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Assessing the Effects of the Urban Forest Restoration Effort of MillionTreesNYC on the Structure and Functioning of New York City Ecosystems

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Abstract

Current forest restoration practices for New York City's (NYC) MillionTreesNYC Initiative on public parkland include site preparation with extensive invasive species removal and tree and shrub planting with the goal of creating new multi-layered forests. We have launched a long-term investigation of these sites in order to understand the primary physical, chemical, and biological responses of urban ecosystems to MillionTreesNYC forest restoration practices. This research will examine high and low diversity tree and understory planting combinations in permanent experimental forest restoration plots across NYC. The study assesses how the interactions between soil heterogeneity, plant population dynamics, and forest restoration management strategies drive urban forest ecosystem structure and functioning. Working in collaboration with the NYC Department of Parks & Recreation (NYC Parks) and the MillionTreesNYC tree planting campaign, we are examining different restoration strategies to assess how restoration practices affect the ecological development trajectories of newly established forests in NYC.

Keywords

Urban Ecosystems; forest; structure; function; restoration; New York City; MillionTreesNYC

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INTRODUCTION

Urban areas are complex combinations of ecological remnants with varying states of human development. Urbanized areas cover only 1% to 6% of Earth's surface, yet they have massive ecological footprints (Rees and Wackernagel 1996) and complex and often indirect effects on surrounding ecosystems (Alberti et al. 2003). Urbanized land already covers more area than the combined total of national and state parks and areas preserved by The Nature Conservancy (McKinney 2002). Urban areas continue to expand as populations increase. For example, New York City (NYC) expects to add nearly 1 million residents by 2030 to an already densely populated city. Additionally, 70% of all humans globally are predicted to live in cities by 2050 (US Census Bureau 2000). Given these trends, one of the primary dynamics that must be understood at a local, regional, and global scale is the effect of humans on the ecology of urban systems (Machlis et al. 1997; Pickett and Grove 2009).

The contemporary ecological paradigm recognizes that humans are integral parts of ecosystems exerting direct and indirect influences on the functioning of ecological systems (Egerton 1993; McDonnell and Pickett 1993; Holling 1994; Cronon 1995; Alberti et al. 2003; Turner et al. 2004). However, the study of urban ecosystems is still a relatively new pursuit in ecology (Pickett et al. 2001; Pickett and Grove 2009). The need to understand the intricacies of urban ecosystems emerges from the increasing fraction of humanity that calls cities home and from the disproportionate impact cities have on both regional and global systems (Collins et al. 2000; Grimm et al. 2000; Pickett et al. 2008). A more nuanced understanding of urban ecosystems, including socio-ecological dynamics, would allow ecologists to use socio-ecological theory to explain and predict urban dynamics (Pickett et al. 2008). Similarly, understanding of urban ecological patterns and processes would allow for improved, adaptive management of cities for healthier and more resilient socio-ecosystems.

There are a number of important examples of ecosystem research in NYC. Early groundwork for an understanding of cities as socio-ecological systems was laid by William H. Whyte's social ecology program in NYC (Whyte 1980; 1988) and continues to be developed by many others (Platt 2006). In addition, the urban to rural gradient studies developed two decades ago (McDonnell and Pickett 1990; McDonnell et al. 1997) and revisited over the years (Gregg et al. 2003) made significant contributions to urban ecology. Here we discuss an initial step towards a greater understanding of NYC as an urban ecosystem through a multi-institutional, interdisciplinary, long-term research study of the dynamics of urban forested ecosystems through the installation of long-term urban forest research plots across NYC.

PLANYC 2030 / MILLIONTREESNYC

On Earth Day 2007 NYC Mayor Michael Bloomberg announced PlaNYC, a comprehensive long-term sustainability plan for New York City (City of New York 2007). PlaNYC includes 127 ambitious sustainability initiatives, one of which is the MillionTreesNYC (MTNYC) Initiative, a public-private partnership between the NYC Department of Parks & Recreation (NYC Parks) and the New York Restoration Project (NYRP), with the goal of planting one million trees by 2017. Since the launch of MTNYC, public, private and non-profit organizations have organized nearly 4,000 citizen volunteers to plant trees across NYC and inspired planting campaigns in other U.S. cities. One aspect of MTNYC directs the planting of nearly 400,000 trees to establish 2,000 acres of new forest on NYC parkland and other public open spaces with the goal of creating multi-story, ecologically functioning forests. This large-scale afforestation effort provides the basis for a citywide ecological research project discussed here.

THE ECOLOGICAL VALUE OF URBAN FORESTS

Urban forests provide cities with numerous ecological benefits including: regulating local surface and air temperatures, filtering pollution from the local atmosphere which may positively impact the health of urban residents, trapping rainwater during heavy storms which prevents pollution of local waterways, and storing and sequestering atmospheric carbon dioxide. One recent study by the U.S. Forest Service put the compensatory value of NYC's forest at over \$5 billion (Nowak et al. 2007) using the Urban Forest Effects Model (UFORE) and data collected in 1997 on the city's forest. UFORE estimated that NYC's forest stores 1.35 million tons of carbon, a service valued at \$24.9 million. The forest sequesters an additional 42,300 tons of carbon per year (valued at \$779,000 per year) and about 2,202 tons of air pollution per year (valued at \$10.6 million per year; Nowak et al. 2007).

We suggest that increased information on the structure and functioning of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the NYC area. Now in its third year, the city has already added over 300,000 young trees to existing urban parks, private lands, and city streets (Figure 1). But will planting trees result in the kinds of complex multi-story structures and ecological functioning desired of forests? How will various planting strategies affect these outcomes?

ESTABLISHING LONG-TERM EXPERIMENTAL PLOTS IN NYC

NYC Parks' Natural Resources Group (NRG) has a long history of coupling ecological research and monitoring with applied urban vegetation management and ecological restoration practices. This has included grant funding and collaboration with universities. For the MTNYC effort, NYC Parks in 2008 worked with EDAW | AECOM, a consulting firm, and with the MTNYC Advisory Board's Research and Evaluation Subcommittee to establish a large-scale research project designed as functional parkland (Felson and Pickett 2005). The goal was to study the short and long-term impacts of the MTNYC tree planting strategies on ecosystem structure and functioning in a couple key NYC parks. More recently, researchers joined with NYC Parks to develop a more comprehensive citywide research project. The project represents a partnership between NRG, The New School's Tishman Environment and Design Center (TEDC), Columbia University's Department of Ecology, Evolution, and Environmental Biology (E3B), and the Yale School of Forestry and Environmental Studies.

