Cardeiro, Forest records referred to *Aralia chinensis* as *Aralia spinosa* or the native devil’s walking stick. This species is actually *Aralia elata* or the Japanese angelica tree. Regionally, *Aralia elata* was commonly misidentified as the native *Aralia spinosa* until the late 2000s when botanists addressed the taxonomic features that distinguish the two species and published naturalized distributions of *Aralia elata* in the northern mid-Atlantic region, New York, and New England (Sarver et al., 2008; Moore et al., 2009). The unpublished Forest herbarium has specimens collected as *Aralia chinensis* and *Aralia spinosa* (Atha et al., 2016).

In 2001 a committee of staff from the Garden’s Science and Horticulture divisions collaborated on the creation of the Forest Management Plan, which built on previous plans to identify threats to the health of the Forest and establish protocols for active management and research. As part of the institution’s strategic planning process, the Garden worked with OLIN in 2007 to create a master plan for restoring the Forest and other important features in heart of the Garden’s historic landscape. Together, the Forest Management Plan (Forrest, 2001) and the landscape master plan (Olin Partnership, 2008) served as the impetus for proposing an ambitious program of restoration, research, and education as a primary initiative within *A New Strategic Plan: Into the 21st Century 2009–2015*.

Japanese angelica tree

Devil’s walking stick

IV. Thain Family Forest Program Goals and Accomplishments 2008–2015

A new era of active restoration, research, and education in the Forest began in 2008 with the development of the Thain Family Forest Program, which was established to achieve the following goals:

1. Improve forest health through active management informed by research
2. Improve visitor access through trail restoration and maintenance
3. Educate Garden visitors and the general public about the local, regional, national, and global importance of forests through interpretive signage, workshops, classes, symposia, and publications
4. Use the Forest as an outdoor laboratory to study the impacts of the urban environment and environmental change on biodiversity, forest health, and ecosystem processes
5. Document the Forest's unique and changing biodiversity
6. Increase the Garden's profile as a research and conservation organization

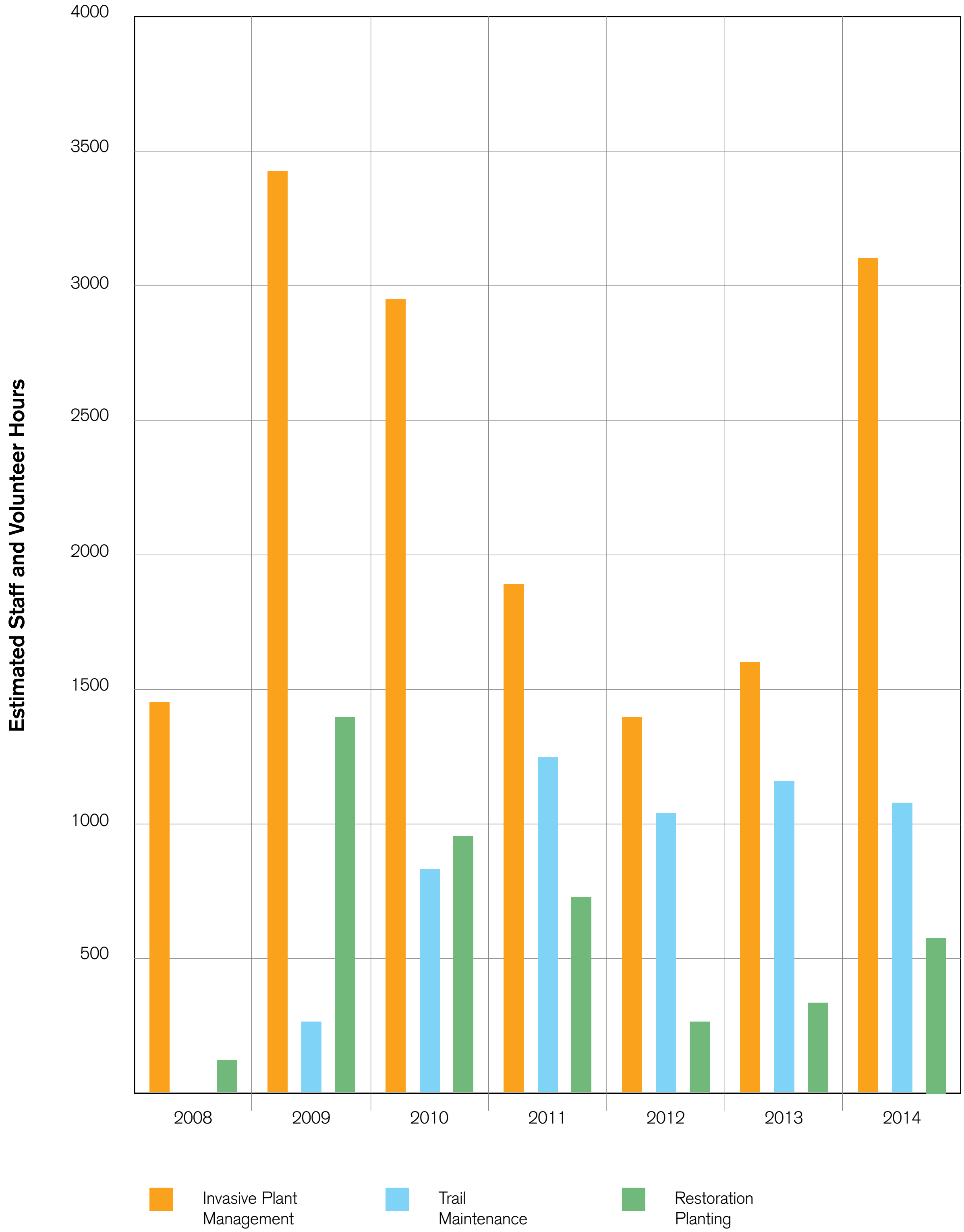
In 2008 the Garden created a new full-time position, Director of the Thain Family Forest, to ensure that that the program makes progress towards achieving each of the above goals. Between 2008 and 2015, the Director developed and implemented an ambitious program of ecological restoration, trail restoration, education, ecological research, biodiversity inventory, and outreach. The following section summarizes key accomplishments achieved in each of these areas during this period.

A. Ecological Restoration

To achieve the goal of improving forest health, the Garden created two additional full-time staff positions (Forest Gardener and Forest Botanical Garden Aide) dedicated to restoration activities, including removal of invasive species, planting native species grown from locally collected seed, managing invasive pests and diseases, and restoring habitat. A healthy forest is defined as an ecosystem dominated by naturally regenerating populations of native plants that respond to and recover from disturbances of all scales with minimal human intervention, provides suitable habitat to a diversity of organisms in a structurally diverse, mixed-aged woodland, and sustains natural processes that support biodiversity (Leopold, 1949; Handel et al., 1994; Kolb et al., 1994; Meier et al., 1996; Seaton,1996; Simberloff, 1998; Lindenmayer et al., 2000; Hobbs, 2007; Tallamy, 2007; Tyrell et al., 2010; Johnson, 2013; Munshi-South and Nagy, 2014). To accomplish the goal of improving the health of the Forest, staff, contractors, and volunteers have dedicated a substantial amount of time—24,400 hours from 2008 through 2014—to three key management activities: invasive plant management, restoration planting, and trail maintenance. Since 2008, more staff time has been devoted to the control of invasive species than any other management task. [Figure 1, page 18]

The Bronx River still tumbles over this 18th-century dam.

Figure 1: Staff and Volunteers Hours Dedicated to Three Priority Management Tasks 2008–2014



It takes many hands to manage invasive species in the Forest.

1. Control of Invasive Plants

Invasive plant species can rapidly displace native plants and disrupt natural plant communities (Luken and Thieret, 1998). The risk of allowing populations of invasive species to expand unchecked include the overall reduction of plant diversity, the loss of native species, and the disruption of ecosystem processes (Hobbs and Humphries, 1995; Luken and Thieret, 1998; Mack et al., 2000; Mooney and Hobbs, 2000; Pimentel, 2002; Pimentel et al., 2005; Wilcove et al., 1998; Simberloff et al., 2013; Fei et al., 2014). In the Forest, populations of invasive species have increased steadily at the expense of native species (Honkala and McAninch, 1981; McDonnell, 1988; Morrison, 1998; Smith, 1998). The impacts of invasive species can be seen most clearly along the Forest edge and along the Forest ridges where there is frequent disturbance. Prior management plans recognized the negative impacts of invasive species and recommended their control (Forrest, 2001; Honkala and McAninch, 1981; McDonnell, 1988; Morrison, 1998).

Forest staff employ either mechanical, chemical, or biological methods to control invasive species. The method of control used at any given time is informed by a survey of the literature to determine which techniques have proven most effective at controlling a given species without causing unintended negative impacts on forest ecosystem processes—care is taken to ensure that efforts to manage invasive species do not create more problems than they solve[3].

Mechanical removal includes hand pulling, weed wrenching, girdling, cutting, or pruning. The primary benefit of mechanical removal is that it does not introduce potentially damaging chemicals or organisms into the forest. Unfortunately, mechanical removal is labor intensive and can lead to soil erosion if performed on high risk areas (exposed slopes, floodplains, etc.) and/or soil disturbance that creates optimal conditions for the growth of invasive species.

Chemical controls are typically more efficient than mechanical removal but care must be taken to avoid adding potentially harmful agents into the system (Paganelli et al., 2010). Mechanical removal is always used as the primary management strategy and chemical controls are applied only when monitoring data shows that mechanical removal methods are ineffective, such as in the case of the Japanese angelica tree. Between 2006 and 2011 the stem frequency and density of Japanese angelica tree significantly increased in spite of years of persistent mechanical removal. Forest managers determined that mechanical removal efforts benefited Japanese angelica tree, which re-sprouts from root fragments and thrives in disturbed soil.

When it is determined that chemical control of invasive species is necessary, appropriately labeled herbicides are applied carefully to cut stems or painted on leaves and stems with great care taken to avoid damage to desirable species. Targeted chemical controls may also be used to preserve trees threatened by pests or disease. Examples include the treatment of American elms to prevent Dutch elm disease and the treatment of ash trees to protect them from emerald ash borer.

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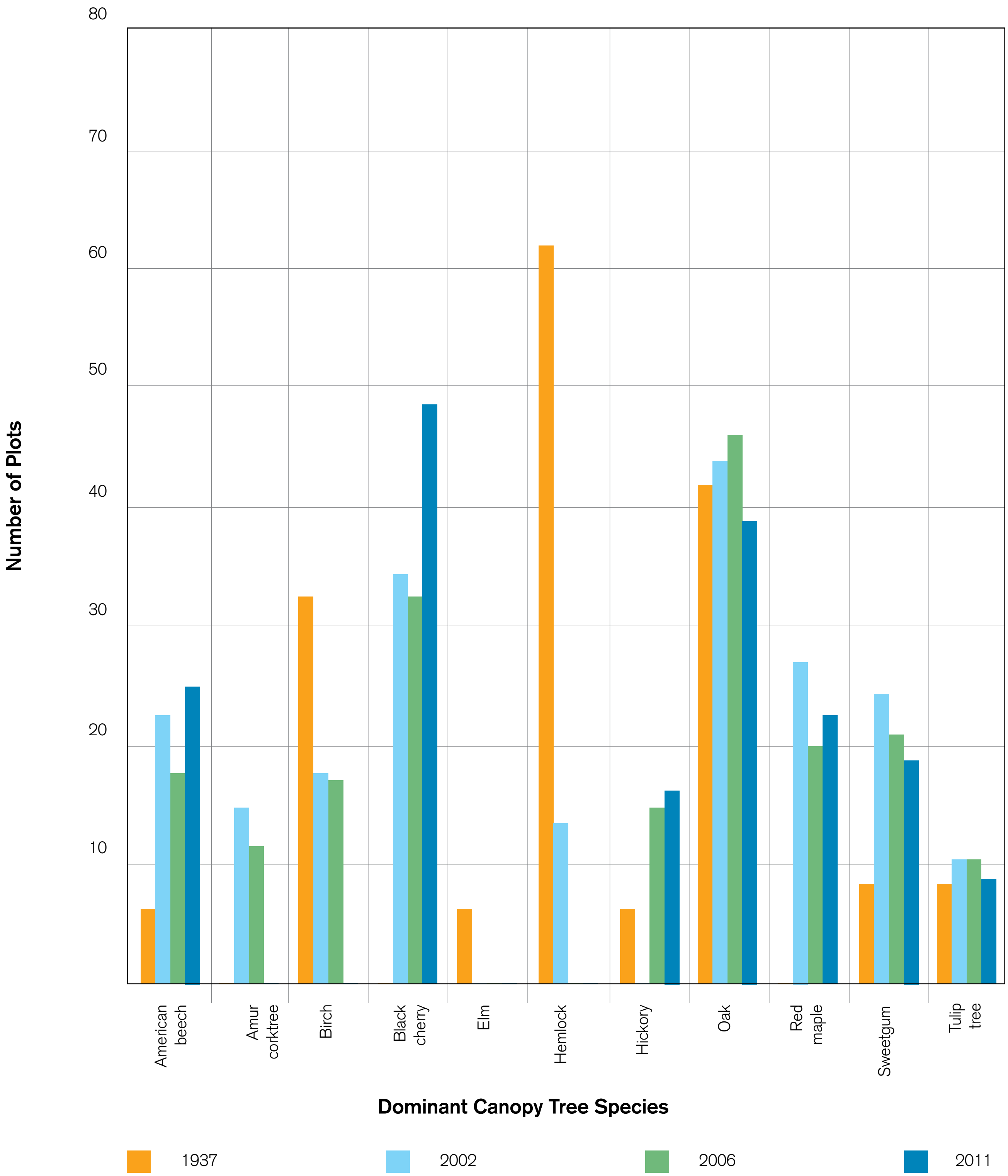
[3]See Appendix 3 for invasive species best management practices

Figure 2: Forest Canopy Change 1937–2011



Arborists removed more than 800 invasive corktrees from the Forest.

Biological controls include insect or fungal pathogens, often introduced, that feed on or disrupt targeted invasive organisms. Biological controls have proven effective in some systems but are difficult to control and should only be used after extensive review. Forest staff and the Director of Plant Health did release a small amount of scale picnic beetle, a beetle used a biological control for elongate hemlock scale, on young hemlock trees south of the Hester Bridge in the mid-2000s. However, this release did not reduce elongate hemlock scale in the Forest. The use of entomopathogenic fungi as a biological control for elongated hemlock scale is currently being researched and may be a future control method for this invasive insect pest (Parker et al., 2005). Golden loosestrife beetle, an insect that feeds on invasive purple loosestrife, has been observed feeding on purple loosestrife along the Bronx River. Although biological controls have seldom been applied in the Forest, their use may increase in the future if proven safe and effective in our region.

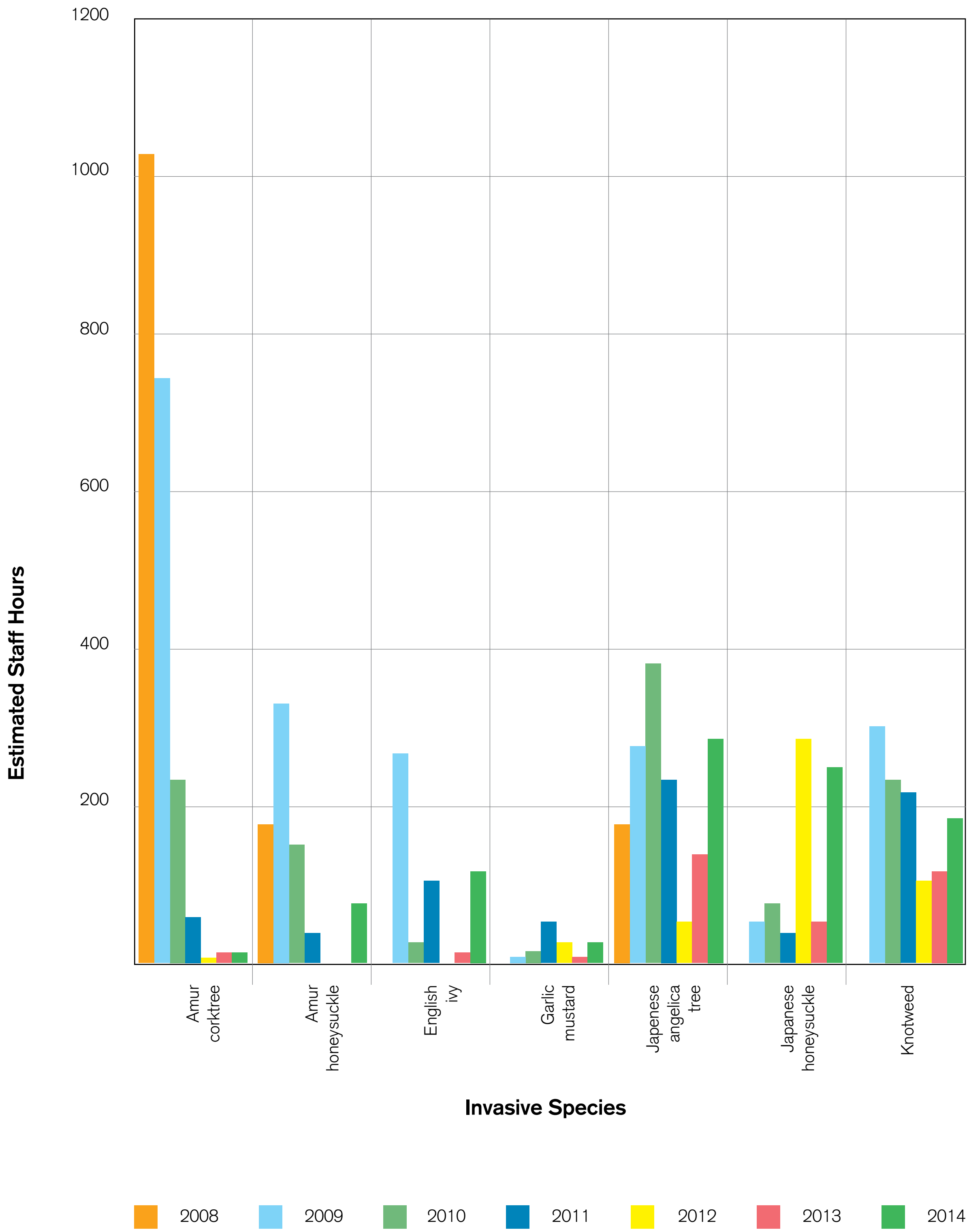
Inventories conducted using 1937 maps and 2002, 2006, and 2011 field sampling provide a clear picture of changes to Forest vegetation over time including the emergence of invasive plant species[4]. Using data from the 2002 and 2006 Forest inventories, staff prioritized populations of five particularly problematic invasive plants to target for removal: Amur corktree, Amur honeysuckle, Japanese honeysuckle, Japanese angelica tree, and knotweed. Data revealed that populations of Amur corktree increased noticeably in the Forest between 2002 and 2006. Between 2008 and 2014, a combination of Forest staff, volunteers, students, and contractors removed more than 800 Amur corktrees, including some with trunk diameters approaching 50 centimeters (24 inches), and tens of thousands of other invasive shrubs, vines, and herbaceous plants. This work was supported by a grant from the New York State Department of Environmental Conservation.

