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RESEARCH ARTICLE

Long-term outcomes of forest restoration in an urban park

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Creating, restoring, and sustaining forests in urban areas are complicated by habitat fragmentation, invasive species, and degraded soils. Although there is some research on the outcomes of urban reforestation plantings during the first 5 years, there is little research on longer term outcomes. Here, we compare the successional trajectories of restored and unrestored forest sites 20 years after initiating restoration. The sites are located within the Rodman's Neck area of Pelham Bay Park, in the northeast corner of the Bronx in New York City (NYC), U.S.A. Compared with unrestored sites, we saw improvements in species diversity, greater forest structure complexity, and evidence of the regeneration and retention of native tree species in restored sites. In addition, we found differences in restoration outcomes depending on the level of intervention: clearing exotic shrubs and vines and planting native trees and shrubs improved tree diversity and canopy closure to a greater extent than clearing exotics alone, and the mechanical removal of invasive plants after the native plantings further improved some measures of restoration, such as tree species diversity and native tree regeneration. The results of this study suggest that the goal of a sustainable forest ecosystem dominated by native trees and other plant species may not be achievable without continued human intervention on site. In addition, these results indicate that the restoration approach adopted by NYC's reforestation practitioners is moving the site toward a more desirable vegetative community dominated by native species.

Key words: canopy closure, foliar height diversity, invasive exotic species, New York City, urban forestry, vegetation structure

Implications for Practice

- Urban forest restoration practices such as targeted removal of exotic invasive species and planting native tree species can increase species diversity and vegetation structure complexity. These effects can be seen two decades after restoration is initiated.
- Targeted removal of exotic invasive plant species alone (i.e. without planting native trees) can increase numbers of exotic invasive shrubs and vines.
- Urban forest restoration requires some level of continued maintenance to ensure success. Additional studies are needed to determine optimal levels (intensity and frequency) of intervention.

Introduction

Municipalities around the world are investing in urban forests, hoping to strengthen the provisioning of essential ecosystem services. Some of these investments are allocated toward increasing urban tree canopy cover by restoring degraded or destroyed ecosystems. For example, the majority of trees planted in New York City's MillionTreesNYC initiative in the United States are part of large restoration sites in urban natural areas. Although there is some research on the outcomes of urban reforestation plantings during the first 5 years, relatively little research has evaluated the dynamics of these plantings beyond a 5-year time frame (Oldfield et al. 2013).

Creating, restoring, and sustaining forests in urban areas are complicated by habitat fragmentation, invasive species, and degraded soils. For example, forests in the city of Portland, Oregon, have seen a decrease in recruitment and increase in tree mortality between 1993 and 2003 (Broshot 2011), trends indicating that these forested ecosystems are not capable of sustaining themselves without intervention. When it does occur, natural regeneration in urban areas may or may not lead to a diverse forest dominated by native species (Alvey 2006). In fact, large forest patches are not necessarily less susceptible to invasive species, and one study in the southeastern United States found that riparian patches surrounded by higher canopy cover are more likely to be invaded than those surrounded by landscapes with lower canopy cover (Vidra & Shear 2008). Invasive plants

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Figure 1. Rodman's Neck, Pelham Bay Park. Unknown. "General view, aerial, looking northwest, Pelham Bay Park." 8 September 1937. 12613_1937-09-08_X039. New York City Parks Photo Archive.

can suppress native plant communities, and depending on the techniques used, native plant communities show varying responses to invasive species removal (Flory & Clay 2009). In fact, repeated removal of invasive plant species is often necessary, and native plant communities may still not recover sufficiently without supplemental plantings (Vidra et al. 2007).