This research leverages the large-scale tree planting activities of the MTNYC campaign to create structured experimental study plot treatments in order to understand the effects of MTNYC's forest restoration efforts on the structure and functioning of urban parkland in NYC (Figure 2). We define forest restoration here as the cumulative management activities of invasive plant removal, dense tree and shrub planting, and soil amendment as motivated and designed by NYC Parks in parks citywide. Motivating questions for our research include: How do variations in planting practices affect the development trajectories of new forest communities? How long will it take for forest canopy closure under different management practices, and how does closure rate affect invasive plant population dynamics? How do planting decisions and restoration practices affect overall forest restoration success, as measured by canopy closure and rate of invasive plant establishment? What are the implications of expected heterogeneity in soil nutrients for plant dynamics and productivity and how might soils be in turn affected as the plant community develops? The goal of the research is to work towards understanding several of these key management questions through a multi-year study to provide baseline scientific data to inform park design and forest management. We will monitor survivorship and growth of individual trees and measure canopy density at the stand level, as well as assess the understory vegetation and changes to soils, both as they exist at the initiation of the restoration and as they develop over time.



Figure 1. MillionTreesNYC Tree Planting Since 2007. MillionTreesNYC plants trees in parks, privately held land, along streets, and other areas around the city with the goal of adding one million trees to NYC by 2017. Source: MillionTreesNYC.org

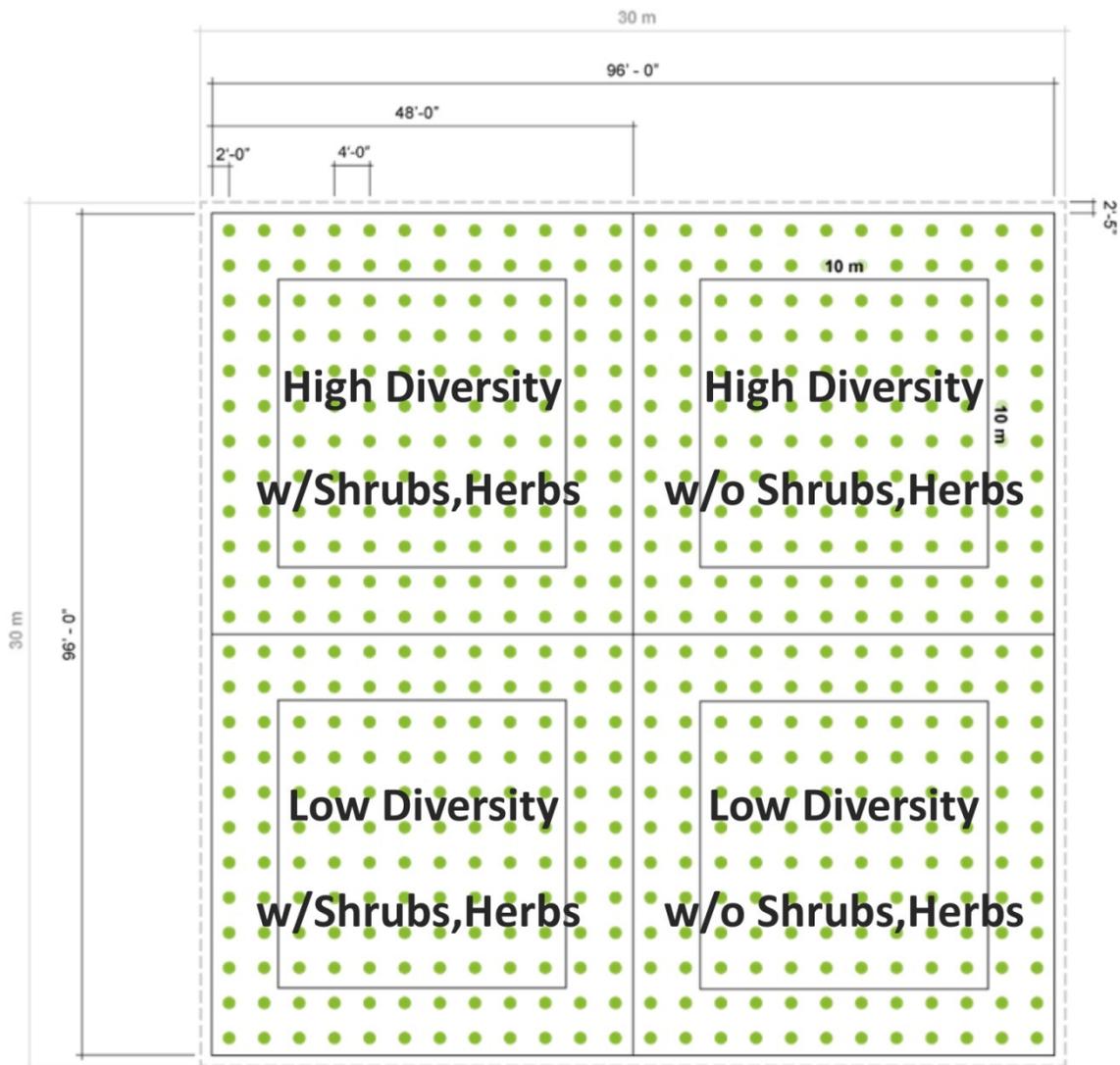


Figure 2. Permanent Plot Design. Experimental research plots consist of a 30m x 30m plot with four 15m x 15m nested subplots in a block design with two main treatments, High and Low Diversity and Understory (w/Shrubs, Herbs) or No Understory (w/o Shrubs, Herbs). Trees are planted four feet on center (shown as green dots). Vegetation and soil data is annually sampled in a 10m x 10m plot nested within the 15m x 15m subplots to minimize edge effects between subplot treatments. Diversity and understory treatments are randomly applied to the subplots when the plot is established. The arrangement of the subplots varies in some parks based on the size and shape of the area being restored.

URBAN VEGETATION AND SOIL ANALYSIS

Long-term study of forest restoration and regeneration is critical to understanding forest dynamics in urban ecosystems. Urban vegetation and soil studies are important to understand urban biodiversity, climate modification, carbon dynamics, and pollution and water absorption functions of soil. We are particularly interested in the role of exotic and invasive species, which have received particular attention in urban ecology (Pickett et al. 2001). In an earlier urban-to-rural gradient study in NYC, the number of exotics in the seedling and sapling size classes of woody species was greater in urban and suburban oak-dominated stands (Rudnicki and McDonnell 1989). There is growing evidence that the presence of exotics is enhanced along pathways in rural recreation areas (Rapoport 1993) and in urban parks (Drayton and Primack 1996). In Boston's Middlesex Fells, a 400 ha urban woodland park inventoried for plants in 1894, a re-census of the flora in 1993 showed that the majority of new species recorded on the site were exotic species and that native species had declined by nearly 10% (Drayton and Primack 1996). By studying vegetation in a large number of heterogeneous sites across the city, we hope to build a more comprehensive picture of invasive plant population dynamics and their effects on the ecological dynamics of NYC forests.