Using inventory data, a cluster analysis was performed to identify woody plant communities for 1937, 2002, 2006, and 2011 with the goal of determining whether or not management of Amur corktree had an impact on the overall composition of the Forest vegetation. Differences in plot composition based on relative basal area of woody stems greater than 5cm dbh (excluding 1937 data, which only measure stems greater than 15cm dbh) were analyzed with pairwise Euclidean distance matrices and UPGMA clustering algorithims (Borcard et al., 2011). The results reveal a shift from a dominant hemlock canopy in 1937 shifting to a mixed hardwood forest with the presence of Amur corktree in 2002 and 2006, to a mixed hardwood forest without a dominant Amur corktree presence in 2011 after three years of active management [Figure 2, page 20].

These data clearly demonstrate how management practices have effectively reduced populations of Amur corktree in the Forest. However, these data also show that Japanese angelica tree has increased in density (number of stems/hectare) and frequency (presence in the plots sampled). Prior to 2011, Forest staff and volunteers manually removed Japanese angelica tree using

[4]See Appendix 4 for Forest Inventory results

Figure 3: Staff Hours Dedicated to Managing Specific Invasive Species 2008–2014



weed wrenches and grub axes. However, inventory data from 2011 showed that manual removal was ineffective[5]. Forest staff now paint leaves and cut stems with an herbicide according to the manufacturer's label. Treatments are monitored every four to six weeks during the growing season and follow-up treatments are made as necessary. Eighteen months after treatment, managed areas are planted with native species. Figure 3 on page 22 shows the distribution of staff hours dedicated to the management of various invasive species between 2008 and 2014. Between 2008 and 2011, staff devoted 1000 hours to controlling Japanese angelica tree with limited management success. In 2012 staff transitioned from mechanical removal to herbicide treatment, which led to a more than 30% reduction in staff time devoted to controlling Japanese angelica tree. Post-treatment monitoring has also shown that herbicide treatments are more effective than mechanical removal.

Over time the data collected from the Forest inventories provide a clear picture of how the Forest is changing in response to environmental conditions and management activities. The most recent data, collected in the summer of 2011, shows that restoration practices have significantly decreased the abundance of Amur corktree in the Forest and made a measurable impact on other invasive species, including Amur honeysuckle, multiflora rose, and English ivy. Map 6 reveals the decrease in occurrence of Amur corktree and an increase in occurrence of Japanese angelica tree in the Forest between the 2006 and 2011 inventories. In addition to Japanese angelica tree, woody invasive plants on the rise in the Forest include linden viburnum, ornamental cherries, and smooth buckthorn. [Map 6: Occurrence of Invasive Species in 2006 and 2011, pages 24–25]

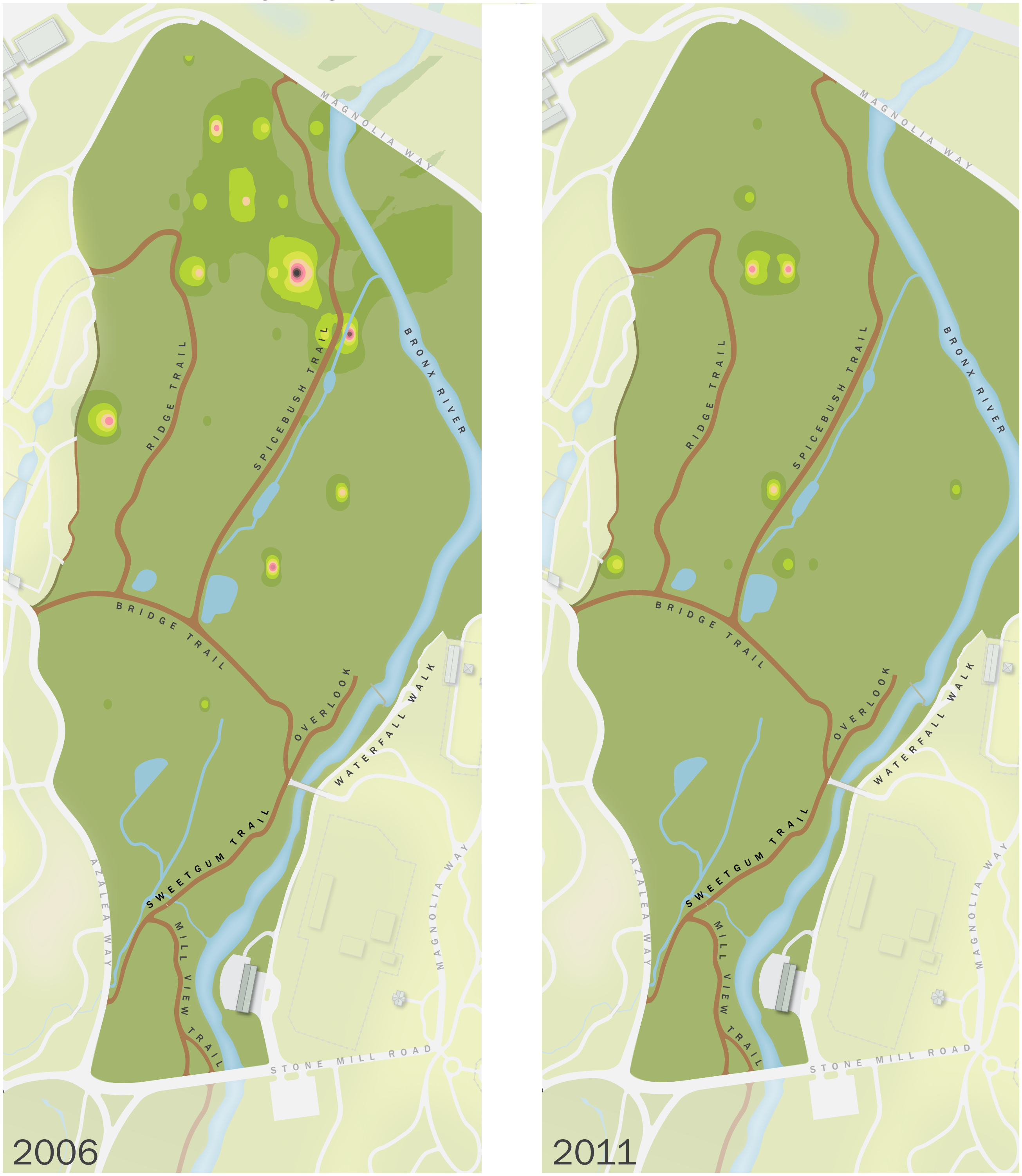
These results show that the Forest ecosystem is a hybrid ecosystem—one that has been impacted by anthropogenic disturbances but not irreversibly (Hobbs, Higgs, and Hall, 2013). Dedicated management activities have shifted trajectories and established a new successional community based on restoration goals (Johnson, 2013). Based on the results of the 2011 inventory, the Forest of the future will be characterized by black cherry, red maple, American beech, and sweetgum rather than Amur corktree, which the 2006 inventory indicated might dominate, or hemlock and oak, which have historically had the highest importance values.

In 2011 Forest staff collected understory data to better understand herbaceous plant communities, woody plant seedling regeneration, and abiotic characteristics such as leaf litter, coarse woody debris, and bare soil. These data reveal that white wood aster and Japanese angelica tree are the most abundant understory species in the Forest. However, the inventories were performed in summer and did not record spring ephemeral plants. One spring ephemeral of particular concern in the Forest and throughout the Garden is the lesser celandine, which has greatly expanded over the past decade (Axtell et al., 2010). Forest staff and volunteers mechanically remove lesser celandine from the Forest interior by hand in late winter or early spring. This method has

[5]See Appendix 4 Table 2

Map 6: Occurrence of Invasive Species 2006 and 2011

Amur Corktree Stem Density Change Between 2006 and 2011



Amur Corktree Stem Density (No. of Stems/100 m²)

0 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
7.01 - 8
8.01 - 9
9.01 - 10

0 70 140 280 Feet

N

Japanese Angelica Tree Stem Density Change Between 2006 and 2011

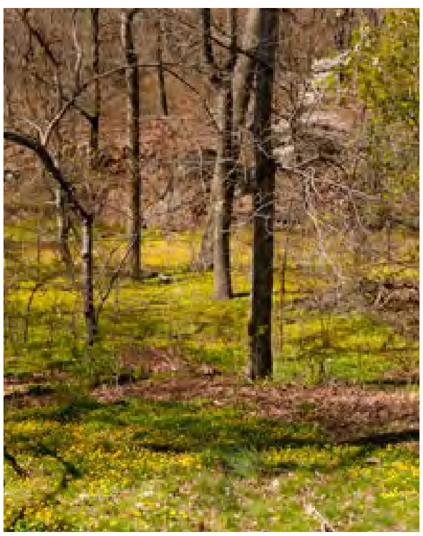
Japanese Angelica Tree Stem Density (No. of Stems/100 m^2)

0 - 5
5.01 - 10
10.01 - 15
15.01 - 20
20.01 - 25
25.01 - 30
30.01 - 35
35.01 - 40
40.01 - 45

0 70 140 280 Feet

N

Interns removing Japanese knotweed from the Bronx River floodplain



Lesser celandine is an aggressive invader that displaces native spring ephemerals.

greatly reduced the number of interior forest patches with an observed control of 80% per treatment. Staff manage larger patches of lesser celandine along the Forest edges and on the banks of the Bronx River bank with properly-timed chemical control. The most successful chemical control occurred in March 2012 when maximum temperatures were in the low 70s and minimum temperatures where in the high 30s (Marlow et al., 2014).

In addition to the management of the lesser celandine, a great effort has also been made to reclaim the Bronx River floodplain and restore the riparian forest. Between 2010 and 2014, the Garden worked with the Bronx River Alliance and the Natural Resources Group of the New York City Department of Parks and Recreation to develop and implement protocols for managing the invasive Japanese and hybrid knotweeds, which have colonized large portions of the floodplain (Yau et al., 2012). This study revealed that repeated cutting of knotweed stems throughout the growing season is the best method for mechanical management (Haight et al., 2014). Forest staff have found that combining repeated cutting treatments with restoration planting can effectively reduce the monoculture of knotweed and restore the riparian forest understory.

Preventing new invasions is a priority of ongoing forest management. Intensive management data from 2008–2014 indicate that preventing invasions is the best way to manage invasive species (Clark, 2003; Reichard, 1997; Pimentel, 2005; Olson, 2006; McGeoch et al., 2010). Forest staff and volunteers are out in the field every day monitoring for new invaders. If a new species is found, staff quickly take action with early detection and rapid response to report, map and remove observed plants. Examples of species of concern that have not yet become established in the Forest but represent a significant threat to Forest health include Japanese stiltgrass, mile-a-minute vine, and incised fumewort.

Japanese stiltgrass is present throughout the region and frequently appears along Forest trails. It is most likely introduced as seed attached to visitors' shoes or clothes. Mile-a-minute vine, also present regionally, has appeared along trails and in newly formed canopy gaps. Incised fumewort is a newly emerging invasive plant that has infested the Bronx River floodplain north of the Garden in the Bronx and Westchester County (Atha et al., 2014). In 2014 Forest staff removed all known individuals along the river bank and will continue to monitor for additional plants in future seasons. Forest staff are vigilant in looking for these species and other new invaders that could threaten the health of the Forest.

2. Managing Pests and Diseases

Invasive plant species are not the only threat to the Forest. Chestnut blight devastated American chestnuts in the Forest in the early 1900s and Dutch elm disease has plagued the Garden's elms since the 1950s. Elongate hemlock scale and hemlock woolly adelgid have all but eliminated hemlock from the Forest. Other organisms currently present in the Forest that represent potential threats to native plant populations include perennial nectria canker, beech bark disease, black knot fungus, gypsy moth, and non-native earthworms.

The introduction of new pathogens to native ecosystems continues unabated and Forest staff must be prepared to react to new threats in the future. Oak wilt has been observed in western New York State and could be devastating to the Forest canopy. Asian long-horned beetle, a voracious pest that feeds on a wide range of native trees, was discovered in Brooklyn in 1996 and has spread throughout southern New England in spite of large-scale eradication and quarantine efforts. Since it was first seen near Detroit in 2002, Emerald ash borer has killed tens of millions of native ash trees in the northern Midwest, Pennsylvania, and western New York. It was confirmed in Westchester County in November 2014 (NYS DEC, 2014).

The Garden's Plant Health Care Program emphasizes monitoring for potentially destructive pests and acting as soon as their populations rise above a pre-determined action threshold. Monitoring the Forest for potentially damaging pathogens is part of this program. Forest staff and volunteers monitor for new pests such as emerald ash borer and Asian long-horned beetle. In 2012 Forest interns mapped all host tree species 1cm or greater diameter at breast height (DBH). These surveys have revealed that the Forest has 642 trees 15cm or greater dbh that are Asian long-horned beetle (ash, maple, birch, sycamore, poplar, willow, and elm) or emerald ash borer (ash) hosts. There are 4603 host trees 1cm dbh or greater: 1302 ash and 3301 maple, birch, poplar, sycamore, willow, and elm. If either insect were to invade the Forest, it would have a great impact. Horticulture staff and USDA-APHIS inspectors survey the entire Garden, including the Forest, for both insects every year. The Plant Health Care Program has also been monitoring the entire Garden including the Forest with pheromone traps for both emerald ash borer and Asian long-horned beetle. If the insects are observed in the Forest, staff will notify the New York State Department of Agriculture and Markets. Once an infestation is confirmed, all host trees will be inspected and all infested trees will be removed to prevent spread.

Viburnum leaf beetle was discovered in the Forest in 2008. That year, staff mapped the infestation and developed a rating system to measure damage to host species. This early research indicated that arrowwood, an important native shrub in the Forest, is the preferred host for viburnum leaf beetle but other native species (mapleleaf viburnum and blackhaw viburnum) are also susceptible. In winter 2009, Forest staff began a trial of mechanically managing viburnum leaf beetle by removing egg sites from arrowwood

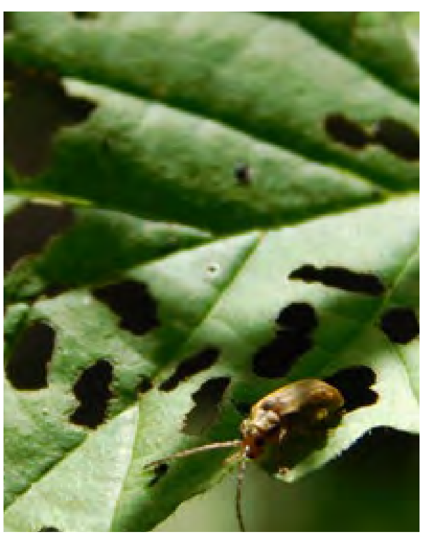
Severe storms pose a serious threat to the health of the Forest.

plants and other native viburnums in a heavily infested section of the Forest. Monitoring data revealed that this method of management resulted in 80% control of the beetle. Inspired by this success, Forest staff, students, and volunteers have manually removed infested branches from arrowwood and other native viburnums in a different section of the Forest each winter. All native viburnums increased in both density and frequency between 2006 and 2011, a clear indication that management has been successful so far. Arrowwood seedlings have also been observed in newly formed canopy gaps.


Students removing viburnum leaf beetle egg sites

3. Responding to and preparing for other disturbances

In addition to invasive plants, pests, and diseases, Forest managers must contend with a number of natural and anthropogenic disturbances in their efforts to keep the Thain Family Forest healthy and safe for visitors. Climate models predict an increase in hurricanes, nor'easters and other severe storms as a result of climate change. Recent severe storms have measurably changed forest structure and composition. The Forest's managers must be prepared to respond quickly to future storms. Climate models also predict increases in summer and winter temperatures and more droughts, which can lead to catastrophic fires. Populations of mammals that feed on the Forest's plants have had a measurable impact on vegetation over the past century. White-tailed deer, which have become a problem in adjacent parkland, could devastate the native flora if they become established in the Forest. Finally, increased use of the Forest by Garden visitors, school groups, and even volunteers represents a potential risk to Forest health that must be carefully managed.


An adult viburnum leaf beetle

3a. Severe Storms

Hurricane Sandy, the most damaging storm in the history of the Garden, destroyed 167 trees with a diameter at breast height of 15cm or greater in the Forest alone. While severe storms are a part of the natural disturbance regime for northeastern forests and have shaped the Forest that we all have come to know today, the Forest's fragility and important role as a visitor destination and outdoor classroom require both short and long-term management responses to major disturbances.

Short-term Responses

1. Clear all downed trees across trails and any damaged trees that could be hazardous along the trails.
2. Repair trails and fencing.
3. Repair or replace damaged interpretive signs.
4. Map and compile a database of trees impacted by the storm documenting tree species, dbh, height and aspect of fall. This dataset will help prioritize management in canopy gaps and prevent invasive species from dominating.
5. Prioritize interior Forest clean-up. Leave all trunks and coarse woody debris within the Forest to protect against erosion, to allow for the

recycling of nutrients back into the ecosystem and to provide habitat for Forest wildlife. Assess accumulated brush for potential fire risk, breakdown and disperse within the Forest to minimize the future risk of brush fires, but keep all materials within the Forest.

6. Monitor new gaps for invasive species and document native plant regeneration.
7. Prioritize invasive species management in newly formed canopy gaps and areas surrounding the canopy gaps to reduce the chance of invasion.

Long-term Responses

1. Develop long-term monitoring protocols for the newly formed canopy gaps.
2. Develop planting plans and production lists to grow plants for restoration.
3. Recruit students to assist with long-term management.
4. Recruit and work with volunteers to assist in invasive species management.
5. Maintain all monitoring and management efforts in a geodatabase.
6. Continue to repeat the Forest Inventory every five years to document changes across the entire Forest.

3b. Drought and Fire

Major storms are not the only natural disturbances that significantly impact the health of the Forest. Droughts kill plants of all ages and increase the risk of catastrophic fire (either lightning-set or accidental). During substantial droughts Forest staff focus on preventing fires and maintaining visitor safety. Fire hoses are connected to the fire hydrants and staff are prepared to assist in fire management as necessary. If drought conditions persist, Forest trails are closed to the public, interpretive signage and fencing placed at all entrances, and all Security and Visitor Services staff are notified to help inform and educate visitors. At least one staff member is trained by the New York Wildfire Academy.

Short-term Responses

1. Inform Security and Visitor Services of drought conditions in Forest.
2. Ensure that fire hydrants are functional and attach hoses.
3. Eliminate potential fire ladders by dispersing brush.
4. If necessary, close Forest trails to visitors to reduce the chance of accidental fire.
5. In case of fire, alert security.

Long-term Responses

1. Develop long-term monitoring protocols for canopy gaps created by the death of mature trees.

2. Develop planting plans and production lists to grow plants for restoration.
3. Recruit students to assist with long-term management.
4. Recruit and work with volunteers to assist in invasive species management.
5. Maintain all monitoring and management efforts in a geodatabase.
6. Continue to repeat the Forest Inventory every 5 years to document changes across the entire Forest.


A camera trap captured this American beaver along the Bronx River.

3c. Herbivory

Herbivory from mammals is a recent concern particularly with two species now frequenting the Garden: the American beaver and white-tailed deer. Although neither has made the Garden or Forest its permanent home, both species use the Bronx River corridor as a means to come and go. Important host trees along the Bronx River bank have been protected by hardware cloth fencing. Winter prunings from the Living Collections are placed along the riverbank to essentially “feed” the beavers and deter them from chopping down large riparian trees. White-tailed deer will have a devastating impact if they do establish permanent residence in the Forest. Deer exclosures should be considered to protect the Forest as deer populations increase in the Bronx and lower Westchester.

3d. Other Anthropogenic Disturbances

The Forest’s size and public nature make it impossible to prevent all direct but unintended human disturbances such as the damage caused by visitors who stray off trails, forage for both native and invasive plants, feed wildlife, and collect wildflowers. Trail fencing, interpretation, and visitor education are important tools in efforts to promote proper stewardship among all Garden visitors. Forest staff are trained to firmly, but politely remind visitors that they play a part in keeping the Forest healthy.