The New York City (NYC) Department of Parks & Recreation's Natural Resources Group (NRG) has been involved in urban forest restoration efforts for over two decades. An early forest restoration project took place in the 1990s in Pelham Bay Park, the largest public park (1,122 ha) in NYC. The land use history of Pelham Bay Park is complex, varied, and emblematic of what frequently occurs in green spaces within major metropolitan areas. The Rodman's Neck section of the park has undergone moderate to intense deforestation over the last 100 years. Prior to acquisition by the NYC Department of Parks and Recreation in the late 1800s, the land was a private estate owned by Samuel Rodman. In the early 1900s, Rodman's Neck was converted to a large permanent campsite for summer recreational use, and by 1917 approximately 500,000 people camped there seasonally. In 1937, Orchard Beach and its parking lot were created in an adjacent area of the park, an operation that required filling in one-third of Pelham Bay with 3 million cubic yards of landfill. Most of Rodman's Neck was deforested during beach construction (Fig. 1).

Floral and faunal surveys of Pelham Bay Park show a 37% increase in exotic plant species and a 25% loss in native fauna between 1947 and 1998 (DeCandido & Lamont 2004). In 1986, Rodman's Neck was a mixed hardwood forest dominated by exotic invasive vines (NYC Department of Parks & Recreation 1986). *Populus alba* and *Robinia pseudoacacia* dominated the canopy, while the understory was comprised largely of *Prunus serotina*.

NRG removed several targeted exotic species of vines, shrubs, and forbs between 1992 and 1995 across 10 ha of the northern Rodman's Neck area of Pelham Bay Park. Several species of native trees were planted in the fall of 1994 and 1995. The goal of this restoration effort—and many others in the NYC metropolitan area—was to increase native tree cover, increase vegetative structure complexity, and quickly promote a closed forest canopy in order to discourage the reemergence of exotic vegetation. This process was expected to allow native tree species to successfully germinate, thereby creating a sustainable forest ecosystem dominated by native trees and other native plant species. To some extent, this restoration approach fits the definition of "intelligent tinkering" in ecological restoration as suggested by Murcia and Aronson (2014). Although a hypothesis was formulated—that planting native trees and quickly creating a closed canopy would discourage the reemergence of exotic vegetation—at the time these activities took place, there was little scientific literature available on urban forest restoration. Thus, the restoration techniques used were based largely on the ecological intuition of NRG staff. The goal of this study is to analyze the results of this past intelligent tinkering in order to generate general principles that can guide other urban forest restoration efforts here and at other comparable sites. In this study, we examined the long-term outcomes of forest restoration and management in Pelham Bay Park. Here, we compare the successional trajectories of restored and unrestored forest sites by following recommendations by Ruiz-Jaén and

Aide (2005) for evaluating the success of ecological restoration projects. They recommend collecting data on three ecosystem attributes: species diversity, vegetation structure, and ecological processes. We used metrics that targeted the three attributes to determine whether the restoration is working and if continued intervention is needed. We hypothesize that compared with control (unrestored) sites, restored sites will have greater tree species diversity, lower numbers of exotic shrub and vine stems, and greater retention of planted and other native trees. In assessing vegetation structure, we expect restored sites to have greater total and native tree basal area, lower exotic tree basal area, greater foliage height diversity (FHD), and lower canopy transparency. To examine ecological processes, we expect the regeneration of native trees to be greater in the restored sites. We also expect greater canopy closure (decreased canopy transparency) to correlate with decreased abundance of exotic shrubs, vines, and herbaceous species. Finally, within the restored sites, we expect sites with greater levels of intervention to have better outcomes for species diversity, vegetation structure, and ecological processes.

Table 1. Exotic and/or targeted tree and shrub species found in the study area. Species targeted for removal by restoration crews are in bold. Three native species (designated with an *) are included in this table as they were also targeted for removal.