Understanding the ecological and management controls on plant diversity is critical for understanding how ecosystems function. The relationship between biodiversity and ecosystem functioning has been an area of intense debate in the ecological sciences (Naeem 2002). It has been argued from theory and empirically demonstrated that biodiversity should increase the functioning of ecosystems (Loreau et al. 2002; Cardinale et al. 2006). However, depending on the functional characteristic measured, this prediction has not held up in all empirical investigations of the relationship (Jiang et al. 2008). In urban ecosystems the question is even murkier. We are examining this relationship in a subset of afforested parks in NYC forest ecosystems by looking specifically at changes in diversity over time and the relationship between diversity, forest development, and ecosystem functions such as net primary productivity and soil carbon storage.

Assessing baseline and changing soil conditions is also essential for prioritizing further ecosystem-scale research in urban forests and for understanding the impacts of soils on vegetation dynamics and restoration outcomes in urban areas. Urban soils are known to be highly heterogeneous (Pouyat et al. 2007). However, soils in NYC are poorly understood and a simultaneous investigation of both citywide (New York City Soil Survey 2005) and local, plot-scale soils will provide critical data for building a more comprehensive understanding of urban ecosystem dynamics. This research is designed to assess how soil heterogeneity varies across space and time in NYC's forested ecosystems and the effects of this heterogeneity on vegetation dynamics. This project will focus first on characterizing the heterogeneity within and among research plots, thereby providing data on variation in soil nutrients, metals, and carbon at local and regional scales. We are interested in whether soil heterogeneity within study plots impacts the survivorship and growth of trees, shrubs, and herbaceous species planted in the MTNYC campaign and whether heterogeneity across sites can help to explain potential variation in species performance.

Most soil studies in urban areas have focused on disturbed and human-constructed soils along streets and in highly developed areas (Craul and Klein 1980; Patterson et al. 1980; Short et al. 1986; Jim 1993, 1998; Pouyat et al. 2007). As a result "urban soils" typically have been viewed as drastically disturbed soil material of low fertility (Craul 1999). Yet other potentially influential factors associated with urban land transformations have received limited attention. In fact, the characteristics of soil can vary greatly across the urban landscape, including not only highly disturbed, but also relatively undisturbed soils that are modified by management and urban environmental factors (Schleuß et al. 1998; Pouyat et al. 2003). Urban soil research that describes the differences in surface soil properties among various land uses and cover types will be useful in differentiating relatively intact remnant soils from highly disturbed and managed soils, and for assessing impacts of soil on vegetation dynamics in long-

term research plots. In addition, those soil properties associated with specific management strategies (such as those employed in MTNYC) and intensity of use may be useful as diagnostic properties to differentiate human impacts on surface soil characteristics in urban landscapes (Pouyat et al. 2007).

HYPOTHESES

We examine the dynamic interactions between plants, soils, and management practices in permanent forest restoration plots, focusing on how they change over time. This research is guided by three overarching hypotheses:

- 1) Forest restoration will enhance urban forest functioning (e.g., net primary productivity and soil fertility) over time at the plot scale and citywide.
- 2) Forest restoration will increase the biological diversity of urban forests over time at the plot scale and citywide.
- 3) Forest restoration will decrease the abundance and distribution of invasive species over time at the plot scale and citywide.

METHODS

Evaluating park planting and management designs requires experimental treatments that can be implemented across sometimes very different park settings with adequate replication. Study plots need to be large enough to capture relevant dynamics but small enough to fit into interstitial restoration areas in existing parks. Methodological approaches also require simplicity given the multiple participants, including researchers, volunteers, local community members, and NYC Parks personnel. Plot size also needs to be reasonably small to allow efficient sampling on an annual basis as the number of plots increases with time (plots and thus replication increase over time as more reforestation sites are designated by NYC Parks & Recreation). The plot size should also reflect the need for permanent plots to facilitate additional field studies and subsequent research projects while meeting the goals of the current study.

Research collaborators chose 900 m² plots (Figure 2), which are similar in scale to other forest studies such as the U.S. Forest Service Forest Inventory and Analysis Program (U.S. Forest Service 2007). Long-term experimental research plots utilize a nested design to allow scientists to evaluate the importance of varying levels of tree diversity and understory on reforestation dynamics. Research plots are a randomized complete block design with four 15m x 15m subplots nested within each 30m x 30m full plot with two treatments (High Tree Diversity/Low Tree Diversity and Understory/No Understory) in a factorial experimental design (Figure 2). Treatments are designed to test how varying levels of tree diversity combined with understory or no understory treatments affect long-term restoration outcomes. Within each subplot is a 10m x 10m sampling plot. The subplot is centered within the treatment plot to minimize edge effects. Therefore, all vegetation and soil sampling takes place at the 10m x 10m subplot scale. Subplot corners are marked with permanently installed rebar with GPS coordinates recorded at plot corners. Site selection for permanent plots was based on availability of forest restoration sites of appropriate size (large enough to accommodate a 900 m² research plot) and canopy openness (in order to limit variation caused by shading from mature trees).