4. Restoration Planting

Anthropogenic and natural disturbances create growing space that is typically filled by more invasive species unless this growing space is restored by planting with propagules of native species (Hobbs and Humphries, 1995; Luken and Thieret, 1998; Emmerich, 1999). This is ecological restoration or “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (SER, 2004). Where invasive plants are managed intensively, it is necessary to plant saplings of native species grown from seed collected in the Forest. This is of particular concern in the Forest, where regeneration of some native species is low due to unusually high herbivore populations or inhibition of germination by invasive species (Honkala and McAninch, 1981; McDonnell, 1988).

Seeds are collected on tarps.

Planting trees in a canopy gap

Between 2008 and 2010 Forest staff sourced thousands of native trees, shrubs and wildflowers and ferns to plant along closed paths, in canopy gaps, and in areas where invasive plant management has occured. During those same years, staff began the process of establishing a native plant production program that involved collecting seed from native plants in the Forest for propagation in the Woody Plant Nursery[6]. Since 2011 staff, students, and volunteers have planted seedlings grown from locally collected seed each spring and fall. Through December 2014 staff, students, and volunteers have planted 7500 trees, 1500 shrubs, 11,500 herbaceous plugs, and 50 pounds of herbaceous seed throughout the Forest. Plant species are chosen according to their suitability for the site to be restored. Inventory plots surrounding the planting site are analyzed to determine which native species, if any, are naturally regenerating. For example, tulip tree is planted in rich, moist soil while red maple and black oak are planted in drier sites. It is important to establish a diversity of species and plant types at each restoration site to assist in the recovery of a functioning ecosystem, to establish succession, and to prevent recurring invasions (Bounds et al., 2015).

Planting techniques differ depending on the characteristics of the area to be planted. For example, on closed trails and large gaps dominated by invasive Amur corktree and Amur honeysuckle, saplings taller than 60cm (24 inches) are planted on 1m centers—far more densely than they would be in areas not dominated by invasives (Bounds et al., 2015). In the early years of active management, containerized plants were sourced from regional nurseries for plantings. Today Forest production has shifted to using bare-root saplings that minimize soil disturbance while planting and reduce the potential for introduction of soil organisms such as earthworms and foreign seeds.

In large restoration areas, post-planting care is absolutely essential. In one location along an old trail, Amur corktree produced a carpet of seedlings that required weeding for two seasons. Forest restoration plantings are limited by the ability to collect and germinate seed in any given year. For example, 2012 and 2013 resulted in mast years for red oaks but not white oaks. When committing to producing restoration plants from a specific site these considerations need to be taken into account. Working with a regional seedbank such as the Greenbelt Native Plant Center can broaden the palette of plants available and provide difficult-to-collect species such as sassafras, which the birds love to eat.

As part of the knotweed management study, Forest staff have followed multiple management applications of cutting knotweed stems with the planting of red maple, sugar maple, pussy willow, black willow, black gum, serviceberry, and cutleaf coneflower to restore the river bank and prevent knotweed from becoming re-established. All restoration sites are maintained regularly until the restoration plantings grow enough to outcompete knotweed.

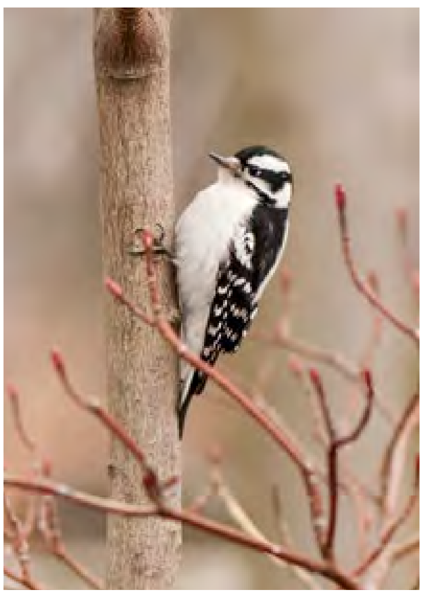
Restoring the extirpated flora and expanding the populations of extant species in small numbers in the Forest has been an objective for ongoing

[6]See Appendix 6 for plant production protocols


Staff and volunteers plant thousands of trees each year.

Planting a wood anemone seedling


Searching for salamanders in a Forest stream


A downy woodpecker hunts for insects.

restoration projects. In May 2014, Forest staff planted flowering wood anemone grown from wild-collected seed of a local population next to a small remnant, self-sterile colony of wood anemone in the Forest to foster cross pollination and re-establish a seed-producing population. The restoration seeds, collected by Garden scientist Matthew Pace in 2011, were sown and germinated in the Woody Plant Nursery in 2012, and the Forest staff cared for them until they bloomed for the first time in May 2014. This population of wood anemone will be monitored to determine if it is producing seed and expanding. In addition to increasing small populations of extant plant species, Forest staff have included 20 extirpated species in restoration projects. Though it is still too early to confirm the establishment of these species, Forest staff are hopeful that they will ultimately form naturally regenerating populations.

5. Improving Habitat for Forest Organisms

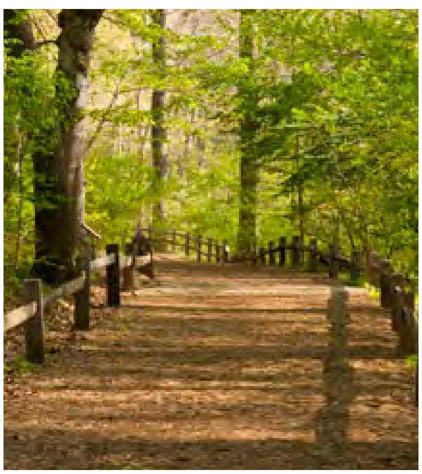
The Forest ecosystem is home to many different species, many of which are poorly understood. In order to carry out the goal of improving Forest health, restoration activities included significant improvements to an intermittent stream that flows into the Forest from the Azalea Garden. In 2010 the Garden collaborated with Applied Ecological Services (AES) to initiate a stream restoration project that began with establishing baseline data for populations of benthic macroinvertebrates, including northern two-lined salamanders. AES installed erosion control measures to reduce bank scouring, altered stream and bank grades, and created step pools to provide suitable habitat for aquatic invertebrates and amphibians. The stream restoration has: improved habitat for northern two-lined salamanders' food/prey and will result in higher trophic web functionality; improved water quality from aeration/stream sequencing and plantings; reduced erosion-derived sedimentation within suitable salamander habitat downstream of the previous erosion hot-spots; and provided refugia in constructed pools that retain water during periods of low flow (McGraw, 2014). During this project 69 plant species were used in restoration plantings that included 102 trees, 241 shrubs, 4,703 herbs, and 10 pounds of restoration seed mix.

In addition to direct efforts to improve habitat throughout the Forest, ongoing restoration efforts have resulted in the improvement of habitat for migratory and resident birds. The decrease of invasive vegetation and increase of native plant regeneration has had a positive impact in birding observations at the Garden by increasing the diversity of bird species observed (Debbie Becker, personal communication). These observations are also in line with research that studies the food web impacts of particular plant species. Native plants support more Lepidoptera caterpillars, which, in turn, support more birds (Tallamy, 2007). For example, in the Mid-Atlantic region, native oaks and cherries support 518 and 429 native Lepidoptera species, respectively, while Amur corktree supports zero (Tallamy, 2015). The Garden, including the Forest, is home to over 200 species of breeding and migratory birds. The Forest

Figure 4: Proposed Trail Improvements

habitat is ideal for interior forest species such as wood thrush, scarlet tanager, and pileated woodpecker. In 2012 birdwatchers recorded the first sighting of pileated woodpecker at the Garden in 73 years. The snags, or standing dead trees, within the Forest are ideal habitat for this species. With increasing fragmentation, habitat for interior bird species is declining regionally. A better understanding of this habitat within the Forest should be an area of focus for future monitoring and research.

Before restoration, trails were often impassable.



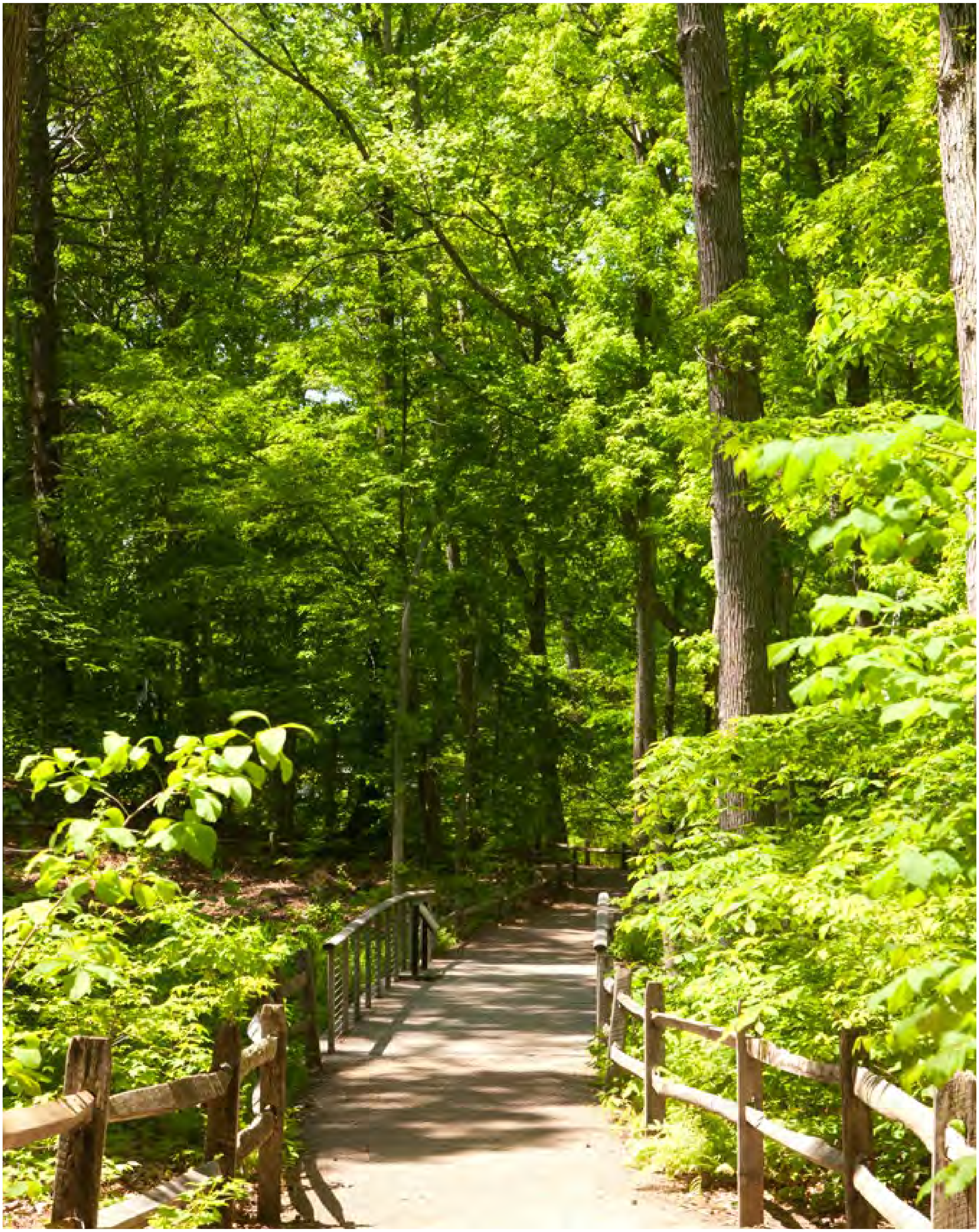
Restored trails are inviting at all times of year.

B. Trail Restoration

In the early 20th century, Garden scientists recognized that hemlocks were not regenerating well in the Forest (N.L. Britton, 1904; Gager, 1907; Robinson, 1908; N.L. Britton, 1926). Britton eventually came to the conclusion that the cause of poor regeneration was “the indiscriminate trampling…of multitudes” (N.L. Britton, 1906). Compaction destroys soil structure, reduces air and water-holding capacities, and can create an impenetrable layer that hinders root growth and seed germination (Brady and Weil, 1996). Some historic trails in the Forest interior were closed in the 1980s in an effort to improve forest health. By the early 2000s, the remaining trails were in such poor repair that visitors were sometimes forced to abandon them in order to continue their journey through the Forest. Poorly constructed and maintained trails were negatively impacting both forest health and the visitor experience. Therefore, improving access has been a priority of the Thain Family Forest Program.

In 2009 the trails in poorest condition, including a muddy path along the east bank of the Bronx River, were closed. In 2010 the Garden retained landscape architecture firm Andropogon Associates to study the remaining trail system and to make recommendations for their improvement [Figure 4, page 36]. In order to make the Forest trails more inviting to a wide range of users, Andropogon designed a series of gathering areas and overlooks, re-engineered existing trails to address persistent drainage issues, replaced a degraded culvert and concrete footbridge that spanned the intermittent stream in the south end of the Forest, and created an accessible loop to provide access to the Forest for all visitors.

Andropogon worked with Forest staff to identify locations along trails to serve as gathering areas that accommodate groups of between ten and twenty people and intimate overlooks that provide dramatic vistas of the surrounding terrain. The Bronx River Overlook nestles into exposed bedrock along the Spicebush Trail with two benches that overlook the Bronx River at a natural bluff. Waterfowl can often be observed here including wood ducks, hooded mergansers, and mallards. Located at the junction of the Bridge Trail and Spicebush Trail, Orientation Point has become a primary meeting place for groups and nexus of activity during the Garden’s “Fall Forest Weekends.” Benches and stone stairs provide places for groups to gather for tours, classes, musical performances, and causal enjoyment of the Forest. The Mill View Trail Overlook, nestled within a pocket of glacially carved bedrock, offers a scenic



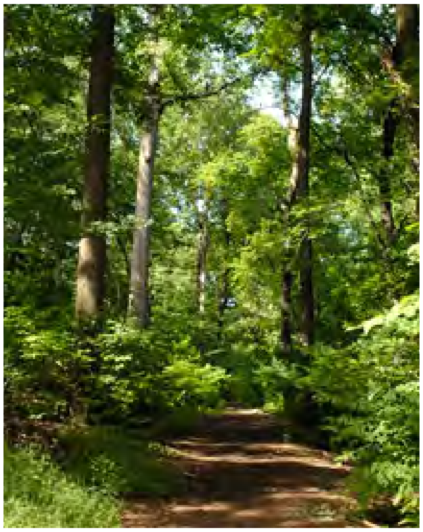
Andropogon Associates designed a new footbridge for the Forest.

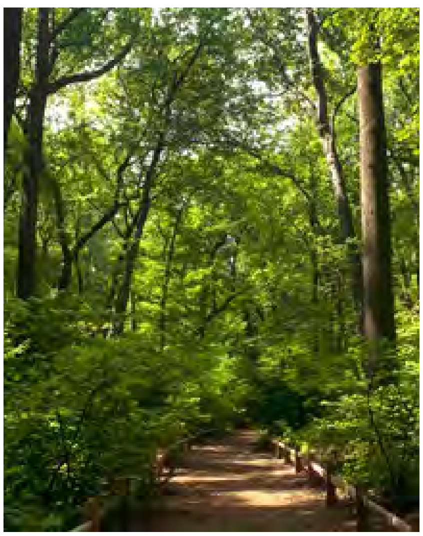
view of the Lillian and Amy Goldman Stone Mill and the Bronx River. Benches in the overlooks and gathering areas were created from logs salvaged from storm-damaged Garden trees, sawn into slabs with a portable sawmill, sealed, finished, and set into place on stone bases reinforced with rebar.

Andropogon used multiple strategies to address drainage issues throughout the trail system. Trails were excavated to remove organic material that had built up over time and reconstructed with 15–20cm of a well-compacted mixture of gravel combined with a high percentage of fines. Rolling grade dips (compacted mounds of gravel) and fords constructed of local stone were installed to move stormwater perpendicularly across particularly wet sections of the trails. Trails were surfaced with a thin layer of wood chips to retain their rustic character.

Following the landscape master plan developed by OLIN, Andropogon designed an accessible trail in the footprint of an abandoned Lorillard carriage path with dramatic views of the Lillian and Amy Goldman Stone Mill and Bronx River. Adhering to proposed guidelines for outdoor accessibility developed by the federal government, this accessible path provides access to a canoe portage south of the Stone Mill Bridge and includes an elegant footbridge, boardwalks, and seating areas that can accommodate visitors in wheelchairs and their companions (USFS, 2013).

The new footbridge replaced a degraded concrete slab that traversed a small stream that originates in the Mitsubishi Wetland and drains large portions of the Azalea Garden and Forest. The gently arching footbridge features decking and handrails fabricated from kiln-dried oak reclaimed from storm-damaged Garden trees. Boardwalks on the path leading to the bridge were also fabricated using reclaimed oak. The bridge and boardwalks allow access to the Forest while preserving habitat for birds, small mammals, and amphibians. In 2012 Forest staff worked with Applied Ecological Services (AES) to restore the stream beneath the bridge to improve habitat for northern two-lined salamanders.


Before new fencing


After new fencing

1. Fence replacement

Ten thousand linear feet of fencing along the trails have been replaced since 2008. Double split rail fences are used at the entrances. A diagonal rail connects these double split rail fences to the single split rail fences that line the trails in the interior of the Forest. The posts and rails are made from locally sourced black locust or oak.

2. Trail Maintenance

Forest staff spend approximately 600 hours each year maintaining trails to ensure that they remain in excellent repair in all seasons [Figure 1, page 18]. The following best management practices have been developed to guarantee the success of the trail restoration for years to come.

2a. Trail Surfaces

Staff rake trails regularly with spring rakes to remove debris and prevent the build-up of organic material. If scouring occurs or holes appear, depressions are filled immediately with gravel free of organic material. Plants that seed into the trail surfaces are removed carefully to avoid damaging the base course. Poison ivy and other vines growing adjacent to the trails are cut back or removed entirely. Staff use loppers, hand saws, and secateurs to prune trees and shrubs that grow into the trails.

A thin layer of composted woodchips screened to 1 inch in size is applied at least every 12 months—more frequently at the Forest entrances—to keep the trail presentable and to prevent excess moisture from collecting on trail surface. Tools used for this task include shovel, leaf rake, and steel rake. Excess or decomposed woodchips are removed as necessary.

2b. Water Management Features

The water management features include fords, swales, rolling grade dips, water bars, and trail pitch. All of these features require regular maintenance to manage erosion and preserve the integrity of the trails. Debris that accumulates between stone treads of the fords is removed using weeding forks and brooms. Debris that accumulates upslope and downslope of the fords is removed with leaf rake, steel rake, and shovel. Sediment and debris are removed from rolling grade dips and swales to prevent clogging.

Water bars have been replaced with fords, swales, and rolling grade dips on every trail except the Ridge Trail. Water bars slow the flow of water on trail surface and divert the water off the trail. In order to properly maintain water bars it is essential to regularly clear sediment that has settled at the outflow end of the water bar and remove sediment that has settled against water bar. Tools used to achieve this are leaf rake, steel rake, Pulaski, McLeod, and spade. The downhill side of the water bar should be flush with the trail surface, slightly longer than the trail, and higher than the Forest grade that it is outflowing into. The uphill side of the water bar should be above the trail surface to collect water into the bar.

Stone fords were designed to shed water from the trail.

A newly installed ford

Maintaining proper pitch is essential to preventing washout on trails. All trails are either crowned or pitched to shed water to the adjacent Forest. If the downhill edge of the trail is blocked by debris, water may erode the trail surface. To prevent this, staff remove debris along trail edges using leaf rakes, Pulaskis, McLeods, and shovels.

2c. Fencing

Fence posts and rails need to be replaced when they are damaged or decayed. Rail replacement requires the use of hand saw or chainsaw, drill, and mallet. Old rails are removed and composted with other woody debris to make mulch. If possible, adjacent rails are shifted so that new rails can be installed without having to be sawn. In some cases, rails may need to be shortened and secured with a screw.

Post replacement requires the use of a level, tape measure, hand saw, post-hole digger, leaf rake, shovel, sledge hammer, and tamper. Old posts are excavated and any broken pieces that remain in the ground are removed. Post holes are excavated deeply enough so that new posts are aligned with neighboring posts and rails are level. If a hole cannot be excavated deeply enough due to shallow bedrock or large rocks, the lower portion of the post is measured level with adjacent posts and shortened with a hand saw or chainsaw. Minimum post-hole depth for a stable post is 18 inches. If a post hole cannot be excavated to the proper depth, posts are secured with Quik-crete™, which is mixed directly in hole using a mixing stick, bucket, water, and rubber gloves. After installation, new posts are double-checked to ensure they are the proper height and plumb and attached rails are level. Post holes are filled with mineral soil packed with a tamper.

To preserve the integrity of the trails, security patrols, trams, and carts are not permitted to drive on the Forest trails except in the case of emergency or to perform necessary maintenance.

3. Tree Management

To maintain a safe environment for visitors, trees along the trails are monitored by the Forest staff, Arboretum and Grounds managers, and arborists. Forest staff observe trees along the trails during the course of their daily work and survey trees along all trails each winter and after storms or high winds to develop a list of necessary tree work. This list identifies removals, pruning, and any additional inspections required. All branches removed from Forest trees are left on the ground to decompose and replenish the soil. Dead trees near trails are topped and allowed to remain as habitat for native birds, insects, and animals. All work is performed by the Garden's Horticulture staff with the assistance of outside contractors if necessary, as was the case after Hurricane Sandy and during initial invasive plant management in 2008 and 2009.

4. Security/Visitor Safety

The Forest website and interpretive signage explain Forest etiquette to all Garden visitors in order to maintain visitor safety and proper stewardship of the Forest.

1. Do stay on the trails for your safety and for the health of the Forest. Venturing off the paths disturbs wildlife, compacts soil, and damages plant communities.
2. Do watch for birds and wildlife.
3. Do put trash in trash cans.
4. Do Not feed the birds or other wildlife.
5. Do Not climb trees and rocks.
6. Do Not pick flowers, leaves, seeds, or branches.

The Forest is regularly patrolled by Garden security. Forest staff have both cell phones and radios and are instructed to contact Security if necessary.

5. Trash Removal

Trash left by visitors or deposited in the Forest during wind storms and floods leaves the impression that the Forest is poorly managed. Staff and volunteers inspect the Forest for trash at least monthly and spend approximately 150 hours each year cleaning trash from Forest trails, Forest edges, the banks of the Bronx River, and adjacent natural areas.

C. Education Programs

The Forest is home to a wide variety of educational programs and activities that serve everyone from elementary school students to Ph.D. candidates. More than forty interpretive signs were installed in 2011 with an accompanying audio tour that provides an introduction to the Forest's history, ecology, and management. Some of these signs change seasonally and all are updated regularly. Also in 2011, a Forest website was launched to provide additional information about public programs and ongoing research in the Forest. Regular Forest tours provide visitors with an overview of ongoing forest management activities, the significance of the Forest to the Garden, and the importance of forests regionally. The Forest is a favorite destination for school groups—more than 90,000 New York City schoolchildren visit each year—and an important outdoor classroom for the Garden's teacher training programs. Local universities use the Forest as an outdoor laboratory for undergraduate course work and graduate research. Adult Education courses use the Forest as an outdoor classroom, a space for wellness activities, and an inspiring subject for painting and photography. The Forest is used by high school interns and in the Garden's Citizen Science programs, including plant phenology and water quality monitoring.


Forest trails are used by hundreds of thousands of visitors each year.

The Garden offers canoe trips on the Bronx River during Fall Forest Weekends.

1. Interpretation

The goal of Forest interpretation is to engage visitors and teach them that forests are dynamic ecosystems that sustain and enhance life. Interpretive signage and audio tours convey diverse educational themes and story lines, including:

- Forests, which cover 31% of Earth's total land area, are complex ecosystems that change over time.
- Forests are threatened. Only 12% of the world's forested area is designated for the conservation of biodiversity. Climate change, degradation, deforestation, and invasive species are all threats to forests world-wide.
- Forests are valued by people and wildlife. Forests are essential to the health of our planet. They filter drinking water; stabilize the soil, and produce oxygen. The livelihood of over 1.6 billion people worldwide depend on forests; forests are homes to 300 million people worldwide; forests provide valuable products such as wood, paper, food, and medicine. Forests are home to 80% of the world's terrestrial biodiversity.
- Only one-third of the world's forests have never been cleared for agriculture or other human purposes. The Thain Family Forest is the largest remnant of original forest that once covered most of New York City.
- The Thain Family Forest is studied, cared for, and managed by the Garden. The Forest is an important scientific research site that has been studied for more than a century. Research has shown that over the past century, pollution, soil compaction, and the introduction of invasive plants, pests, and diseases have impacted the health of the Forest. The Garden actively manages the Forest to preserve and enhance its unique character as the largest remaining native forest in New York City.

2. Public Programs

During the first two weekends of November each year the Garden hosts "Fall Forest Weekends," which engage a diverse audience in the Forest and provide educational programming and nature recreation opportunities. On these weekends, visitors can join bird watching, natural history, fall foliage, and forest ecology tours; attend tree climbing demonstrations; enjoy live birds of prey and woodcrafting demonstrations; paddle canoes on the Bronx River; and learn about citizen science. Between 2011 and 2014, 19,605 people participated in the Fall Forest Weekends.

In addition to the Fall Forest Weekends, regular tours of the Forest are provided by trained tour guides. Between 2008 and 2014 a group of 13 dedicated tour guides provided 435 tours that reached nearly 2,000 visitors.

Young scientists analyze macroinvertebrates collected in the Bronx River.

These tour guides are great advocates for the Forest and often provide tours longer than the allotted hour if participants show interest. The Garden is extremely fortunate to have such knowledgeable and generous volunteers to provide in-depth enrichment to visitors throughout the year.

3. Children's Education

Engaging the next generation of land stewards within the Forest is one of the most rewarding aspects of the Garden's programming. There are many ways in which children learn about forests, ecosystems, nature, and water. School groups from grades K-8 use the Forest for a variety of instructor-led programs and have grown by 1,200 student participants from 2008 to 2014. The instructor-led programs are:

> Wooded Walk conducts tree studies by using field guides and identification keys to study the parts and functions of trees. Students also search for ways animals use trees. In 2008–2014, a total of 5,300 students participated in this program.
>
> A Forest in the City investigates the factors that characterize a forest ecosystem by conducting an outdoor ecology field study in the Forest. There were a total of 3,328 student participants from 2008–2014.
>
> Fall Harvest explores the outdoors to find the fruits and seeds that animals harvest in fall. There were nearly 6,000 student participants in this program from 2008–2014.

With funding from a WCS-NOAA Lower Bronx River Partnership grant, the Garden began a new citizen science program to monitor water quality in the Forest stream and Bronx River. This program provides valuable hands-on experience for middle school and high school students in New York City. Over 2,000 students participated in these volunteer led programs from 2010 to 2014 to collect monthly data on macroinvertebrate diversity in the Forest stream and Bronx River. This program has since grown and is now being offered through the instructor led Urban Advantage Program as a pilot program with the New York City Department of Education in the 2014–2015 school year. To date, the new instructor-led program has had 736 participants.

Phenology Citizen Science is also a new initiative in 2014–2015 school year as a pilot study with the New York City Department of Education that is utilizing the established Forest Phenology program as a tool for teaching middle school students about phenology, climate change, ecological monitoring and data collection. This program had 300 student participants in the 2014–2015 school year.

Self-guided materials including a student packet and teacher's guide are available for teachers to use on field trips to the Garden with their students. In the 2013–2014 school year, nearly 19,000 students participated in self-guided activities at the Garden. These programs are not registered for individually, however, the casual observer in spring and fall knows that many of the self-guided school groups walk through the Forest. The following self-guided activities involve the Forest:

> "Color Me Autumn" explores the seasons and how they affect the plant life cycles. Answering the questions: Why are leaves so special? What happens to leaves in autumn? What causes the leaves to change colors?
>
> "Into the Woods and Forest Forays" investigates the ecology of forests for two different age groups, grades K–1 and 6–8. Providing answers to what is a forest? What is biodiversity? What is decomposition? What is so special about the Forest at the Garden? Bronx River Walk investigates the factors that characterizes a forest ecosystem through field studies while navigating through the Forest and along the Bronx River.

To teach children about forests, the Children's Education department offers several workshops that train teachers on the various topics that are covered in the school group curriculum. There are six-day immersion workshops in which participants learn how to make teaching fun through field-tested, hands-on, inquiry-based activities. During the week-long institutes, teachers access the Forest for 1–3 days in the following programs:

> "Seedlings" strengthens science instruction using plant and ecology concepts and inquiry-based activities to support cross-curricular connections to math and literacy.
>
> "Geology Rocks! Earth Science and Evolution" teaches the importance of the living and non-living aspects of ecosystems in the science curriculum and make cross-curriculum connections to math and literacy.
>
> Customized One-Day Workshops that include the Forest are on the topics "Forests of the World" and "Wonderful Wetlands."

The Urban Advantage Program is a standards-based partnership program designed to improve students' understanding of scientific inquiry through collaborations between urban public schools and scientific cultural institutions. The Garden is a partner in this program and provides the following workshops for teachers:

> "Field Investigations: Phenology." What do your data really mean? Teachers explore data sets including the Forest phenology data set. "Field Investigations: Exploring the Bronx River Watershed." Teachers study the human impact on natural systems through investigating water quality indicators along the Bronx River watershed.

Researchers collecting fish in the Bronx River

The Forest is an outdoor classroom for students of all ages.

4. Forest Interns

Between 2008 and 2014 the Forest hosted 30 interns who learned about Forest restoration and ecological research. Many of these interns have been inspired by their experience to pursue graduate studies in forestry, ecology, or conservation biology or careers in natural resource management. In 2009 the Garden partnered with Sewanee: The University of the South to provide an annual internship for an undergraduate student. This program has been extremely successful and Sewanee interns have proven to be knowledgeable and engaged students.

In 2011 and 2013, the Forest hosted research undergraduate students through the Fordham University Calder Summer Undergraduate Research Program. This generous collaboration provided two enthusiastic and knowledgeable students who helped with critical forest research: the Forest inventory in 2011 and post-Sandy monitoring 2013.

Explainers are high school interns that facilitate experiences with nature and plant science for children and families. They are involved in enrichment and intern activities throughout the Garden including the Forest. Explainers have been involved in restoration activities, phenology, and water quality monitoring. A ninth grade Explainer wrote in his journal after his first visit to the Forest, "I would describe the Forest now as a place full of hidden gems. You never know what you may find in the Forest, it may be a sprouting plant, a creepy bug, or a beautiful waterfall." With these hands-on experiences, the Explainers develop a greater knowledge of ecology and nature that is shared with all the children and families they teach.

5. Colleges and Universities

Fordham University students regularly use the Forest for undergraduate ecology labs that teach vegetation sampling, water quality monitoring, biodiversity assessment, and pollination biology. Columbia University has used the Forest for forest ecology and herpetology labs. New York University has visited for urban forest management and nature in the city. Yale University has used the Forest for courses on urban ecology and has also provided instructors for Adult Education Forest Ecology courses. Both Macaulay Honors College and Lehman College use the Forest for urban biodiversity instruction and plant science courses. The Garden hosted the Macaulay Honors College Bioblitz in September 2014 as part of a sophomore undergraduate ecology seminar. During the Bioblitz, over 400 undergraduates investigated the Garden and Forest to document as many living organisms as possible from September 6 to September 7, 2014. Experts from collaborating institutions including the American Museum of Natural History, City College at CUNY, Fordham University, Hofstra University, New York City Audubon, North Carolina State University, Rutgers University, SUNY Orange County Community College, and University of Connecticut documented more than 500 species that occur spontaneously in the Garden. This was a great educational experience to provide city-based students with fieldwork exposure.

6. Adult Education

Many classes offered through the Garden's Adult Education program use the Forest as an outdoor classroom. The Forest is used to teach subjects including plant identification (School of Professional Horticulture Plant Walks, Herbaceous Plant Identification, Mushroom Mania, Tree Identification, and Dendrology); ecology and nature studies (Bird Watching in New York City, Ecology Walk: Forest Trees and Flowers, Ecology: The Living Forest, and Forest Ecology); art and landscape design (Painting Fruits of the Forest, Designing and Building Woodland Paths, Fall Leaves in Watercolor, and Field Sketching in the Garden), and wellness and fitness (Meditation and Tai Chi).

7. Professional Development

The Garden offers several professional development opportunities that take advantage of the Forest. Since 2008 Garden educators have taught a multi-day training course on urban tree care for staff from the New York City Department of Parks and Recreation. This course includes a full day of training in the Forest. The Garden presents an annual field day for the New York Turf and Landscape Association that has featured workshops on ecological restoration, invasive species identification and management, and native plant alternatives to invasive plant species. The Garden has recently become a site for training professionals and citizen scientists how to use iMapInvasives. This database documents the distribution of invasive species throughout New York, provides a platform for reporting observations of new or potentially invasive species, acts as a tool for land managers to help prioritize management, and provides data for policymakers to establish regulations that prevent the spread of invasive species. The Garden is also a member of the Sentinel Plant Network a partnership between the American Public Gardens Association, USDA-APHIS, and National Plant Diagnostic Network that engages public garden professionals, volunteers, and visitors in the detection and diagnosis of high consequence pests and pathogens. With the support of this network, the Garden has hosted training sessions in the Forest on the identification of invasive pests and diseases for green industry professionals and concerned citizens.

8. Citizen Science

Citizen science or participatory science engages volunteers and students from varying backgrounds in the scientific process. Citizen Scientists are engaged in many aspects of Forest monitoring and research.

Installing a knotweed research plot

Volunteering in the Forest is both satisfying and exhausting.

A northern two-lined salamander

Citizen Scientists on a phenology walk

8a. Plant Phenology

In 2002 Garden scientist Charles Peters established a program that trains volunteers to observe and record plant phenology (the timing of seasonal events such as leafing out, flowering, fruiting, and leaf drop) in the Forest. In 2008 the Garden partnered with the National Phenology Network to formalize this innovative citizen science program. Since 2009 approximately thirty Citizen Scientists have observed and recorded phenological data on twenty-one plant species in the Forest and entered these data into Nature's Notebook, the USA National Phenology Network's database. The Garden's program is part of a regional partnership that includes organizations such as The New York Phenology Project and the Environmental Monitoring and Management Alliance of the Hudson Valley, and is tailored to match the needs of scientists who use the data to study climate change and its impact on plants. Participants receive intensive training in basic botany, trail locations, tree identification and location, and data entry and commit to weekly monitoring in spring, summer, and fall.

In 2011 the Garden established a Picture Post along the Bridge Tail in the Forest. Signage at the post encourages visitors to take photos of the Forest and upload these photos to a phenology database at the University of New Hampshire. Phenology researchers then use these photos to assess regional phenology changes throughout the year.

8b. Macroinvertebrate Monitoring Program

Since 2012 more than 2,000 schoolchildren and their teachers have been monitoring macroinvertebrates and water quality in a Forest stream. "Restoration and Education in The New York Botanical Garden's Forest-Stream Continuum" (2011–2013) was supported by a grant from the WCS-NOAA Lower Bronx River Partnership. Using the Stroud Leaf Pack Network protocols, kick netting, and the Bronx River Alliance's water quality protocols, participants collect data on the stream's biodiversity and water quality [Figure 5, page 54]. The data collected will help determine if the restoration of the stream has improved water quality and created better habitat for amphibians.

8c. Bird Phenology

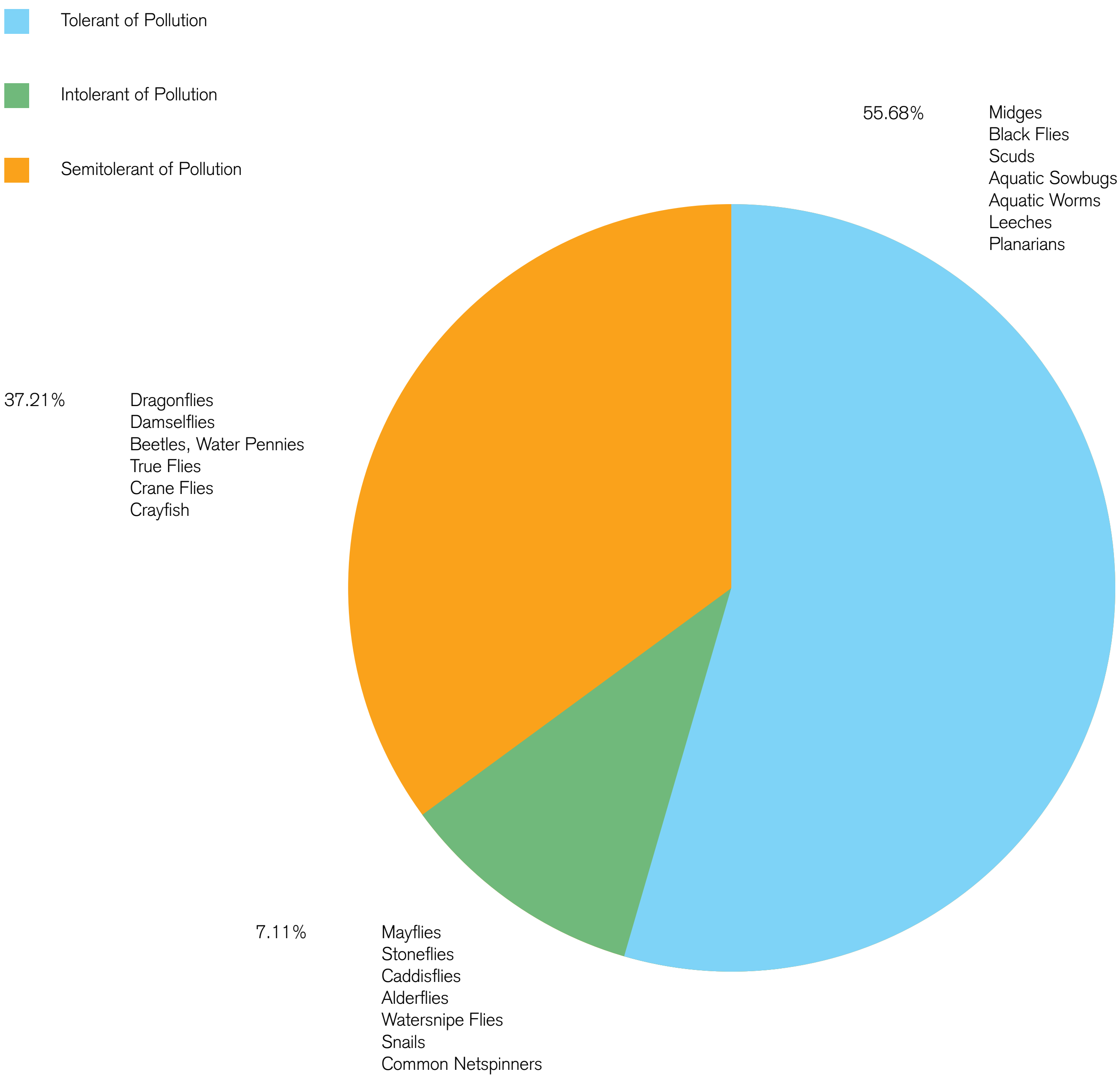
The Garden offers bird walks every Saturday morning from September to June. Attendees are encouraged to record their sightings in eBird, a database developed by the Cornell Lab of Ornithology, so that the diversity and abundance of birds at the Garden can be monitored over time.