Subplots are planted, in coordination with NRG field crew leaders, MTNYC personnel, volunteers, and contractors, with 7.6 L (2-gallon) container trees (tree height varies from 0.5 - 1.0meters) in high (6 species) and low (2 species) diversity treatment configurations randomized across blocks within the full plot. The diversity levels were chosen to span the range of tree species richness typically found in

areas of similar size in existing NYC urban forests. The understory treatment contains 3.8 L (1-gallon) shrubs planted at a density of 36 shrubs per subplot (Figure 2). Tree and shrub species were chosen based on known or expected adaptations to particular urban park conditions, local biophysical characteristics of site type, availability from local nurseries, and park landscape design parameters in collaboration with NYC Parks ecologists to establish standardized planting palettes for both mesic and hydric site types across the city. Mesic sites include six tree species (*Quercus rubra*, *Nyssa sylvatica*, *Amelanchier canadensis*, *Prunus serotina*, *Quercus coccinea*, and *Celtis occidentalis*) and six shrub species (*Sambucus canadensis*, *Lindera benzoin*, *Aronia arbutifolia*, *Rosa virginiana*, *Viburnum acerifolium*, and *Hamamelis virginiana*). Hydric sites also include six tree species (*Quercus palustris*, *Nyssa sylvatica*, *Quercus bicolor*, *Liquidambar styraciflua*, *Platanus occidentalis*, and *Diospyros virginiana*) and six shrub species (*Cornus amomum*, *Clethra alnifolia*, *Viburnum dentatum*, *Rosa palustris*, *Cephalanthus occidentalis*, and *Ilex verticillata*). Tree and shrub density follows the current planting practices of NYC Parks, where trees are planted with approximately 1.2 m (four foot) spacing and shrubs (Figure 2). The expectation is that as the canopy closes, invasive plants will be shaded out in a natural process of competition with native trees for light, nutrients and water.

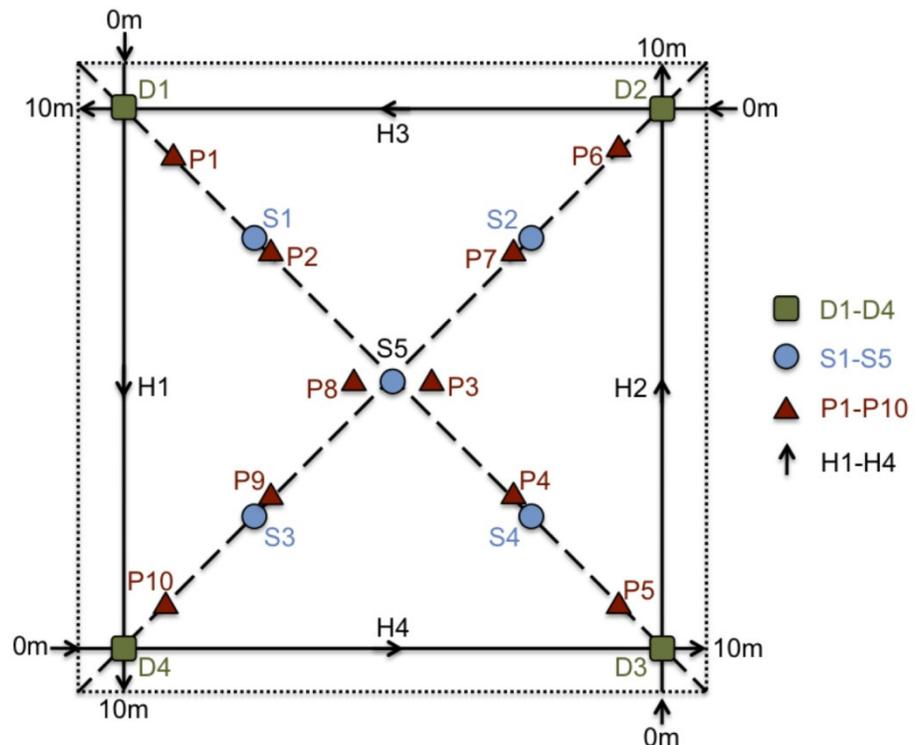
An important part of this study involves recording recent management history on all study sites, which typically involves invasive plant removal (by chemical sprays, selective cutting, and mowing) as a site preparation strategy. Invasive removal is a critical but costly preparation for tree seedling establishment in urban parks often dominated by invasive plant species. Invasive species management has become an area of intense focus and expense for NYC Parks. Current urban invasives removed as part of forest restoration efforts include *Artemisia vulgaris* (mugwort), *Phragmites australis* (common reed), *Rosa multiflora* (multiflora rose), *Ampelopsis brevipedunculata* (porcelain berry), *Ailanthus altissima* (tree of heaven), *Fallopia japonica* (Japanese knotweed), and *Celastrus orbiculatus* (Asiatic bittersweet). Management practices may also include soil amendments such as mulching newly planted trees and watering during the susceptible periods of early tree establishment. This project includes extensive interaction with NYC Parks staff to document recent (past three years) and current management at the research sites in order to understand the ecosystem management practices which may affect the experimental response variables.

Annual monitoring of vegetation and soils in permanent field plots will allow us to accumulate a time series of vegetation and soil dynamics data in order to follow community development among experimental treatments. Pilot research plots were installed in April 2009 to refine the experimental design and data collection methodology discussed above. The pilot sites were also vital to developing research protocols to coordinate NYC Parks' site preparation and management practices and MTNYC tree planting events with plot installation and data collection. Permanent long-term research plots were installed beginning in Summer 2009. Plot installation includes collecting pre-planting baseline vegetation and soil data. As of October 2010, permanent experimental plots have been established in the following parks: Roy Wilkins and Alley Pond in Queens; Clove Lakes and Conference House in Staten Island; Pelham Bay in the Bronx; Canarsie and Marine in Brooklyn. We plan to add additional plots in subsequent years, expanding until MTNYC sites that meet the requirements of the research design are exhausted.

Plot scale analyses rely on both pre- and post-planting vegetation and soil assessment in order to monitor responses to experimental treatments. Annual vegetation and soil monitoring are completed in July and August (in order to maximize the potential to identify the largest proportion of plants within a single field visit), prior to scheduled forest restoration plantings in the fall (usually October). Vegetation data collection includes surveying trees, shrubs, and herbaceous plants at the 10m x 10m subplot scale at all sites. We sampled the presence and percent cover of all existing vegetation at the plot scale, which allows us to address questions about tree and shrub growth, regeneration and productivity, mortality, recruitment, density, invasive species dynamics, and other related metrics of vegetation structure and function. By examining tree, shrub, and herb dynamics over time, this project will establish the baseline database for further interdisciplinary analyses of other ecological, social, and economic impacts of forest restoration on urban ecosystems.

Tree and shrub cover is monitored using two line transects, 1cm wide by ~14.1m long, drawn diagonally from subplot corners, along which the total number of centimeters intercepted by individuals is recorded (Figure 3). The line intercept method has been used in other restoration studies in NYC parklands and has been used successfully in previous pilot studies with a high level of accuracy. The line intercept method is also used to assess the herbaceous plant community by stretching four 1cm wide x 10m long transects (H1-H4) one meter in from each subplot corner (Figure 3) and recording the total area that herbs intercept the line for a total of 4000 cm² cover per subplot. Shrubs are also assessed for cover and location, and size (dbh) of trees, if any, are recorded. Nearby canopy cover is measured using a spherical densiometer since trees near plots may impact light availability and therefore vegetation responses near plot edges. All vegetation measures are assessed annually and preliminary baseline vegetation results are presented below.