8d. Amphibian Monitoring

In 2010 the Garden installed cover boards throughout the Forest in an effort to monitor populations of eastern red-backed salamander. Staff, volunteers, students, and interns sample the plots beneath the cover boards in spring and fall and collect structural habitat data in early fall. These data are used to gauge the impacts of management activities on salamander populations.

Figure 5: Macroinvertebrate Monitoring Results

Macroinvertebrates found through Leaf Pack Monitoring in the Bronx River 2010–2014



8e. Forest Health Monitoring

Every five years volunteers, students, and interns assist staff with a comprehensive inventory of the Thain Family Forest. Participants sample nearly 250 10-meter by 10-meter plots and collect data on all plants and abiotic variables present in the plots. In 2013 the Garden established a monitoring project to evaluate the impacts of the canopy gaps formed by Hurricane Sandy to help inform future management practices.

8f. Invasive Species

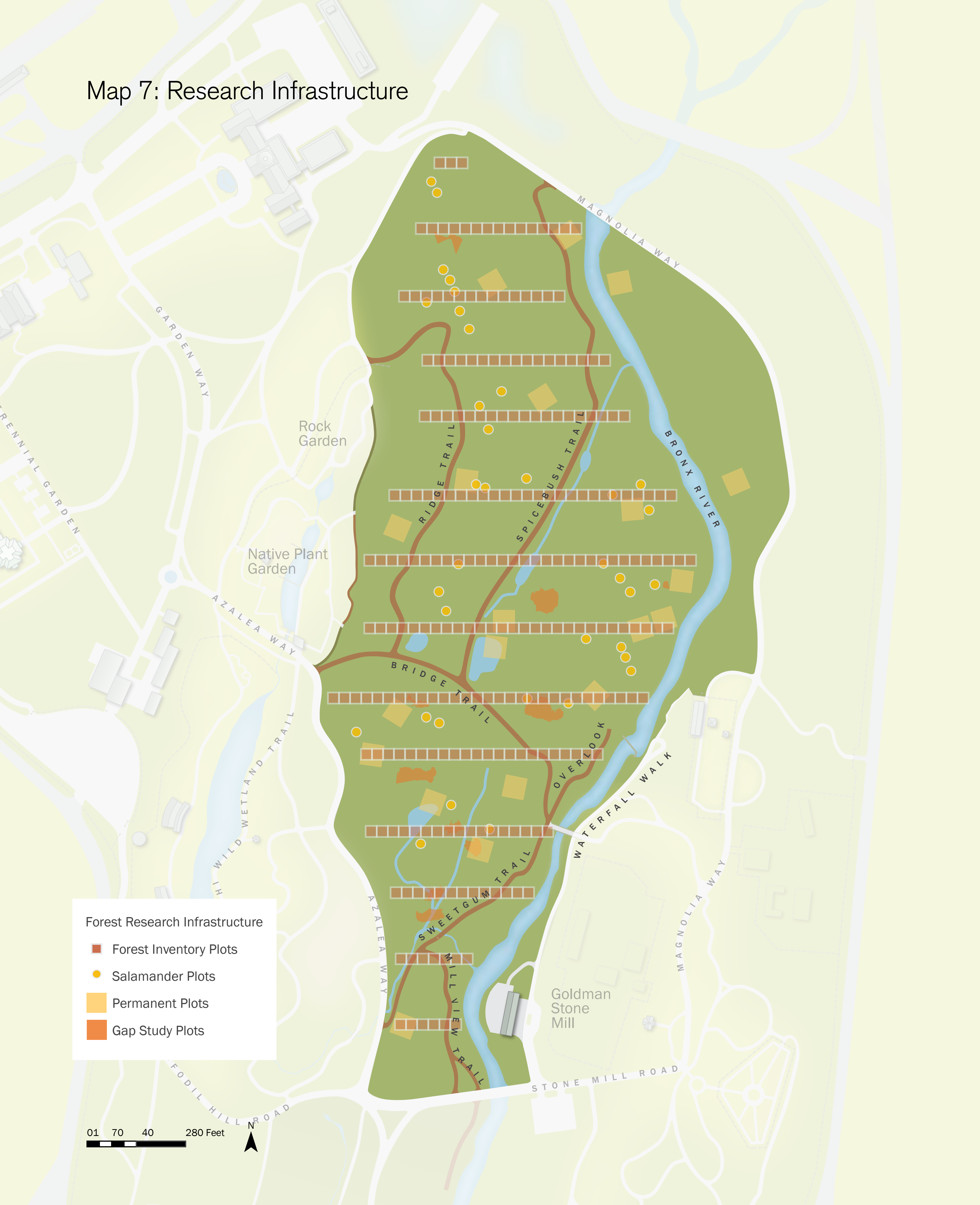
Since 2008 volunteers, students, and interns have participated in a project to monitor and manage the invasive viburnum leaf beetle in the Thain Family Forest. The Garden partners with the Sentinel Plant Network—through the American Public Gardens Association and the Lower Hudson Partnership for Regional Invasive Species Management—to train and disseminate information about invasive species to staff, volunteers, and students. The Garden hosts trainings for iMapInvasives, a Citizen Science monitoring database for invasive species.

D. Ongoing Research

Forest research has been an important component of the Garden's scientific program since N.L. Britton first commissioned a study of hemlock regeneration in the Forest in 1900 (Lloyd, 1900). Research in the Forest, primarily focused on hemlock, continued through the first three decades of the 20th century. Little research was performed in the Forest during the middle part of the 20th century and did not resume until the early 1980s when ecologists Dee Anne Honkala and Jay McAninch documented plant and animal diversity in the Forest and made management recommendations (Honkala and McAninch, 1981). In 1984 Mark McDonnell and his collaborators at the Institute of Ecosystem Studies in Millbrook, NY, began a systematic program of research in the Forest. In the late 1990s, ecologist Janet Morrison studied the ecology of garlic mustard and dogwood anthracnose (Morrison, 1998). In 1999 Charles Peters initiated a seed bank study and in 2002, the plant phenology study.

The Forest is fertile ground for scientific and ecological research. It is a unique living laboratory for studies that illuminate the impact of a changing climate and an urban environment on the flora and fauna of the region, the development of best management practices for invasive species, and the best techniques for forest restoration. Both Garden scientists and outside researchers are encouraged to propose research projects in the Forest. The Director of the Forest evaluates each proposal based on its potential to contribute to the knowledge of urban forest ecology and its potential impacts on the health of the Forest. The Director facilitates access for outside researchers. If necessary, Forest staff, students, and volunteers assist with research. Visiting researchers are required to follow established protocols:

Map 7: Research Infrastructure



Marking out a research plot

1. Visiting Research Protocols:

1. Requests to perform research are submitted to the Director of the Thain Family Forest who notifies the VP for Horticulture and Living Collections.
2. The Director reserves the right to reject any research that is not in line with the management principles outlined in this document.
3. All requests must include a description of the proposed research activities including project title, background, materials and methods, and hypotheses.
4. The Director corresponds with the principal investigator regarding project details, questions, and logistics. Research projects may be allowed to use existing research infrastructure in the Forest.
5. The Director arranges for an onsite meeting to discuss sampling locations and methods. Researchers are instructed of the Garden's rules and policies.
6. The Director arranges access for the researchers by notifying the appropriate Garden staff members; and is present as much as possible throughout the sampling and site visit(s).
7. Data, results, a project summary, and any resulting posters and publications are presented to the Director at the completion of the project.
8. The New York Botanical Garden is acknowledged in all publications based in part on research in the Forest.

Ongoing and completed research projects are listed on the Forest website and updated periodically. Recent research collaborations have involved scientists, staff, and students from Fordham University, City University of New York, Columbia University, Yale University, Rutgers University, Wildlife Conservation Society, Cornell University, Yorktown High School, Bronx High School of Science, Ossining High School, and Pelham Memorial High School.

2. Forest Research (2008–2014)

2a. Forest Inventory Transect Study

Every five years Garden staff sample plots along fourteen ten-meter wide transects that run west to east across the Forest from its western edge to the west bank of the Bronx River [Map 7: Research Infrastructure, page 56]. All trees and shrubs 1cm or greater in diameter at breast height (1.3m from the ground) are identified and measured. All herbaceous plants are identified and tree seedling percent cover is estimated. Data collected from this study are used to monitor how the Forest is changing, to track the results of invasive plant management, and to help prioritize ongoing restoration work. The results of the 2011 survey show that management has successfully reduced populations of Amur honeysuckle and Amur corktree. These same data

A wide-angle lens allows researchers to determine canopy cover.

indicate that Japanese angelica tree populations have increased substantially in response to management activities and natural disturbance. Forest staff will focus future management efforts on this species (Schuler et al., 2011).

2b. Filling in the Gaps: Plant Establishment After Hurricane Sandy

On October 29, 2012, Hurricane Sandy destroyed 167 trees in the Forest 15cm in diameter at breast height or greater, creating canopy gaps and providing growing space for invasive species. While devastating natural disturbances have always played a major role in shaping the vegetation of the Forest, Hurricane Sandy was the most damaging storm in the Garden's recorded history. In 2013 Forest staff established research plots within ten canopy gaps created during Sandy and along transects north and south of the gaps. Staff recorded first-year seedlings in these plots and will continue to monitor the re-establishment of plant species for several years. In addition to the in situ monitoring of forest change, soil cores were removed from canopy gaps for a soil seed bank study. Data collected will guide future forest management activities (Gaeta et al., 2013; Zhou, 2014).

2c. Long-term Eastern Red-backed Salamander Monitoring

In 2010 a long-term monitoring study was established in the Thain Family Forest to document the abundance and distribution of eastern red-backed salamander populations, which is considered to be an indicator of forest health in northeastern deciduous forests (Hartwell et al., 2001).

2d. Knotweed Management Study

In 2009 Forest staff developed a study in partnership with the Bronx River Alliance, the Natural Resources Group of the New York City Department of Parks and Recreation, and Columbia University to determine best management practices for controlling Japanese and hybrid knotweeds. Two management techniques have been assessed:

1. Cutting knotweed back three times a year
2. Cutting knotweed once and removing roots and rhizomes two times a year

Between 2009 and 2014 staff collected data on plant species diversity, plant species percent cover, restoration tree establishment, and knotweed height and stem count to determine which management technique is more successful. The results of this study showed that there was statistically no difference between the two treatments and future management should incorporate regular cutting of growing knotweed throughout the growing season (Haight et al., 2013). The "Riparian Invasive Plant Management Plan" (2009–2011) was supported by a grant from the WCS-NOAA Lower Bronx River Partnership.

2e. Macroinvertebrate Monitoring

Freshwater streams are among the most biologically diverse ecosystems on earth. They share interdependence with forests, outflow into larger bodies of water, and are greatly impacted by overuse, pollution, and urbanization. In partnership with the Bronx River Alliance, Forest staff established a Citizen Science project to monitor benthic macroinvertebrates (small animals living among sediments and stones on the bottom of rivers, lakes, and streams. Insects represent the largest diversity of these organisms). Using the Stroud Leaf Pack Network protocols, kick netting, and the Bronx River Alliance's water quality monitoring protocols, students and Citizen Scientists collect data on the biodiversity and water quality in the Bronx River and in the Forest stream along the Sweetgum Trail. These data document the health and interdependence of the Forest stream and Bronx River ecosystem. This project was supported by a WCS-NOAA Lower Bronx River Partnership grant (2011–2013). Project is ongoing 2010 to present [Figure 5, page 54].

3. Visiting Researchers (2008–2014)

3a. Researchers

- Dr. Jason Munshi-South, Fordham University. Long-term monitoring of white-footed mice in the Forest (2010 to present). As a faculty member at Fordham University he has also used the Forest actively during lab exercises and special projects for his undergraduate students.

- Dr. Mark Weckel, AMNH, Chris Nagy, Mianus River Gorge Preserve, and Jason Munshi-South, Fordham University (2010 to present). Colonization of Coyotes in NYC. The Forest program has been monitoring animals in the Forest and is collaborating with a study citywide documenting the colonization of coyotes.

- Dr. Steve Franks, Fordham University (2012 to present). Project Baseline: A Seedbank to Study Plant Evolution. Steve and students are collecting seeds to contribute to a nationwide seedbank that will evaluate the impacts of climate change on plants over time. Species on the Project Baseline list with populations at the Garden have been collected and Garden volunteers continue to help these researchers clean the seed in preparation for storage. As a faculty member at Fordham University he has also used the Forest actively during lab exercises and special projects for his undergraduate students.

- Dr. Eric Sanderson, Wildlife Conservation Society (2010 to present). The Welikia Project.

- Dr. Charles Merguerian, Hofstra University and Duke Geological Laboratory (2012–2013). Geology of The New York Botanical Garden.

- Dr. Chanda Bennett, Wildlife Conservation Society (2011). Urban Bat Survey.

- Dr. Craig Frank, Fordham University (2011. The effects of climate change on hibernation of eastern chipmunks (*Tamias striatus*).
- Dr. Dena Vallano, Cornell University (2008). Partitioning the relative influence of soil N, mycorrhizal associations, and direct leaf nitrogen uptake on foliar 15N patterns along a temperate forest N deposition gradient.
- Dr. Catherine Burns, WildMetro, University of Maine, Earthwatch (2008–2009). Urbanization's impacts on flora and fauna in the New York metropolitan region.

3b. Graduate Students

- Xiupeng Zhang, Fordham University (2014 to present). Soil Carbon and Nitrogen Cycles in Riparian Zone under the Effect of Urbanization.
- Acer VanWallendael, Fordham University (2014 to present). Epigenetic diversity of Japanese knotweed (*Fallopia japonica*) in North America.
- Richard DeMarte, SUNY Binghamton; Michael Bednarski, Massachusetts Division of Marine Fisheries; Merry Camhi, Wildlife Conservation Society; John Waldman, CUNY (2014). The Effects of Dams on Densities and Sizes of American Eels in the Bronx River. Using a combination of electrofishing and eel pot trapping, these researchers are modeling the American eel population that is impacted by dams along the Bronx River. They have sampled in the reach of the river from just below the waterfall to the Stone Mill terrace.
- Lea Johnson, Rutgers University (2010 to 2013). Long-term outcomes of urban forest restoration: Assessing trajectories in plant community ecology to improve environmental health.
- Alison Cucco, Fordham University (2009 to 2011). Urbanization effects on nitrogen cycling and plant productivity.
- Rosalind Becker, Fordham University (2011). Genetic approaches for characterizing soil microbial communities.
- David Waring, Fordham University (2010–2011). Population dynamics of the invasive plant *Alliaria petiolata* (garlic mustard) along an urban-rural gradient.
- Chris Nagy, City University of New York (2010). Abundance, Survival, and Landscape-Level Selection in Screech Owls in New York City.
- Eric Morgan, Bartlett Arboretum (2008–2009). Determining the Invasive Capabilities of the Exotic Tree *Phellodendron amurense* in Northeastern North America.

Soil seed bank studies reveal the Forest of the future.

An enormous common snapping turtle from Twin Lakes.

3c. Undergraduate Students

- Erica Gaeta, Humboldt State University (2013). Effects of Hurricane Sandy on the Terrestrial Eastern Red-backed Salamander.
- Erica Gaeta, Humboldt State University (Fordham University CSUR Program) (2013). Filling in the Gaps: Plant Establishment After Hurricane Sandy in an Urban Old-Growth Forest.
- Michelle Mathios, Fordham University (2012). Bats of the Bronx: An Acoustic Survey.
- Alyssa Beasley, College of New Rochelle (Fordham University CSUR Program) (2011). The Future of the Forest: Vegetation Change Over Time and Invasive Plant Species in an old-growth Forest.
- Rolando Rojas (Fordham University CSUR Program) (2011). New York's Melting Pot: Forest Fragmentation Effects.

3d. High School Students

- Abrahim Assaily, Bronx High School of Science, Bronx NY (2013–2014). Correlations between macroinvertebrate populations and phosphates/nitrate levels in the Bronx River.
- Cherry Huang, Bronx High School of Science, Bronx NY (2013–2014). Herbarium specimens and field observations show changes in first flowering dates for *Prunus serotina* and *Acer rubrum* within US regions.
- Cindy Zhou, Bronx High School of Science, Bronx, NY (2013–2014). Regeneration in Forest Gap Understory at The New York Botanical Garden After Hurricane Sandy.
- Megan Krause, Pelham Memorial High School, Pelham, NY (2013). Assessing the Plant Species, Mortality Rates, and Water Availability under the Canopies of the MillionTreesNYC Plots.
- Owen Robinson, Pelham Memorial High School, Pelham, NY (2012). Impact of Leaf Species on Northeastern Macroinvertebrate Populations.
- Leah Buchman, South Side High School, Rockeville Centre, NY (2010 to 2012). Effects of Biotas on Pollinator Apoidea (Anthophilia) Diversity.
- Francesca Giordano, Yorktown High School, Yorktown, NY (2010 to 2012). Increasing plant species richness by managing *Fallopia japonica* (Japanese knotweed) in an urban forest.
- Rebecca Policello, Ossining High School, Ossining, NY (2010 to 2012). The effects of urbanization on cutaneous bacteria ability to inhibit the threatening Chytrid fungus on eastern red-backed salamanders (*Plethodon cinereus*).

- Erik Zeidler, Bronx Science High School, Bronx, NY (2009 to 2010). Investigating the ecology of *Chelydras serpentina*, the common snapping turtle, in a highly urban setting. The New York Times City Room blog - The Turtle Gatherer of the Bronx.

American mink are recolonizing the Forest along the Bronx River.

E. Biodiversity Inventory

Understanding the Forest ecosystem as a whole and its context within the Garden landscape, Bronx River watershed, and New York City landscape matrix is essential for future management, conservation efforts, and better understanding the human impacts on forest ecosystems. Urban ecology and biodiversity conservation have been hot topics in scientific literature in the past decade, and New York City is very involved in this research with its diversity of habitat types (Kiviat and McDonald, 2004; Kiviat, 2012; Aronson et al., 2014; Kiviat and Johnson, 2013). Between 2008 to 2014 several projects greatly increased the knowledge of the Forest's unique biodiversity. The Historic and Extant Spontaneous Vascular Flora of The New York Botanical Garden has found that more than 400 native and naturalized flowering plant species occur throughout the Garden's natural areas including the Forest. Of these species, approximately 30% are non-native and 8% are considered invasive (Atha et al., 2016). In documenting the spontaneous flora, scientists have determined 155 native species that were known to grow at the Garden at one point are no longer present.

More than 200 bird species have been recorded as breeding at the Garden or migrating through the Garden landscape. Scientists have also documented twenty nine different mammals and thirteen different fish. Amphibian and reptile surveys throughout the Garden in 2010 determined that there are four amphibian species and eight reptile species (McGraw, 2011; Zeidler, 2013). Historical data from the American Museum of Natural History indicate that eight additional amphibian species and two reptile species were once found at the Garden but have been extirpated (Dickey and Kizirian, 2010). Relatively little research has been performed on the invertebrates at the Garden. Even with a paucity of research, more than 120 beetle species, 30 bees and wasps, 20 damselflies and dragonflies, 45 butterflies and moths, 40 flies, 8 mollusks, and 13 ants have been documented at the Garden. A new species of bee, gotham bee, was described from a specimen collected at the Garden by a Forest intern, Leah Buchman (Gibbs, 2011; Snyder, 2011).

F. Outreach

The Thain Family Forest has increased the Garden's profile as a leader in biodiversity research and conservation through a series of symposia and professional conferences and the establishment of new partnerships with local and regional universities and conservation organizations.

Symposia engage audiences in Forest research.

1. Symposia and Conferences

The dedication of the Thain Family Forest in 2011 was the catalyst for new programs that engage broad audiences in the complex issues surrounding forest conservation, ecological restoration, and education about forests and nature. In November 2011, the Garden hosted two symposia: "The Future of Forests: A Teen Symposium" which brought together local teens and educators to tour the Forest, view an award-winning film from the United Nations International Forest Film Festival, and participate in an interactive challenge related to forest ecology; and "The Future of Forests: Global, Regional, and Local" featured presentations by Dr. Steven Schwartzman, Dr. William Schuster, Dr. Eric Sanderson, and Todd Forrest that addressed the role forests play in preserving biodiversity, mitigating human-caused environmental change, and promoting, research and connecting people with nature.

In 2013 the Garden hosted the New York City Restoration Practitioners Annual Meeting. Over 100 representatives from a diverse group of organizations (New York City Department of Parks and Recreation, Prospect Park Alliance, Bronx River Alliance, New York Restoration Project, New York City Department of Environmental Protection, New York State Department of Environmental Conservation, Central Park Conservancy, US Forest Service, Natural Areas Conservancy, Wave Hill Forest Project, Larry Weaner Associates, Stone Barns Center for Agriculture, The Dawson Corporation, Mianus River Gorge Preserve, and National Park Service) attended to listen to presentations, contribute to discussions, and attend tours of ongoing restoration work in the Forest.

In November 2014 "The Changing Nature of Nature in Cities" symposium brought together over four hundred scientists, botanists, landscape and garden design professionals, urban planners, architects, and interested amateurs to discuss the concept of novel ecosystems in urban areas. A diverse group of international experts presented on the impacts of humans on nature, showing how rampant urbanization has led to the spread of invasive species, disruption of nutrient cycles, and decline of native species, affecting natural systems on a global scale. The presenters included Dr. Richard Hobbs, Emma Marris, Dr. Peter Del Tredici, and Kate Orff.

2. Meetings and Presentations

Forest staff have taken advantage of networking and outreach opportunities at professional meetings including: the Society for Ecological Restoration World Conference, Society for Ecological Restoration Mid-Atlantic Chapter Annual Conferences, Annual NYC Restoration Practitioners Meetings, Arbor Day Foundation Conference, Ecological Society of America Mid-Atlantic Chapter Annual Meetings, Northeast Natural History Conferences, Lower Hudson

Partnership for Regional Invasive Species Management Meetings, Bronx River Alliance Ecology Team Meetings, The Native Plant Center's Go Native U Adult Education Program, American Public Gardens Association Conference, and Garden Clubs. Staff have presented on the Knotweed Management Study, Stream Restoration Project, Engaging the Public in an Urban Old Growth Forest, Studying the Unique Flora and Fauna of an Urban Old-growth Forest, Invasive Plant Management and Introduction to Ecological Restoration, and Native Plant Alternatives to Invasive Plants.

3. New and Continued Partnerships

Through the ongoing restoration and research work in the Forest, the Garden has entered into partnerships with the Lower Hudson PRISM, Ecological Restoration Alliance of Botanic Gardens coordinated by Botanic Gardens Conservation International, the National Phenology Network, New York Phenology Project, and Ecological Monitoring and Management Alliance of the Hudson Valley. Staff have further developed existing collaborations by becoming advisors and active participants in local organizations including the Bronx River Alliance, Torrey Botanical Society, Natural Areas Conservancy, and the Native Plant Center. Working closely with the Lower Hudson PRISM, Bronx River Alliance, and the Natural Resources Group of the NYC Parks Department, the Garden has entered into a new collaboration with Westchester County Parks Department and Wildlife Conservation Society to develop a whole river approach to ecological restoration and ecosystem management along the Bronx River corridor.

The Bronx River is a haven for native plants and wildlife within New York City.

V. Thain Family Forest Program Goals 2016–2025

Since 2008 the Forest's managers have directed their work to achieving the goals outlined in the Forest Management Plan of 2001. Forest staff and their research partners have learned a great deal from ongoing efforts to mitigate the impacts of anthropogenic disturbances on the health of the Thain Family Forest. While some of the native plant and animal communities in the Forest have persisted in spite of significant anthropogenic disturbance and environmental change, recent research has confirmed that without active management, these natural communities are at risk of declining and, perhaps, disappearing. Forest staff have also learned that management and research activities guided by the primary goals of the previous Management Plan have measurably improved the health of the Forest and increased its value as a research and educational resource. These goals will continue to inform future management decisions.

The primary goal of future management will be to maintain viable populations of naturally regenerating native plant species in the face of new and intensifying disturbances:

1. Invasive Species—Established invasive species, the constant pressure of potential invasion from regional invasive species that have yet to invade the Forest, and the establishment of new invasive species yet to be discovered present a substantial threat to the long-term health of the Forest.
2. Climate Change—Climate models predict that severe weather events will increase in frequency and intensity as climate change continues.
3. Pests and Diseases—The impacts of native and introduced pests and diseases will be intensified by environmental change.
4. Increased Use—New programs and activities have substantially increased the use of the Forest by Garden visitors. Care must be taken to ensure that increased use does not lead to further degradation.
5. Wildlife—The Forest is a refuge for wildlife and a major bird migration stopover. The absence of predators has led to increased populations of small mammals that feed on native plants. Populations of white-tailed deer, which have devastated suburban and rural forests, are increasing in New York. Invasive earthworms, present in the Forest since at least the 1980s, alter nutrient cycling and impact native plant regeneration. Active management must address these and other threats to forest health.
6. Pollution—The impacts of high concentrations of heavy metals in forest soils and nitrogen in the urban air must be studied further.

The Forest is continually changing and must be continually managed.

The goals of the Thain Family Forest Program for 2016–2025 are:

A. Continue to improve Forest health through active management informed by research.
Objective #1: Prevent new invasive species from becoming established in the Forest
Objective #2: Reduce existing populations of invasive species.
Objective #3: Increase native plant species regeneration.
Objective #4: Improve habitat through active management.
Objective #5: Determine if the restoration of extirpated species is feasible and would contribute to the overall goal of improving Forest health.

B. Provide improved access through continued trail restoration and maintenance.
Objective #1: Maintain restored trails using developed best management practices.
Objective #2: Complete restoration of Ridge Trail, Overlook Trail, and Cherry Valley.

C. Engage and educate new audiences about the local, regional, national, and global importance of forests and threats to forest health through signage, electronic media, classes, workshops, symposia, publications, and other methods.
Objective #1: Build on the success of current education programs by engaging more people.
Objective #2: Update interpretive signage as necessary.
Objective #3: Provide workshops, classes, and symposia relevant to the ongoing work in the Forest.
Objective #4: Publish articles and blog posts about Forest Program activities.
Objective #5: Maintain Forest website content with the most current information about ongoing research and restoration work.

D. Collaborate with researchers and Citizen Scientists to study the impacts of the urban environment and environmental change on biodiversity, forest health, and ecosystem processes and to better understand the role that nature plays in promoting human health and well-being.
Objective #1: Continue to conduct research and publish results from research in the Forest.
Objective #2: Develop new research initiatives to help answer questions about the Forest ecosystem such as:
  a) Can we define the reasons for species extirpation?
  b) Can we predict future invasions by learning from past invasions?

c) Can we prevent future native species extirpations and non-native species invasions?
d) How will climate change impact the Forest ecosystem?
e) What is the quality of the Forest habitat? Is it a refuge for species in the urban landscape? Do Forest interior species thrive? What breeding birds use the Forest?

Objective #3: Invite visiting researchers to use the Forest. Possibly host a visiting researcher in residence.
Objective #4: Expand upon the established Citizen Science program and publish findings.

E. Document and enhance the Forest's unique biodiversity.
Objective #1: Increase the knowledge of the forest through continued surveys of the flora and fauna and close gaps in our knowledge of the Forest's breeding birds, insects, and other invertebrates such as earthworms.

F. Cultivate partnerships that improve our stewardship of the Forest and enhance the Garden's profile as a leader in studying and conserving regional biodiversity.
Objective #1: Work closely with the Garden's Conservation Program.
Objective #2: Continue to develop existing partnerships.
Objective #3: Expand beyond existing network to increase exposure.
Objective #4: Stand as a leader by hosting professional meetings, symposia, and conferences and presenting on the work in the Forest at meetings and conferences.
Objective #5: Publish the ongoing work in the Forest in peer-reviewed literature, popular media, and blogs.

The ongoing program of active management, education, and research in the Thain Family Forest has had a measurable impact on forest health, engaged and informed tens of thousands of students, and improved our knowledge of the impacts of an urban environment on forested ecosystems. Continued management efforts will ensure that the Thain Family Forest will continue to be a celebrated natural area, favorite visitor destination, priceless educational resource, and notable research site for decades to come.

Appendix 1: Species Cited

Plants

Common Name	Scientific Name
American beech	*Fagus grandifolia*
American chestnut	*Castanea dentata*
American elm	*Ulmus americana*
Amur corktree	*Phellodendron amurense**
Amur honeysuckle	*Lonicera maackii**
arrowwood	*Viburnum dentatum*
ash	*Fraxinus* spp.
birch	*Betula* spp.
bitternut hickory	*Carya cordiformis*
black cherry	*Prunus serotina*
black gum	*Nyssa sylvatica*
black oak	*Quercus velutina*
black willow	*Salix nigra*
blackhaw viburnum	*Viburnum prunifolium*
Canada mayflower	*Maianthemum canadense*
cutleaf coneflower	*Rudbeckia laciniata*
devil's walking stick	*Aralia spinosa*
double-file viburnum	*Viburnum plicatum**
elm	*Ulmus* spp.
English ivy	*Hedera helix**
false Solomon's seal	*Maianthemum racemosum*
flowering dogwood	*Cornus florida*
Fuji cherry	*Prunus incisa**
garlic mustard	*Alliaria petiolata**
great blue lobelia	*Lobelia siphilitica*
hairy Solomon's seal	*Polygonatum pubescens*
hemlock	*Tsuga canadensis*
hickory	*Carya* spp.
Higan cherry	*Prunus subhirtella**
hop-hornbeam	*Ostrya virginiana*
hornbeam	*Carpinus caroliniana*
hybrid knotweed	*Reynoutria × bohemica**
incised fumewort, purple kumen	*Corydalis incisa**
Japanese angelica tree	*Aralia elata**
Japanese honeysuckle	*Lonicera japonica**
Japanese knotweed	*Reynoutria japonica**
Japanese stiltgrass	*Microstegium vimineum**

A red maple in full fall color

*non-native organism

Common Name	Scientific Name
lesser celandine	*Ficaria verna**
linden viburnum	*Viburnum dilatatum**
maple	*Acer* spp.
mapleleaf viburnum	*Viburnum acerifolium*
mile-a-minute vine	*Persicaria perfoliatum**
mockernut hickory	*Carya tomentosa*
multiflora rose	*Rosa multiflora**
Norway maple	*Acer platanoides**
oak	*Quercus* spp.
pignut hickory	*Carya glabra*
pin oak	*Quercus palustris*
poplar	*Populus* spp.
purple loosestrife	*Lythrum salicaria**
pussy willow	*Salix discolor*
red maple	*Acer rubrum*
red oak	*Quercus rubra*
Sargent's cherry	*Prunus sargentii**
serviceberry	*Amelanchier canadensis*
shagbark hickory	*Carya ovata*
silver maple	*Acer saccharinum*
smooth buckthorn	*Rhamnus frangula**
spicebush	*Lindera benzoin*
sugar maple	*Acer saccharum*
swamp white oak	*Quercus bicolor*
sweet birch	*Betula lenta*
sweet cherry	*Prunus avium**
sweetgum	*Liquidambar styraciflua*
sycamore	*Platanus occidentalis*
tree-of-heaven	*Ailanthus altissima**
trout-lily	*Erythronium americanum*
tulip tree	*Liriodendron tulipifera*
white ash	*Fraxinus americana*
white oak	*Quercus alba*
white wood aster	*Eurybia divaricata*
willow	*Salix* spp.
witch-hazel	*Hamamelis virginiana*
wood anenome	*Anemone quinquefolia*
Yoshino cherry	*Prunus × yedoensis**

*non-native organism

Insects and Diseases

Common Name	Scientific Name
Asian long-horned beetle	*Anoplophora glabripennis**
beech scale	*Cryptococcus fagisuga**
black knot fungus	*Apiosporina morbosa*
chestnut blight	*Cryphonectria parasitica**
dogwood anthracnose	*Discula destructiva**
Dutch elm disease	*Ophiostoma* spp.*
elongate hemlock scale	*Fiorinia externa**
emerald ash borer	*Agrilus planipennis**
hemlock woolly adelgid	*Adelges tsugae**
golden loosestrife beetle	*Galerucella pusilla**
gypsy moth	*Lymantria dispar**
perennial nectria canker	*Neonectria* spp.
scale picnic beetle	*Cybocephalus nipponicus**
viburnum leaf beetle	*Pyrrhalta viburni**

Animals

Common Name	Scientific Name
American beaver	*Castor canadensis*
American mink	*Neovison vison*
common snapping turtle	*Chelydra serpentina*
Cooper's hawk	*Accipiter cooperii*
eastern chipmunk	*Tamias striatus*
eastern cottontail	*Sylvilagus floridanus*
eastern gray squirrel	*Sciurus carolinensis*
eastern red-backed salamander	*Plethodon cinereus*
gotham bee	*Lasioglossum gotham*
great horned owl	*Bubo virginianus*
hooded merganser	*Lophodytes cucullatus*
mallard	*Anas platyrhynchos*
northern goshawk	*Accipiter gentilis*
northern two-lined salamander	*Eurycea bislineata*
pileated woodpecker	*Hylatomus pileatus*
red fox	*Vulpes vulpes*
red-tailed hawk	*Buteo jamaicensis*
scarlet tanager	*Piranga olivacea*
white-footed mouse	*Peromyscus leucopus*
white-tailed deer	*Odocoileus virginianus*
wood duck	*Aix sponsa*
wood thrush	*Hylocichla mustelina*

*non-native organism

Appendix 2: Extirpated Species

Plants

Common Name	Scientific Name
white baneberry	_Actaea pachypoda_[+]
black baneberry	_Actaea racemosa_*[+]
northern maidenhair fern	_Adiantum pedatum_[+]
wild leek	_Allium tricoccum_[+]
speckled alder	_Alnus incana_ ssp. _rugosa_
thimbleweed	_Anemone virginiana_*
Adam and Eve	_Aplectrum hyemale_
eastern red columbine	_Aquilegia canadensis_[+]
Canadian wild-ginger	_Asarum canadense_[+]
wallrue	_Asplenium ruta-muraria_
common lady fern	_Athyrium filix-femina_*
subartic lady fern	_Athyrium filix-femina_ var. _angustum_
southern lady fern	_Athyrium filix-femina_ var. _asplenioides_
yellow birch	_Betula alleghaniensis_
lace-frond grape fern	_Botrychium dissectum_
grasspink	_Calopogon tuberosus_[+]
tuberous grasspink	_Calopogon tuberosus_ var. _tuberosus_
marsh marigold	_Caltha palustris_*[+]
Gray's sedge	_Carex grayi_*[+]
blue cohosh	_Caulophyllum thalictroides_[+]
New Jersey tea	_Ceanothus americanus_
American bittersweet	_Celastrus scandens_
fairywand	_Chamaelirium luteum_[+]
summer coralroot	_Corallorhiza maculata_
summer coralroot	_Corallorhiza maculata_ var. _maculata_
autumn coralroot	_Corallorhiza odontorhiza_
pale corydalis	_Corydalis sempervirens_
American hazelnut	_Corylus americana_*
arrowhead rattlebox	_Crotalaria sagittalis_
pink lady slipper	_Cypripedium acaule_
longbract frog orchid	_Dactylorhiza viridis_
silver false spleenwort	_Deparia acrostichoides_
Dutchman's breeches	_Dicentra cucullaria_[+]
shield fern	_Dryopteris carthusiana_
Clinton's woodfern	_Dryopteris clintoniana_
crested woodfern	_Dryopteris cristata_

Great blue lobelia

*Species reintroduced through restoration plantings
[+]Species planted in Native Plant Garden

Common Name	Scientific Name
Goldie's woodfern	*Dryopteris goldiana*+
intermediate woodfern	*Dryopteris intermedia*
marginal woodfern	*Dryopteris marginalis**+
eastern bottlebrush grass	*Elymus hystrix**
trailing-arbutus	*Epigaea repens*
field horsetail	*Equisetum arvense*
water horsetail	*Equisetum fluviatile*
scouringrush horsetail	*Equisetum hyemale*
showy orchid	*Galearis spectabilis*
shining bedstraw	*Galium concinnum*
wild geranium	*Geranium carolinianum*
spotted geranium	*Geranium maculatum**+
white avens	*Geum canadense**
downy rattlesnake-plantain	*Goodyera pubescens*
round-lobed hepatica	*Hepatica nobilis**
eastern waterleaf	*Hydrophyllum virginianum*
blue flag iris	*Iris versicolor**+
Engelmann's quillwort	*Isoetes engelmannii*
larger whorled pogonia	*Isotria verticillata*
butternut	*Juglans cinerea*
black walnut	*Juglans nigra*
marsh pea	*Lathyrus palustris*
Canada lily	*Lilium canadense*+
Turk's-cap lily	*Lilium superbum**+
woodland flax	*Linum virginianum*
yellow widelip orchid	*Liparis loeselii*
great blue lobelia	*Lobelia siphilitica**+
coral honeysuckle	*Lonicera sempervirens*
southern clubmoss	*Lycopodiella appressa*
bog clubmoss	*Lycopodiella inundata*
princess-pine	*Lycopodium obscurum*
wild bergamot	*Monarda fistulosa**+
bayberry	*Morella pensylvanica*+
Adder's-tongue fern	*Ophioglossum vulgatum*
cinnamon fern	*Osmunda cinnamomea**+
interrupted fern	*Osmunda claytoniana*+
royal fern	*Osmunda regalis**+
royal fern	*Osmunda regalis* var. *spectabilis*
green arum	*Peltandra virginica*
long beechfern	*Phegopteris connectilis*
broad beech fern	*Phegopteris hexagonoptera*
small green wood orchid	*Platanthera clavellata*
Hooker's orchid	*Platanthera hookeri*

*Species reintroduced through restoration plantings
+Species planted in Native Plant Garden