Figure 3. Subplot Annual Sampling Design. Vegetation and soil sampling occurs in each 10m x 10m subplots. D1-D4 refer to spherical densiometer measurements taken to assess canopy cover at each plot corner. P1-P10 are locations for high resolution soil samples, leaf litter measurements, and soil penetrometer readings taken every 2.36 meters along diagonals and twice offset from center. S1-S5 are locations for soil sampling locations used for composite samples. H1-H4 are transects used for percent cover assessment of vegetation including shrubs and herbs. T_x and T_y refer to diagonal transects used to establish soil sampling locations for each subplot.



We acquired soil samples within each subplot using two techniques: (i) by taking ten undisturbed 5-cm-diameter by 10-cm-deep samples (P1-P10; Figure 3) from one randomly chosen subplot in each full plot per site for high resolution soil analysis; and (ii) by taking a composite soil sample from 0-10cm depth, composited from 5 locations within each subplot (S1-S5; Figure 3), taken with a sampling probe. Soil monitoring in both pre- and post-planting phases includes assessing physical and chemical characteristics including all major nutrient, heavy metal, and carbon analyses, leaf litter depth, soil compaction, and pH. Subsamples of the pre-planted dry-sieved soil were analyzed for all major nutrients (P, K, Ca, Mg, Mn, Zn, Al, NO₃), total and organic carbon, and heavy metals (Al, Ca, Co, Cu, Cr, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Ti, V) at Cornell University’s Nutrient Analysis Laboratory. However, initial soil results are not presented here. Fall 2009 site descriptions including general soil type descriptions are included in Appendix 1.

ANALYSES

Plant diversity and percent cover from plant data collected in July and August 2009 was analyzed from five of the six sites that were planted with MTNYC trees in October 2009 in Bronx, Queens, and Brooklyn (Alley Pond, Pelham Bay, Roy Wilkins, Marine and Canarsie Park). Clove Lakes Park in Staten Island was added late and was not sampled in 2009. For each site, species abundance (cm²) was summed across all transects. Total abundance across all species for a single 1cm x 10m transect could exceed 1000 cm² because multiple species could occupy the same space as measured by vertical projection of the transect boundary (1cm x 10m) onto the ground. Proportions of introduced and invasive species at each site were calculated based on species counts, using nativity and invasive status information from USDA (2010) and Uva et al. (1997). Species coverage at each site was calculated by dividing each species’ abundance by 16000 cm², the total sampled area at each site. Shannon diversity index (Shannon 1948) and evenness (Magurran 1988) were calculated using these cover values.

RESULTS AND DISCUSSION

Permanent research plots in seven different parks across Brooklyn, Queens, Bronx, and Staten Island have been installed and sampled to date. We show here preliminary vegetation diversity and percent cover results from the five permanent plots assessed in 2009. Plant diversity varied across the five sites with Shannon diversity highest in the Orchard Beach site in Pelham Bay Park, Bronx and species richness highest in Roy Wilkins Park, Queens (Table 1; see Appendix 2 for a complete species list). We have not yet investigated drivers of variation in species richness across our sites, though we expect site history and anthropogenic disturbance to be important. Similar studies along an urban-rural gradient in Germany found that non-native species richness was correlated with various indicators of anthropogenic disturbance, though native species richness was not (Brunzel et al. 2009).

Site	Richness	Diversity	Evenness
Alley Pond	22	0.65	0.48
Canarsie Beach	23	0.69	0.51
Marine Park	19	0.81	0.63
Pelham Bay	28	0.95	0.66
Roy Wilkins	31	0.80	0.54

Table 1. Diversity Across Fall 2009 Sites. Diversity is shown for Fall 2009 study sites (Alley Pond (1 plot), Canarsie (1 plot), Marine Park (calculated from 2 subplots), Pelham Bay (1 plot), Roy Wilkins (2 subplots)). Richness is total number of species found at a site. Diversity is Shannon Diversity, and evenness is calculated by dividing Shannon diversity by maximum possible diversity.

Invasive species are of particular concern to forest restoration in NYC because of their ability to outcompete tree seedlings and, therefore, inhibit canopy development in MTNYC forest restoration sites. In initial analyses, all sites were dominated by invasive species prior to tree planting, with the highest proportion of vegetative cover by invasives in Marine Park, Brooklyn (91%), and the lowest in Canarsie Park, Brooklyn (71%; Figure 4). Interestingly, though all sites were dominated by invasive species, not all invasives were non-native. Initial surveys revealed that three sites (Alley Pond, Marine, Roy Wilkins Parks) dominated by non-native species, one site, Canarsie Park, had relatively equal cover of natives and non-natives, and the Pelham Bay site was dominated by natives, though the majority were still largely invasive (Figure 4).

Figure 4a. The proportion of native and introduced plant abundance expressed as a percent of total abundance (y-axis)