Common Name	Scientific Name
green fringed orchid	*Platanthera lacera*
lesser purple fringed orchid	*Platanthera psycodes*
rose pogonia orchid	*Pogonia ophioglossoides*+
Appalachian rockcap fern	*Polypodium appalachianum*
rocky polypody	*Polypodium virginianum*+
Christmas fern	*Polystichum acrostichoides**+
bracken fern	*Pteridium aquilinum*
bracken fern	*Pteridium aquilinum* var. *latiusculum*
pussy willow	*Salix discolor**
shining willow	*Salix lucida*
bloodroot	*Sanguinaria canadensis*+
early saxifrage	*Saxifraga virginiensis*
rock spike-moss	*Selaginella rupestris*
northern wild pink	*Silene caroliniana* ssp. *pensylvanica*
needle-tipped blue-eyed grass	*Sisyrinchium mucronatum*
smooth carrionflower	*Smilax herbacea*
white goldenrod	*Solidago bicolor*
broadleaf goldenrod	*Solidago flexicaulis*+
roundleaf goldenrod	*Solidago patula**
showy goldenrod	*Solidago speciosa*+
nodding ladies' tresses	*Spiranthes cernua*
northern slender ladies' tresses	*Spiranthes lacera*
northern slender ladies' tresses	*Spiranthes lacera* var. *gracilis*
spring ladies' tresses	*Spiranthes vernalis*
trailing fuzzybean	*Strophostyles helvola*
smooth aster	*Symphyotrichum laeve**
rue-anemone	*Thalictrum thalictroides*+
New York fern	*Thelypteris noveboracensis**+
eastern marsh fern	*Thelypteris palustris* var. *pubescens*
eastern marsh fern	*Thelypteris palustris*
nodding trillium	*Trillium cernuum*
feverwort	*Triosteum perfoliatum*
merrybells	*Uvularia perfoliata*+
green false hellebore	*Veratrum viride*+
sweet white violet	*Viola blanda*
American dog violet	*Viola labradorica*
early blue violet	*Viola palmata*
birdfoot violet	*Viola pedata*+
downy yellow violet	*Viola pubescens*
roundleaf yellow violet	*Viola rotundifolia*
downy yellow violet	*Viola pubescens* var. *scabruiscula*
bluntlobe cliff fern	*Woodsia obtusa*
netted chain fern	*Woodwardia areolata*

*Species reintroduced through restoration plantings
+Species planted in Native Plant Garden

Animals

Common Name	Scientific Name
American toad	*Anaxyrus americanus*
Fowler's toad	*Anaxyrus fowleri*
black racer snake	*Coluber constrictor*
dusky salamander	*Desmognathus fuscus*
milk snake	*Lampropeltis triangulum*
northern slimy salamander	*Plethodon glutinosus*
spring peeper	*Pseudacris crucifer*
pickerel frog	*Rana palustris*
northern leopard frog	*Rana pipiens*
southern leopard frog	*Rana utricularia*

Appendix 3: Invasive Species Best Management Practices

This list of invasive species has been developed based on experience as well as publications, including the 2015 NYS Department of Environmental Conservation and Agriculture and Markets, 6 NYCRR Part 575 Prohibited and Regulated Invasive Species.

a. Invasive Plants of Immediate Concern

***Acer platanoides*—Norway maple—Sapindaceae**

Norway maple is a wind-dispersed, shade-tolerant tree that has become one of the most widespread and destructive invasive exotic species in eastern forests (Emmerich, 1999). It produces allelopathic chemicals that inhibit the growth of native species.

Native range: Europe

First record at Garden: 1897 (N.L. Britton, 1898)

Threat to Forest: Norway maple is present in small numbers in the Forest but will certainly increase over time. This shade-tolerant species inhibits the regeneration of native plants and can lead to erosion by reducing the herbaceous layer.

Control: Seedlings and saplings can be removed by hand or with a weed-wrench. Mature specimens can be girdled or cut and treated with glyphosate. Cut stumps should be monitored for resprouting and recut and treated with herbicide if necessary. Injection with glyphosate has proven ineffective.

***Ailanthus altissima*—tree-of-heaven—Simaroubaceae**

This fast-growing, extremely aggressive tree produces root suckers that can colonize large areas. It is dioecious and female trees can produce huge quantities of wind-dispersed seeds. Tree-of-heaven grows vigorously in full sun and outcompetes all other tree species on poor soils.

Native range: China

First record at Garden: 1897 (N.L. Britton, 1898)

Threat to Forest: Tree-of-heaven has colonized dry ridges in the Forest and is present in the soil seedbank.

Control: Young seedlings should be removed by hand. Older seedlings and trees should be cut and painted with herbicide. Cutting and painting reduces soil disturbance that promotes the germination of new seedlings.

***Alliaria petiolata*—garlic mustard—Brassicaceae**

Garlic mustard is a shade-tolerant biennial herb that spreads from edges and canopy gaps into forest interiors. It produces heavy seed crops.

Native range: Europe
First record at Garden: unknown
Threat to Forest: Garlic mustard completely displaces native herbs. It is one of the most obvious and problematic invasive species in the Forest (Morrison, 1998).
Control: Second year plants are removed before they go to seed in May. First-year seedlings can be pulled until the soil freezes. Plants may be composted after they are removed.

***Ampelopsis brevipedunculata*—porcelain-berry—Vitaceae**

Porcelain-berry is a fast-growing, bird-dispersed woody vine that thrives along forest edges and in canopy gaps where it damages saplings and tree crowns. Seeds remain viable in the soil for two years (Emmerich, 1999).

Native range: China, Korea, Japan, and the Russian Far East
First record at Garden: unknown, has spread substantially since 1999
Threat to Forest: Porcelain-berry engulfs seedlings and saplings of native trees, damages crowns of mature plants, and shades out herbaceous plants.
Control: Physical removal of mature plants is potentially damaging to surrounding native plants. Cut climbing vines, remove from native vegetation, if possible, and grub roots or apply herbicide to cut stump. Most porcelain-berry present in the Forest are seedlings and young saplings that can be mechanically removed.

***Aralia elata*—Japanese angelica tree—Araliaceae**

Japanese angelica tree is a spiny, colony-forming tree that spreads by root suckers and forms large clumps in disturbed or open areas throughout our region.

Native range: Japan, Korea, Manchuria, and Russian Far East
First record at Garden: 1901 accession record
Threat to Forest: : A vigorous grower that outcompetes native trees and shrubs. This is by far the most threatening woody invasive plant species currently growing in the Forest. Its seeds are more abundant in the Forest soil seedbank than any other species. Previous mechanical management and recent natural disturbances have resulted in an exponential spread of this species over the past five years.
Control: First- and second-year seedlings are carefully weeded using a weed fork to remove all parts of the root system. Saplings less than one meter tall are treated with a 50% Rodeo® mixture applied with a foam brush to leaves and stems. Young trees larger than one meter tall are cut with a handsaw by 1/3 diameter and the fresh cut is treated with 50% Rodeo® mixture. Wounding the trees but not felling them results in greater uptake and better control. Based on inventory data, Forest staff target priority areas throughout the growing season and remove

all flowering individuals in July to reduce additional seed production in August. All treated areas are monitored for three to four weeks after an application. Follow-up treatments are necessary for at least two years.

***Celastrus orbiculatus*—Asian bittersweet—Celastraceae**

Bittersweet is a bird-and animal-dispersed, aggressive woody vine that colonizes forest edges produces copious quantities of fruit. Its seeds have a high germination rate. Once established it is very difficult to remove.

Native range: Japan and China

First record at Garden: unknown

Threat to Forest: Bittersweet can choke out native trees, shrubs, and herbs. Aggressive climbing stems pull down saplings and damage tree crowns. Bittersweet is a problem in disturbed areas along edges and in canopy gaps.

Control: Physical removal of mature plants is difficult and often damages surrounding native plants. Seedlings and young plants should be pulled as soon as they are seen.

***Corydalis incisa*—incised fumewort—Papaveraceae**

Incised fumewort is a new invasive species in the mid-Atlantic region with known populations in New York, Pennsylvania, Maryland, Virginia, and the District of Columbia. A biennial with explosively dehiscent fruit, fumewort can form dense stands in forests or wetlands.

Native range: Korea, Taiwan, eastern China

First record at Garden: 2010 field inventory

Threat to Forest: There are well-established populations of fumewort present in Westchester County and Bronx County north of the Garden along the Bronx River (Atha et al., 2014).

Control: Fumewort is an early detection and rapid response species. Forest staff and Garden scientists scout the Bronx River bank for fumewort in May and manually remove all individuals they encounter.

***Ficaria verna*—lesser celandine—Ranunculaceae**

Lesser celandine is a spring ephemeral that grows from belowground tubers, bulbils, and seed. It leafs out in early spring, flowers in March-April, and goes dormant by early summer. It thrives in disturbed areas, spreads easily, and forms dense monocultures that inhibit the growth of native species.

Native range: Europe

First record at Garden: 1900 accession record

Threat to Forest: Lesser celandine has spread across the Garden landscape and region in the past decade, primarily invading river banks, streams, and roadsides, but also invading upland forests. Water plays a role in spreading this species' seeds and bulbils. Lawn mowers, string trimmers, and other garden tools also spread lesser celandine across the landscape.

Control: This species is extremely difficult to control. Hand weeding smaller upland patches in the Forest has been successful with 80% control per season. All bulbils and tubers must be removed completely and discarded plant material kept separate from regular compost and monitored closely. Herbicide treatment with a 33% Rodeo® mixture before the plants flower can be effective if the conditions for uptake are perfect.

***Hedera helix*—English ivy—Araliaceae**

English ivy is a shade-tolerant, evergreen vine, commonly used as a groundcover in cultivation, which spreads vegetatively or by bird-dispersed seeds.

Native range: Europe
First record at Garden: unknown
Threat to Forest: English ivy forms a dense groundcover that overwhelms native species. Forest staff have been removing all fruiting specimens across the grounds over the past decade, reducing the amount of propagule pressure within the landscape and Forest.
Control: English ivy is effectively managed by mechanical removal in late fall or early winter when native plants are dormant.

***Humulus japonicus*—Japanese hops—Cannabaceae**

Japanese hops is a climbing or trailing annual vine that flowers and fruits from July to September. It is often found in open, disturbed sites such as abandoned fields, forest edges, and river banks.

Native range: Asia
First record at Garden: unknown
Threat to Forest: Japanese hops is densely established on the Bronx River bank and a priority for management along the entire Bronx River corridor.
Control: Mechanical control by cutting stems and removing roots 2–3 times per year is a recommended best management practice (Yau et al., 2012).

***Lonicera japonica*—Japanese honeysuckle—Caprifoliaceae**

Japanese honeysuckle is a bird-dispersed, evergreen, climbing vine that rapidly colonizes large areas.

Native range: Asia
First record at Garden: unknown
Threat to Forest: Japanese honeysuckle forms dense mats of intertwining vines on the Forest floor that inhibit the growth of native species. If left unchecked, it will climb and overwhelm small trees and shrubs.

Control: Mechanically remove dense mats by cutting and rolling. Follow-up weeding is required for many years. Climbing vines should be removed with care or cut and left to avoid additional harm to native vegetation.

***Lonicera maackii*—Amur honeysuckle—Caprifoliaceae**

Amur honeysuckle is a bird-dispersed, shade-tolerant shrub that thrives in woodlands where it displaces native vegetation.

Native range: Asia

First record at Garden: 1917 accession record

Threat to Forest: Honeysuckle displaces native shrubs and inhibits native plant growth through allelopathy.

Control: Amur honeysuckle has been successfully managed in the Forest by mechanical removal.

***Microstegium vimineum*—Japanese stiltgrass—Poaceae**

Stiltgrass is a mammal- and water-dispersed annual grass that thrives in a variety of habitats. It spreads vegetatively or by seed and has formed dense monocultures in forests throughout the mid-Atlantic and southern New England.

Native range: Asia

First record at Garden: 1991 field inventory

Threat to Forest: Stiltgrass is regularly found growing along Forest trails and in the turnaround oval of the Waterfall Walk. We believe it is brought in on the shoes or clothing of visitors.

Control: Stiltgrass is an early detection and rapid response species that Forest staff monitors for and removes immediately. This method of control has been successful to date.

***Persicaria perfoliatum*—mile-a-minute vine—Polygonaceae**

This rapidly growing, annual vine can reach lengths of over 20 feet in a single growing season and form dense patches that inhibit the growth of native species. Its metallic blue fruits ripen from September to November and are dispersed by birds and small mammals.

Native range: Asia

First record at Garden: 2011 field inventory

Threat to Forest: Mile-a-minute vine is present throughout the region, creating monocultures in forest openings, inhibiting the growth of all native species. This species has been introduced to the Garden by birds, nursery stock, and construction materials.

Control: This species is discovered annually along Forest trails and in canopy gaps. It is an early detection and rapid response species that Forest staff monitors for along trails and in canopy gaps. Plants are removed as soon as they are discovered. This method of control has been successful to date.

***Phellodendron amurense*—Amur corktree—Rutaceae**

Amur corktree has the qualities of the perfect invasive: it is bird-dispersed, shade and drought-tolerant, and long lived. Female trees can produce large seed crops at a relatively young age.

Native range: China, Korea, Siberia, Japan

First record at Garden: 1896 accession record

Threat to Forest: Since it is shade-tolerant, Amur corktree competes with the regeneration of native tree species throughout the Forest. Amur corktree thrives on good soils and competes with tulip tree and sweetgum on the best sites. Amur corktree is abundant in the Forest soil seedbank and a continual threat to the future of the Forest.

Control: Seedlings and saplings can be removed by hand or with a weed-wrench. Mature specimens are effectively managed by injecting glyphosate. Cut stumps will resprout and require additional herbicide treatments. Surrounding areas will require at least two years of post-removal management to eliminate seedlings.

***Reynoutria japonica*, *Reynoutria x bohemica*—knotweeds—Polygonaceae**

Knotweed is a wind-or water-dispersed, sun-loving, perennial that grows from nearly impenetrable mats of rhizomes. Once established, it forms a monoculture that prevents the growth of native plants. It is very difficult to control.

Native range: Asia

First record at Garden: 1901 accession record

Threat to Forest: Knotweed has colonized large areas of the Bronx River floodplain and is invading the upland forest along edges and in gaps. It completely displaces native vegetation—in fact, nothing can grow through the mats of rhizomes.

Control: Small populations can be treated with a 33% Rodeo® mixture, applied with a foam paint brush to all leaves and stem surfaces. Start applications in early May to prevent stems from growing tall and hardening off. If this is not possible, consider cutting stems and then treating. Repeat treatments are necessary. Larger colonies are a challenge and their management requires repeated monthly cutting beginning in May and ending in September. Once stem density of a colony decreases, densely planting an area with restoration trees and continuing knotweed management will further reduce its vigor.

***Viburnum dilatatum*—linden viburnum—Adoxaceae**

Linden viburnum is a bird-dispersed, understory shrub that has invaded forests throughout eastern North America.

Native range: Asia

First record at Garden: 1895 accession record

Threat to Forest: Linden viburnum is increasing in the Forest understory. With the rise of viburnum leaf beetle, which feeds on native viburnums but not linden viburnum, this species will likely become even more abundant in the Forest if not managed.

Control: Mechanically removing linden viburnum is an effective method of control. It can resprout from roots, so thorough removal of all root fragments and follow-up treatments may be necessary.

b. Invasive Plants of Potential Concern in the Future

***Acer pseudoplatanus*—Sycamore maple—Sapindaceae**

This wind-dispersed, shade tolerant tree inhibits the growth of native species.

Native range: Europe

First record at Garden: 1896 accession record

Threat to Forest: Sycamore maple is present in small numbers in the Forest but has the potential of increasing over time. This shade-tolerant species inhibits the regeneration of native plants and can lead to erosion by reducing the herbaceous layer.

Control: Seedlings and saplings can be removed by hand or with a weed-wrench. Mature specimens can be girdled or cut. Cut stumps should be monitored for resprouting and cut again or treated with herbicide as necessary. Injection with glyphosate is not an effective method of control.

***Anthriscus sylvestris*—wild chervil—Apiaceae**

This biennial reproduces by seed and is spread by landscape maintenance activities.

Native range: Europe

First record at Garden: unknown

Threat to Forest: Distributions of wild chervil have increased in recent years north of the Garden along the Bronx River corridor. It has the potential of invading the banks of the Bronx River, Forest edges, and outlying areas of the Garden. Once established it will quickly form a monoculture. For these reasons, wild chervil is an early detection and rapid response species.

Control: Mechanical management by removing individuals and mowing patches before they go to seed in June has proven to be successful. Caution should be taken when handling this plant—its sap causes phytophototoxicity.

***Commelina communis*—common dayflower—Commelinaceae**

This annual grows quickly in disturbed soils in full sun and is a common weed in eastern North America.

Native range: Eastern Asia

First record at Garden: 1897 (N.L. Britton, 1898)

Threat to Forest: Asiatic dayflower is one of the most common herbaceous species in the Forest.
Control: Chemical control with glyphosate is recommended by some sources. Mechanical removal followed by restoration planting should be used to manage dense patches. If this approach is not successful, chemical controls should be implemented.

***Magnolia kobus*—Kobus magnolia—Magnoliaceae**
An ornamental flowering tree that has escaped cultivation, particularly around mature parks and gardens.
Native range: Asia
First record at Garden: 1918 accession record
Threat to Forest: Kobus magnolia has naturalized in the Forest from the Magnolia Collection and should continue to be monitored.
Control: No control is necessary at this time. Mechanical control methods such as girdling or removal may be effective if control is necessary in the future.

***Paulownia tomentosa*—empress tree—Paulowniaceae**
Empress tree is a wind-dispersed shade-intolerant tree that produces copious quantities of seed. It grows very quickly on disturbed soils and produces root and stump sprouts.
Native range: Asia
First record at Garden: 1897 (N.L. Britton, 1898)
Threat to Forest: There are a number of large empress trees growing on the grounds of the Garden adjacent to the Forest. These trees are a source of seed. Empress tree has been observed growing along forest trails and in canopy gaps.
Control: Young seedlings and saplings can be removed mechanically. Larger specimens can resprout from girdling and cut stumps and will require an herbicide stump or sprout treatment.

***Persicaria* spp.—smart weeds—Polygonaceae**
A variety of non-native smart weeds have become established in the northeastern United States.
Native range: Asia
First Record at Garden: 1897 (N.L. Britton, 1898)
Threat to Forest: The non-native smartweeds outcompete native species and disturb ecosystem processes. They should be monitored and managed as necessary.
Control: Mechanical weeding should suffice.

***Prunus* spp. (*avium*, *subhirtella*, × *yedoensis*, *sargentii*, *incisa*)—weedy cherries—Rosaceae**

A variety of ornamental flowering cherries have escaped from cultivation in North America. These fast-growing, bird-dispersed trees colonize disturbed areas, edges, and canopy gaps.

Native range: various

First record at Garden: 1897 (N.L. Britton, 1898)

Threat to Forest: Weedy cherries have been noted in forest inventories for several decades and are expanding in recent inventories.

Control: Tree seedlings and young saplings can be removed mechanically. Older specimens are best controlled by cutting and applying herbicide.

***Rhamnus frangula*—smooth buckthorn—Rhamnaceae**

This bird-dispersed, understory shrub is increasing its foothold in disturbed areas throughout the northeastern United States.

Native range: Eurasia

First record at Garden: 1964 accession record

Threat to Forest: Smooth buckthorn has only recently become established in the Forest and its population is growing. It still may be possible to eradicate.

Control: Mechanical removal is an effective method of control.

***Rubus phoenicolasius*—wineberry—Rosaceae**

Wineberry, a relative off blackberry and raspberry, is a common weed of disturbed woodlands in our region.