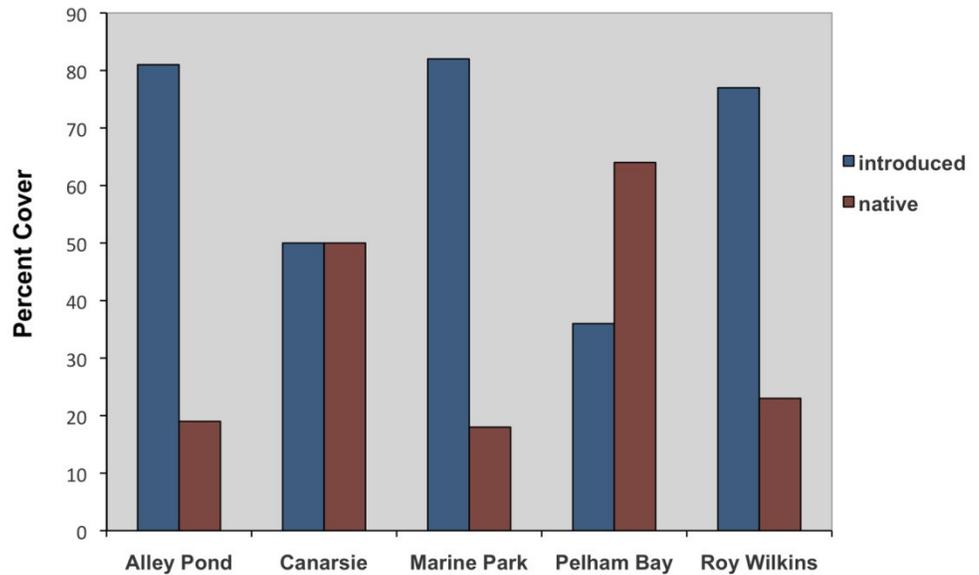
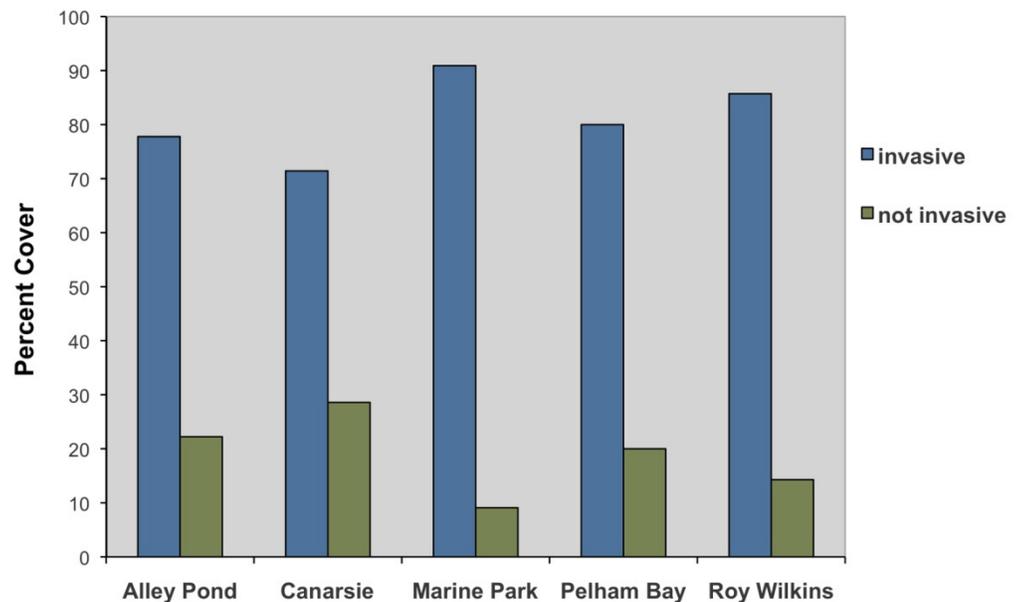
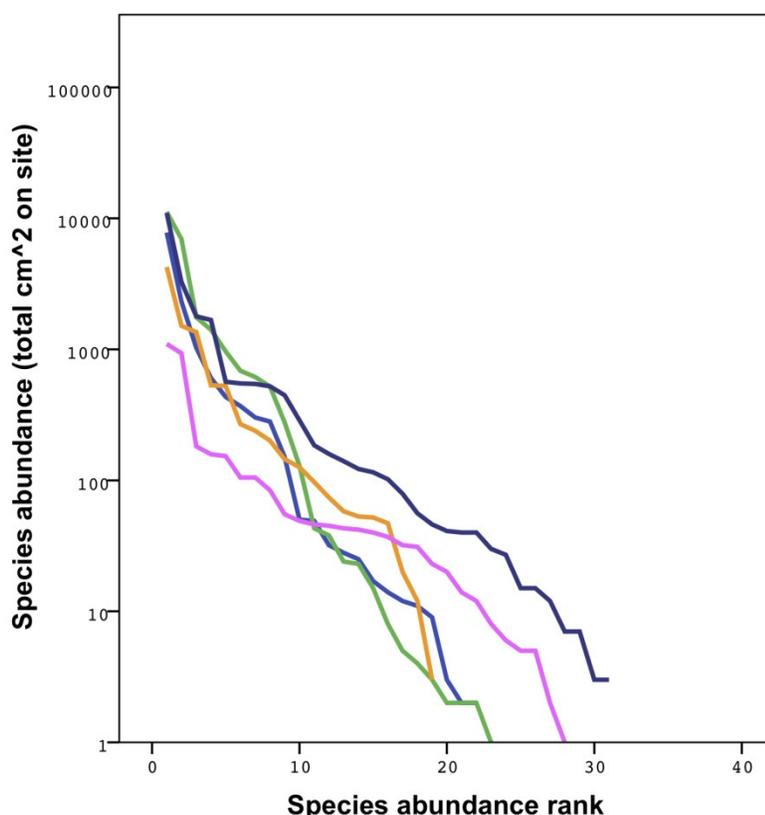


Figure 4b. The proportion of invasive and non-invasive plant abundance expressed as a percent of total abundance (y-axis). Abundance is calculated by measuring percent cover along transects in research plots in Alley Pond and Roy Wilkins Parks (Queens), Canarsie and Marine Parks (Brooklyn), and Pelham Bay Park (Bronx) (x-axis).



The most abundant individual species in all study plots were invasive. For example, *Artemisia vulgaris* (Mugwort), a common non-native invasive (Barney et al. 2008, 2009) being combated in parks and private land throughout NYC, was the most abundant species in Canarsie, Marine, and Roy Wilkins Park, and second most abundant at Alley Pond Park. *Fallopia japonica* (Japanese knotweed) was the most abundant species in the Pelham Bay Park site. Rank abundance plots show the relatively steep curves for Alley Pond and Canarsie Park, which indicate how a small number of species dominate the sites, with abundance quickly dropping off among the lower-ranked, less-abundant species (Figure 5). Conversely, the less-steep curve in the rank abundance plot for Pelham Bay indicates a higher degree of evenness, with smaller differences between the more- and less-abundant species. We expect this research will provide direct measures of invasive species dynamics by linking plot scale data to a growing citywide analysis of the effect of management strategy on plant diversity and abundance. Additionally, aggregated vegetation data will allow an analysis of how community dynamics in different patches in the city change over time due to understory and tree diversity treatment variables.

Figure 5. Rank Abundance for Fall 2009 Sites. The rank abundance plot shown with rank on the X-axis and abundance on the Y-axis for each site. Rank is a sequential number assigned to each species in decreasing order of abundance, within each site. For each site, the most-abundant species has a rank of one.



CONCLUSION

The MTNYC reforestation experimental plots are a long-term project designed to understand the controls on urban ecosystem structure and function in forest restoration sites, and how ecosystem management practices may affect these controls. We focus on the abiotic and biotic drivers that may impact structure and function in urban forest vegetation and soils. The study is organized around repeated measurements of 900 m² plots to provide a framework for scaling up in space and time. Study plots are located in parks throughout NYC (Appendix 3) and are sampled both before trees and understory species are planted, and annually thereafter in order to assess ecosystem change over time. Long-term study of urban ecosystems is critical to the future of urban ecology. Over the next several years, this project will focus on analyzing vegetation and soil data from the experimental research plots to better understand the

development of urban forest ecosystems. This study will also provide a baseline of intensive data for future ecological research within NYC. We have found interesting vegetation patterns among sites across the city and expect with further analysis and integration of soil analyses to begin explaining these patterns. These analyses will provide new data for understanding the effects of 2000 acres of afforestation on ecosystem structure and functioning, and will provide the potential to connect intensive, neighborhood and site scale analyses of ecological, physical and social processes and mechanisms with other citywide, extensive research. Ultimately we expect our research on ecological restoration in urban centers and the impacts on the structure and functioning of regional scale environments to prove useful for urban ecosystem management and policymaking.

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SUPPLEMENTARY MATERIAL

APPENDIX 1: FALL 2009 SITE DESCRIPTIONS

Two terminal moraines from the Pleistocene ice age run east-west through the greater New York City area. The Harbor Hill moraine stretches across Brooklyn, Queens, and Staten Island. As a result, outwash is predominant on Long Island; elsewhere, till deposited by the glaciers is more common (New York City Soil Survey Staff 2005). Soil series from the New York City Reconnaissance Soil Survey (New York City Soil Survey Staff 2005) are described in this section, but must be considered provisional pending our detailed soil analyses, due to the survey's coarse scale. The importance of geologic characterization as well as accurate soil mapping to the understanding of urban plant diversity is suggested by findings that richness of both native and nonnative species at somewhat broad scales (tens of km) can be considerably more correlated with geologic diversity than with land cover type or the distinction between urban and rural areas (Kühn et al. 2004). The finding that cities are disproportionately located in areas of high geologic diversity is also relevant in this regard (Kühn et al. 2004).

The Alley Pond Park site, elevation 3m, is bounded by a major street (~2 m away), a parking lot (~3 m away) for a golf driving range, and on two sides, open woodland that separates the site from marshland along Little Neck Bay to the north and a narrow inlet of the Bay to the west. It is heavily dominated by *Poa pratensis*, with *Artemisia vulgaris* as a co-dominant. In the past, the site has been managed with the goal of maintaining a meadow cover type, including seeding of grasses and meadow forbs and probably the addition of sandy soil (Mike Morris, NYC Parks, pers. comm.). With one *Malus* sp. individual, three patches of *Rosa multiflora* and two of *Lonicera japonica*, this site has more woody vegetation than the others.

Canarsie Park, elevation 2m, lies adjacent to a baseball field and a road (~3 m away). The northeastern plot boundary is contiguous with open, weedy areas that were planted with trees simultaneously with the planting of the research site in October 2009. To the southeast, a 40m wide band of trees separates the site from a multilane freeway and 150m beyond that lays Jamaica Bay. As of August 2009, the site was heavily dominated by *Artemisia vulgaris*, with *Poa compressa* as a co-dominant. There is no woody vegetation apart from one patch of *Elaeagnus umbellata*.

The soils of both the Alley Pond and Canarsie Park sites are likely of the Inwood-Laguardia-Ebbets complex, which consists of a well-drained mixture of loamy fill and construction debris, with proportions of coarse fragments (>2 mm diameter) ranging from 10% to more than 75%, including 5 to 10% gravel (2 to 76 mm) and as much as 5% cobbles (76 to 250 mm) (New York City Soil Survey Staff 2005). Soil pH ranges from strongly acid to neutral.

At Cloves Lakes Park, elevation 56 m, space permitted only two subplots, bounded by a parking lot, a Parks Department maintenance building, and wooded patches. Suburban residential areas lie roughly 150 m to the south and west; to the east and north the park boundaries lie 250 to 500 m away. This is the only sloping site in the study so far, with a mild slope of approximately 5%. Vegetation surveys were not conducted in 2009 because the site was not accessible until after the flowering season. This site is not included in our preliminary vegetation analyses. Clove Lakes' soil likely consists of the Wethersfield-Ludlow-Wilbraham complex, relatively undisturbed glacial till comprised of silt loam, loam or sandy loam with 5 to 75% coarse fragments, pH ranging from very strongly acid to mildly alkaline, and a wide range of drainage classes (New York City Soil Survey Staff 2005).

The Marine Park site, elevation 3m, is bounded on three sides by woodland, approximately three meters from the plot boundaries, and on the fourth by an unimproved walking path, one to two meters from the plot boundary. *Artemisia vulgaris* dominated the site before clearing. Two patches of *Rhus copallinum* are the only woody vegetation. The site lays roughly 200m from an inlet off the sound that separates the southern shore of Brooklyn from the Rockaway Peninsula, and 900 m from the Brooklyn

shoreline proper. The site's soils are of the Bigapple-Fortress complex, moderately- to well-drained gneissic outwash plains partially covered with anthropogenic fill in the form of sandy dredge deposits (New York City Soil Survey Staff 2005). Soil pH ranges from extremely acid to slightly alkaline.

The Orchard Beach site in Pelham Bay Park, elevation 4m, is surrounded by wooded parkland on three sides. The beach on the shore of Pelham Bay lies roughly 90 m to the east, separated from the research plots by a ~30m wide band of trees and shrubs and ~ 60m of lawn. Co-dominants before clearing were *Fallopia japonica* and *Erechtites hieraciifolia*. This site's soils are likely of the Charlton-Sutton complex, consisting of moderately well to well-drained loam or sandy loam, with parent material of glacial till derived primarily from gneiss and schist, and having 5 to 35% coarse fragments in the A, B, and E horizons (New York City Soil Survey Staff 2005). Acidity ranges from very strong to moderate.

The four subplots at Roy Wilkins Park, elevation 8m, were separated into two non-adjacent pairs due to space limitations. The northernmost subplots are bounded by a suburban residential area to the north, open park land (including a baseball field) to the east and west, and park woodland to the south. The other two plots are surrounded by narrow (15-30m) wooded patches, beyond which lie open parkland, a large community garden, and suburban residential areas. Jamaica Bay lies 6 km to the southwest. Both sections had irregular wooded patches lying several meters from the plot boundaries; one was also bounded by a paved but disused service road and the other by a baseball field. *Artemisia vulgaris* dominated all subplots before clearing. Roy Wilkins Park appears to consist of the Flatbush-Riverhead complex, a mixture of well-drained silt loam, loam or sandy loam with parent material of both glacial outwash and anthropogenic fill over glacial outwash which is found in sites such as residential areas, athletic fields and cemeteries south of the terminal moraine (New York City Soil Survey Staff 2005). Coarse fragment content can range up to 35% and pH varies widely.