Native range: East Asia

First record at Garden: unknown

Threat to Forest: Wineberry is well established along the Forest edges and throughout the understory. Its impacts on the Forest and the effectiveness of potential control measures are still relatively unknown.

Control: Mechanical weeding or cut stem herbicide treatments are recommended.

***Ulmus parvifolia*—Chinese elm—Ulmaceae**

This relative of our native American elm has escaped cultivation in urban and suburban areas. Drought tolerant and adaptable to tough sites, Chinese elm is on the rise as an invasive species in the northeastern United States.

Native range: East Asia

First record at Garden: 1932 accession record

Threat to Forest: Chinese elm has been observed naturalizing in the Forest and throughout the NYC region. This species should continue to be monitored and considered a candidate for early detection and rapid response in the Forest.

Control: Mechanical removal of seedlings and young saplings should be an effective method of control.

c. Invasive Pests and Diseases of Immediate Concern

Adelges tsugae—hemlock woolly adelgid—Adelgidae

Hemlock wooly adelgid is a small aphidlike insect that is threatening the existence of hemlock in the eastern United States.

Native range: Asia

First record at Garden: 1985

Threat to Forest: Hemlock woolly adelgid was introduced to the Forest on the winds of Hurricane Gloria in 1985 and has led to the severe decline of hemlocks in the Forest.

Control: Hemlocks in the Living Collections are treated with horticultural oil.

Fiorinia externa—elongate hemlock scale—Diaspididae

Elongate hemlock scale is an armored scale that was first identified in Queens, NY in 1908. It feeds on stressed hemlocks and has thrived in the Forest since hemlock woolly adelgid arrived in 1985.

Native range: Japan

First record at Garden: circa 1908

Threat to Forest: Elongate hemlock scale has essentially finished off hemlocks weakened by hemlock woolly adelgid.

Control: Due to restricted site access and the proximity of the Bronx River, chemical controls have never been an option for this insect. However, new studies are revealing the potential for entomopathogenic fungi as a biocontrol for elongate hemlock scale. If this is method is proven safe it could be an option for the future control of elongate hemlock scale on the remaining hemlocks in the Forest.

Pyrrhalta viburni—viburnum leaf beetle—Chrysomelidae

This invasive beetle is devastating to native viburnums, particularly arrowwood. Larvae hatch from eggs on young twigs in April, feed on the new leaves, and pupate in the soil in June. Adult beetles hatch in late June/July and feed on new leaves, mate, and lay eggs until the frosts of November/December.

Native range: Eurasia

First record at Garden: 2008 field inventory

Threat to Forest: Arrowwood, the preferred host species, is a common understory shrub throughout the Forest. If viburnum leaf beetle reduces or eliminates arrowwood from the Forest, it will have cascading impacts on the entire ecosystem.

Control: Forest staff have established a monitoring and management program that includes removing egg sites from half of the Forest's arrowwoods each winter. This mechanical pruning of egg sites is labor intensive but has proven to be 80% effective. Only cutting back half of the population each year allows for arrowwood regeneration.

***Ophiostoma novo-ulmi*—Dutch elm disease—Ascomycota**

Dutch elm disease is one of the most destructive shade tree diseases in North America, impacting American elms as street trees and in their native habitats of bottomland forest. Although this disease has resulted in tremendous losses, American elm is still present in the Forest today as part of the canopy and understory.

Native range: Europe

First record at Garden: introduced into region in 1950s

Threat to Forest: American elm is an important canopy tree in the Forest ecosystem that is constantly threatened by Dutch elm disease.

Control: Chemical control by microinjecting fungicide into individual trees has proven effective throughout the Living Collections and in specimen trees along the Spicebush Trail in the Forest. This method of control should continue to preserve the presence of canopy American elms along the Forest trails.

d. Invasive Pests and Diseases of Future Concern

***Agrilus planipennis*—emerald ash borer—Buprestidae**

Emerald ash borer is a beetle that has quickly spread from an original infestation in Michigan across the eastern United States. This larvae bore into the stems of ash trees and ultimately girdle them. Over the last decade, emerald ash borer has destroyed millions of ash trees across the eastern United States and all attempts at its control management have been unsuccessful.

Native range: Asia

Threat to Forest: Ash tree species are regenerating in great numbers in the Forest understory. While not yet present at the Garden, emerald ash borer represents a significant threat to the health of these trees. If it does reach the Garden, emerald ash borer will substantially change the future composition of the tree canopy.

Control: Currently, preventative treatments are recommended for mature specimens. There are currently only a few large ash trees present in the Forest, all of which are in poor condition and not candidates for treatment. If emerald ash borer is found at the Garden, managers will notify USDA-APHIS and NYS DEC and follow required protocols.

***Anoplophora glabripennis*—Asian long-horned beetle—Cerambycidae**

The larvae of Asian long-horned beetle bore into the stems of a wide variety of native trees including maple, sycamore, and birch. Infestations of Asian long-horned beetle have devastated urban forests in New York City, Boston, and Chicago.

Native range: Asia

Threat to Forest: Asian long-horned beetle has an extensive host tree range, including many species native to the Forest. Its establishment would decimate a high percentage of the existing Forest canopy.

Control: This species is in the category of early detection and rapid response. Garden staff participate in regular scouting in partnership with USDA-APHIS inspectors to confirm that the beetle is not present at the Garden. The Plant Health Care Program also maintains pheromone traps to aid in monitoring. If Asian-long horned beetle is discovered at the Garden, managers will notify USDA-APHIS and NYS DEC and follow required protocols.

***Ceratocystis fagacaerum*—oak wilt—Cerotocystidaceae**

This vascular wilt has devastated oaks in Texas, the Midwest, and portions of the Northeast. In 2008 there was a small outbreak in upstate New York that has been eradicated. Oak wilt affects species in both the red and white oak subgenera but is more immediately lethal to the red oaks killing them within a few months of infection. The fungus spreads by sap beetles and root grafts.

Native range: unknown

Threat to Forest: Today, the most abundant Forest canopy species is red oak. Oak wilt can kill a red oak tree within months of infection.

Control: Oak wilt is the category of early detection and rapid response. If found at the Garden, managers will notify USDA-APHIS and NYS DEC and follow required protocols.

***Phytophthora ramorum*—sudden oak death—Peronosporaceae**

This fungal pathogen kills native oak trees and understory shrubs including viburnums. First identified in California in 1995, this disease has spread to other states through infested nursery stock and has been observed in New York State.

Native range: unknown

Threat to Forest: Oaks are currently the dominant canopy species in the Forest, the infestation of this disease would have a similar effect as the American chestnut blight in the early 1900s.

Control: Sudden oak death is an early detection and rapid response species. If observed in the Garden, managers will notify USDA-APHIS and NYS DEC and follow required protocols.

Chinese elm has the potential to become invasive in the Forest.

Appendix 4: Forest Inventory Results

Table 1. Living Stems Greater Than or Equal To 15cm DBH

Taxa	Mean dbh (cm)	Density (no./ha)	Basal area (mxm/ha)	Frequency (%)	Importance value (iv)*
1937 Survey					
Tsuga canadensis	38	60	7.8	37	100
Quercus spp.	47	35	7.5	22	72
Betula lenta	35	29	3	22	48
Liquidambar styraciflua	44	6	1	6	12
Liriodendron tulipifera	46	5	1	5	11
Fagus grandifolia	36	6	0.7	4	11
Carya spp.	32	6	0.6	5	10
Ulmus americana	36	4	0.6	4	8
Acer spp.	36	3	0.4	2	5
Fraxinus americana	32	3	0.3	2	5
Cornus florida	19	3	0.1	2	4
Ostrya virginiana	22	2	0.1	2	4
Sassafras albidum	24	3	0.1	2	4
Phellodendron amurense	24	2	0.1	1	2
2 others	38	0	0	1	2
Total	38	168	23.3		300
2002 Survey					
Quercus spp.	46	51	10.5	35	69
Tsuga canadensis	33	31	3	24	33
Acer rubrum	29	34	2.6	23	32
Prunus serotina	24	34	1.8	22	29
Liquidambar styraciflua	42	18	3.1	13	23
Fagus grandifolia	36	20	2.5	14	22
Betula lenta	37	15	1.8	14	18
Liriodendron tulipifera	57	11	3.2	7	17
Carya spp. (*tomentosa, cordiformis, glabra, ovata*)	31	11	1	10	12
Phellodendron amurense	23	11	0.5	10	10
Acer saccharum	29	10	0.7	8	10
12 others	28	22	1.9		24
Total	35	266	32.7		300

Tulip tree thrives in the Forest.

*Importance Value (iv) is the sum of the relative density, frequency, and basal area.

Taxa	**Mean dbh (cm)**	**Density (no./ha)**	**Basal area (mxm/ha)**	**Frequency (%)**	**Importance value (iv)***
2006 Survey					
Quercus spp.	50	47	12	33	89
Acer rubrum	29	27	2	18	32
Liquidambar styraciflua	44	17	3.1	11	27
Prunus serotina	23	30	1.4	17	32
Betula lenta	36	13	1.5	10	19
Liriodendron tulipifera	69	7	2.8	6	17
Fagus grandifolia	32	15	1.5	10	19
Carya spp. (*tomentosa*, *cordiformis*, *glabra*, *ovata*)	29	11	0.8	9	14
Phellodendron amurense	27	9	0.6	8	12
Tsuga canadensis	40	6	0.8	5	10
Acer saccharum	30	6	0.5	6	9
Acer platanoides	25	3	0.2	2	3
12 others	28	11	0.8	11	16
Total	36	201	28		300
2011 Survey					
Quercus spp.	45	39	7.8	27	74
Prunus serotina	24	27	1.4	18	35
Acer rubrum	32	22	2.3	17	35
Liquidambar styraciflua	41	15	2.5	11	28
Fagus grandifolia	34	17	2	10	26
Liriondendron tulipifera	70	6	3.1	6	21
Carya spp. (*tomentosa*, *cordiformis*, *glabra*, *ovata*)	32	10	0.9	8	15
Betula lenta	32	9	0.9	6	13
Acer saccharum	39	7	1.1	6	13
Tsuga canadensis	40	5	0.7	4	9
Acer platanoides	39	4	0.6	3	7
Fraxinus americana	33	4	0.4	3	6
Phellodendron amurense	32	4	0.3	4	6
9 others	22	9	0.1	8	13
Total	32	178	24		300

*Importance Value (iv) is the sum of the relative density, frequency, and basal area.

Table 2. Living Stems Greater Than or Equal To 1cm DBH

Taxa	**Mean dbh (cm)**	**Density (no./ha)**	**Basal area (mxm/ha)**	**Frequency (%)**	**Importance value (iv)***
2006 Survey					
Prunus serotina	6	296	2	57	40
Quercus rubra	43	36	7.8	27	35
Lindera benzoin	2	189	0.1	27	19
Acer rubrum	13	78	2.1	30	19
Liquidambar styraciflua	19	47	3.2	21	19
Aralia elata	3	129	0.1	27	15
Phellodendron amurense	7	85	0.8	30	15
Fagus grandifolia	9	83	1.6	10	14
Liriodendron tulipifera	57	9	2.8	7	12
Betula lenta	18	31	1.6	18	11
Carya spp. *(tomentosa, cordiformis, glabra, ovata)*	13	35	0.9	18	10
Viburnum dentatum	1	84	0	16	9
Acer saccharum	7	47	0.6	16	9
Fraxinus americana	3	42	0.2	23	9
Quercus alba	48	7	2	7	9
Quercus velutina	44	8	1.8	7	8
Prunus spp. *(avium, incisa, sargentii, subhirtella, × yedoensis)*	3	33	0	13	5
Viburnum dilatatum	2	45	0	8	5
Tsuga canadensis	36	7	0.8	6	5
Sassafras albidum	8	11	0.1	7	3
27 others	7	169	1.3	63	30
Total	8	1471	30		300

*Importance Value (iv) is the sum of the relative density, frequency, and basal area.

Taxa	**Mean dbh (cm)**	**Density (no./ha)**	**Basal area (mxm/ha)**	**Frequency (%)**	**Importance value (iv)***
2011 Survey					
Prunus serotina	5	375	2	67	40
Lindera benzoin	2	346	0.1	39	25
Fagus grandifolia	7	177	2.3	23	22
Acer rubrum	11	98	2.6	35	22
Quercus rubra	35	31	4.4	19	22
Aralia elata	2	204	0.1	33	17
Liquidambar styraciflua	17	44	2.6	23	17
Liriodendron tulipifera	47	10	3.1	7	14
Acer saccharum	6	81	1.2	23	13
Fraxinus americana	4	71	0.5	30	11
Quercus velutina	40	12	2.2	9	11
Viburnum dentatum	1	128	0	18	10
Carya spp. *(tomentosa, cordiformis, glabra, ovata)*	16	26	0.9	15	8
Betula lenta	14	25	0.9	14	8
Phellodendron amurense	6	37	0.3	17	7
Prunus spp. *(avium, incisa, sargentii, subhirtella, × yedoensis)*	4	41	0.1	18	6
Acer platanoides	11	19	0.6	11	6
Viburnum dilatatum	2	54	0	13	5
Tsuga canadensis	36	6	0.7	4	4
Quercus alba	18	8	0.6	5	4
36 others	8	221	1.4		30
Total	6	2,010	26.7		300

*Importance Value (iv) is the sum of the relative density, frequency, and basal area.

Appendix 5: Forest Restoration Calendar

Regular Tasks throughout the Year

Bronx River Water Quality Monitoring (Weekly)
Mapping (Weekly)
Fence Repair (Weekly)
Data Entry (Weekly)
Trash Sweep of Trails (Biweekly)
Forest Production including watering, sowing, collecting, and cleaning seed (Weekly, April to November)
Japanese angelica tree management (Weekly, May to October)
Early detection and rapid response for mile-a-minute vine and Japanese stilt grass (Weekly, May to October)
Trash Sweep of Bronx River (Monthly)
Camera Trap Monitoring (Monthly)
Macroinvertebrate Sampling (Monthly)
Manage visiting researchers and classes (Monthly)
Weed Stone Mill plantings (Monthly, April to November)
Trail Maintenance (Monthly, April to November)
Knotweed management (Monthly, May to October)

Tasks Month by Month

December to February
Viburnum leaf beetle management
English ivy, Japanese honeysuckle, and wintercreeper management until ground freezes
Tree work and inspections
Analyze management data and create annual management maps

March to April
Lesser celandine management
Garlic mustard management
Eastern red-backed salamander coverboard sampling
Restoration planting (woody plants)

May to June
Viburnum leaf beetle monitoring
Restoration planting (herbaceous plants)
Porcelainberry, oriental bittersweet, linden viburnum, Amur honeysuckle, smooth buckthorn, Amur corktree, Japanese honeysuckle management

July to September
Viburnum leaf beetle monitoring
Eastern red-backed salamander structural habitat monitoring
Forest Inventory (every five years)
Restoration planting (herbaceous plants)
Dodder management
Purple loosestrife management
Woody invasive plant management

October to November
Eastern red-backed salamander coverboard sampling
Restoration planting (woody plants)

Appendix 6: Plant Production Protocols

Woody Plant Production Protocols 2011–2014

Seeds are collected from plants, processed and directly sown into 8ft by 4ft by 1ft seed beds. The seeds are covered with leaves to mimic the forest floor and then covered with a secured, hardware cloth frame to prevent rodent predation over winter. The plants are grown until they reach heights of 12in to 18in. It is usually 18–24 months after sowing until the seedlings are bareroot planted into restoration areas in the Forest in spring and fall.

Species	Collection Date	Collection Method	Seed Processing
Acer saccharum	August	Seed Tarps	Remove any samaras that appear damaged.
Acer saccharinum	May	Seed Tarps	Remove any samaras that appear damaged.
Acer rubrum	May	Seed Tarps	Remove any samaras that appear damaged.
Carya cordiformis, *glabra*, *ovata*, *tomentosa*	September to October	Seed Tarps	Remove outer husks and discard damaged nuts.
Fagus grandifolia	October to November	Seed Tarps	Remove outer husk and discard damaged nuts.
Hamamelis virginiana	October to November	By Hand	Store in a grain bag in a dry place and allow dishiscent capsules to open on their own. Discard capsules.
Lindera benzoin	August to September	By Hand	Soak seeds for 20-30 minutes in warm water to soften flesh, processor using a plastic blade. Rinse seeds and repeat until seeds are flesh free.
Liquidambar styraciflua	November	Seed Tarps	Store in a grain bag in a dry place and allow dehiscent capsules to open on their own. Discard capsules.
Liriodendron tulipifera	November	Seed Tarps	Separate aggregates of samaras and remove any samaras that appear damaged.
Nyssa sylvatica	September	Seed Tarps	Soak seeds for 20-30 minutes in warm water to soften flesh, processor using a plastic blade. Rinse seeds and repeat until seeds are flesh free.
Ostrya virginiana	August	Seed Tarps	Remove nutlets from infructes-cence. Remove any nutlets that appear damaged.
Quercus rubra	September to October	Seed Tarps	Remove any damaged acorns and conduct a float test.
Quercus alba	September to October	Seed Tarps	Remove any damaged acorns and conduct a float test.
Staphylea trifolia	October to November	By Hand	Remove inflated capsule.

Post and rail fencing adds
rustic charm to Forest trails.

Woody Plant Seed Bed Soil Mix

Pine bark nuggets (sterilized)	(73%)
Coarse sand	(17%)
Compost (sterilized)	(10%)
Sanctuary fertilizer	(negligible)

Cover with leaves in fall to mimic forest floor.

Herbaceous Plant Production 2011–2014

Seeds are collected by hand from plants, processed and sown into seedling flats to follow propagation protocols specific to each species. Plants are pricked out into individual pots and grown on until they reach planting size. Depending on the species and stratification requirements this ranges from 4 months to 24 months.

Species	Collection Date	Seed Processing	Stratification/Sow Date
Aralia racemosa	October	Remove seeds from fleshy fruits, dry overnight on paper towel.	Sow immediately in moist, covered flats that are placed in a protected frame outdoors for wet, winter cold stratification.
Geranium maculatum	June	Remove seed from capsules.	Sow immediately in moist, covered flats. Keep moist all summer and fall, then place in a protected frame outdoors for wet, winter cold stratification.
Hibiscus moscheutos	October to November	Remove seeds from husks.	Store seed in paper envelopes in fridge over winter, sow following spring, May 1.
Maianthemum racemosum	July	Remove fleshy fruit and rinse seeds with water.	Sow immediately and place in protected frame outdoors for winter cold stratification.
Polygonatum pubescens	July	Remove fleshy fruit and rinse seeds with water.	Sow immediately and place in protected frame outdoors for winter cold stratification.
Rudbeckia laciniata	October to November	Remove seeds from flower heads	Store seed in paper envelopes in fridge over winter, sow following spring, May 1.
Verbesina alternifolia	October to November	Remove seeds from flower heads	Store seed in paper envelopes in fridge over winter, sow following spring, May 1.

Herbaceous Plant Soil Mix

5:1 mix of 3B Mix: Coarse sand Sanctuary fertilizer
Pine bark nuggets (up to 10%)

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The New York Botanical Garden is an iconic living museum and, since its founding in 1891, has served as an oasis in this busy metropolis. A National Historic Landmark, the 250-acre site's verdant landscape supports over one million living plants in extensive collections. Each year more than one million visitors enjoy the Garden not only for its remarkable diversity of tropical, temperate, and desert flora, but also for programming that ranges from renowned exhibitions in the Haupt Conservatory to festivals on Daffodil Hill. Year-round arts and culture events as well as educational and family-friendly activities for all ages make NYBG America's premier urban garden.

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