In order to standardize replicates across various sites all sites at the start of the experiment are required to be level, and, apart from the few exceptions noted above, devoid of woody vegetation. All sites are dominated by one or two common grasses or weedy forbs that in recent years have been regularly managed by mowing and/or herbicide application.

APPENDIX 2: PLANT SPECIES LIST – FALL 2009 SITES.

Site	Species	Nativity	Invasive
Alley Pond	<i>Artemisia vulgaris</i>	introduced	yes
Alley Pond	<i>Dactylis glomerata</i>	introduced	yes
Alley Pond	<i>Daucus carota</i>	introduced	yes
Alley Pond	<i>Elytrigia repens</i>	introduced	yes
Alley Pond	<i>Festuca rubra</i>	*	no
Alley Pond	<i>Hypericum perforatum</i>	introduced	yes
Alley Pond	<i>Linaria vulgaris</i>	introduced	yes
Alley Pond	<i>Lonicera japonica</i>	introduced	yes
Alley Pond	<i>Melilotus alba</i>	introduced	yes
Alley Pond	<i>Phragmites australis</i>	native	yes
Alley Pond	<i>Plantago lanceolata</i>	introduced	yes
Alley Pond	<i>Poa pratensis</i>	*	no
Alley Pond	<i>Rosa multiflora</i>	introduced	yes
Alley Pond	<i>Solidago juncea</i>	native	no
Alley Pond	<i>Taraxacum officinale</i>	introduced	yes
Alley Pond	<i>Toxicodendron radicans</i>	native	yes
Alley Pond	<i>Trifolium pratense</i>	introduced	no
Alley Pond	<i>Vicia tetrasperma</i>	introduced	yes
Canarsie	<i>Ambrosia artemisiifolia</i>	native	yes
Canarsie	<i>Artemisia vulgaris</i>	introduced	yes
Canarsie	<i>Aster lanceolatus</i>	introduced	no
Canarsie	<i>Aster pilosus</i>	native	yes
Canarsie	<i>Aster racemosus</i>	native	no
Canarsie	<i>Crataegus spp.</i>	unclear	no
Canarsie	<i>Cuscuta gronovii</i>	native	yes
Canarsie	<i>Daucus carota</i>	introduced	yes
Canarsie	<i>Elaeagnus umbellata</i>	introduced	yes
Canarsie	<i>Erigeron strigosus</i>	native	no
Canarsie	<i>Medicago lupulina</i>	introduced	yes
Canarsie	<i>Melilotus alba</i>	introduced	yes
Canarsie	<i>Oenothera biennis</i>	native	no
Canarsie	<i>Phragmites australis</i>	native	yes
Canarsie	<i>Plantago lanceolata</i>	introduced	yes
Canarsie	<i>Poa compressa</i>	native	yes
Canarsie	<i>Polygonum persicaria</i>	introduced	yes
Canarsie	<i>Solidago canadensis</i>	native	yes
Canarsie	<i>Taraxacum officinale</i>	introduced	yes
Canarsie	<i>Toxicodendron radicans</i>	native	yes
Canarsie	<i>Trifolium pratense</i>	introduced	no
Marine Park	<i>Achillea millefolium</i>	introduced	yes
Marine Park	<i>Ambrosia artemisiifolia</i>	native	yes

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Marine Park	<i>Artemisia vulgaris</i>	introduced	yes
Marine Park	<i>Dactylis glomerata</i>	introduced	yes
Marine Park	<i>Daucus carota</i>	introduced	yes
Marine Park	<i>Hieracium caespitosum</i>	introduced	yes
Marine Park	<i>Linaria vulgaris</i>	introduced	yes
Marine Park	<i>Plantago lanceolata</i>	introduced	yes
Marine Park	<i>Prunus avium</i>	introduced	yes
Marine Park	<i>Rhus copallinum</i>	native	no
Marine Park	<i>Verbascum blattaria</i>	introduced	yes
Pelham Bay	<i>Achillea millefolium</i>	introduced	yes
Pelham Bay	<i>Ampelopsis brevipedunculata</i>	introduced	yes
Pelham Bay	<i>Chamerion angustifolium</i>	native	no
Pelham Bay	<i>Fallopia japonica</i>	introduced	yes
Pelham Bay	<i>Geum canadense</i>	native	no
Pelham Bay	<i>Impatiens capensis</i>	native	no
Pelham Bay	<i>Phytolacca americana</i>	native	yes
Pelham Bay	<i>Robinia pseudoacacia</i>	native	yes
Pelham Bay	<i>Rubus phoenicolasius</i>	introduced	yes
Pelham Bay	<i>Solidago canadensis</i>	native	yes
Pelham Bay	<i>Toxicodendron radicans</i>	native	yes
Roy Wilkins	<i>Artemisia vulgaris</i>	introduced	yes
Roy Wilkins	<i>Celastrus orbiculatus</i>	introduced	yes
Roy Wilkins	<i>Daucus carota</i>	introduced	yes
Roy Wilkins	<i>Erigeron strigosus</i>	native	no
Roy Wilkins	<i>Linaria vulgaris</i>	introduced	yes
Roy Wilkins	<i>Melilotus alba</i>	introduced	yes
Roy Wilkins	<i>Plantago lanceolata</i>	introduced	yes
Roy Wilkins	<i>Plantago major</i>	introduced	yes
Roy Wilkins	<i>Poa pratensis</i>	*	no
Roy Wilkins	<i>Prunus serotina</i>	native	yes
Roy Wilkins	<i>Solidago canadensis</i>	native	yes
Roy Wilkins	<i>Taraxacum officinale</i>	introduced	yes
Roy Wilkins	<i>Trifolium repens</i>	introduced	yes

(Nativity and invasive status were taken from Uva and Ditomaso 1997 and USDA's PLANTS Database 2010)

*some infrataxa are native, some are introduced.

APPENDIX 3: NYC URBAN FOREST RESTORATION SITES 2009-2010



Figure for Appendix 3. Blue and green dots indicate locations of permanent research plots in NYC parks. Spring Creek, Highbridge and Old Place Creek Parks (orange dots) are sites of earlier (Spring 2009) pilot studies.