Scientific Name	*Common Name*
Acer platanoides	**Norway maple**
Acer pseudoplatanus	**Sycamore maple**
Ailanthus altissima	**Tree of heaven**
Ampelopsis brevipedunculata	**Porcelain berry**
Celastrus orbiculatus	**Oriental bittersweet**
Frangula alnus	**Glossy buckthorn**
Juglans nigra*	**Black walnut**
Lonicera japonica	Japanese honeysuckle
Lonicera maackii	Amur honeysuckle
Morus alba	**White mulberry**
Paulownia tomentosa	Princess tree
Polygonum cuspidatum	Japanese knotweed
Polygonum perfoliatum	Mile-a-minute vine
Populus alba	**White poplar**
Rhus typhina*	**Staghorn sumac**
Rosa multiflora	**Multiflora rose**
Rubus occidentalis*	**Black raspberry**

Methods

Site Description and Study Design

The study site was located within the Rodman's Neck area of Pelham Bay Park, in the northeast corner of the Bronx in NYC (Fig. 2). The site is characterized by soils belonging to the Paxton complex, Scio, and Scio-Tonawanda soil series (soil methods and analysis data are provided in Table S1 of Appendix S1, Supporting Information). From 1991 to 1996, the site was chemically and mechanically cleared of exotic vegetation. A combination of cut stump, foliar spraying, and basal bark treatments was employed for treating exotic species listed in Table 1. Garlon 4 and Garlon 3A (triclopyr) were the most widely used herbicides throughout the site, ranging in concentrations from 2 to 50% depending on application method. Oust (sulfometuron methyl) was used in addition to the Garlon for foliar spraying in the fall of 1993 and spring of 1994. Roundup (glyphosphate) was utilized specifically for *Polygonum cuspidatum* removal. Exotic trees were targeted in specific locations in Rodman's Neck. The presence of introduced *Acer* spp. (*Acer platanoides* and *A. pseudoplatanus*), *Ailanthus altissima*, and *Populus alba* was seen as competition for native vegetation and targeted for removal. A dense stand of *P. alba* was present in the southeast corner of Rodman's Neck, believed to be planted by the city during the Orchard Beach construction in the 1930s. In 1992, a strong wind event toppled a large portion of the poplar stand and creating space for additional exotics, like *P. cuspidatum*, to establish. A combination of mechanical removal of the large downed poplars and herbicide treatment (previously described) took place between 1994 and 1995. Vines and shrubs targeted for removal (referred to as "targeted exotic vegetation") are listed in Table 1 along with other exotic species that were present but not targeted for removal. Around 4,000 container class #2 and #3 (based on the American Standard for Nursery Stock, Quinn 2014) native trees and shrubs ("planted native vegetation" listed in Table 2) were then planted at 1-m spacing. The planted treatment areas in this study received approximately the same number of planted trees. Following these plantings, the middle portion of the study site was maintained via mechanical invasive plant removal on several occasions, including in 1996, 1999, and 2001. Maintenance ceased in this portion of the site after 2001. The northern and southern portions of the site received no mechanical removal of invasive plants after 1996 (Fig. 2). This yielded three treatments: "cleared, planted, and maintained" (CPM treatment); "cleared and planted but not maintained" (CP treatment); and "cleared but not planted or maintained" (C treatment). In addition, areas that had received no management but were otherwise similar to the treated areas formed the control.

During the summers of 2010 and 2011, forty-eight 20-m diameter circular plots (314 m^2) were established in areas with these three management treatments and control areas. The plots were randomly placed within the different areas while controlling for the size of the management area using Hawth's Analysis Tools v3.24 within ArcGIS v9.3 (ESRI, Redlands, CA, U.S.A.). Sixteen plots were located in areas that were cleared, planted, and maintained (CPM treatment); seven plots were installed in areas that were cleared and planted but received no maintenance (CP treatment); and 12 plots were located in areas that were cleared but not planted or maintained (C treatment). Finally, we installed 13 plots in areas that had no management but were located within the Rodman's Neck area (within 400 m from the nearest C, CP, or CPM plot) that remain unrestored (control).

Vegetation Data Collection

A nested plot design was used to collect data on trees, shrubs, vines, and herbaceous plant species within each plot. Within the 20-m diameter circular plot, tree species, diameter at breast height (dbh), and height were recorded for all trees $\geq$3 cm

Table 2. Native tree and shrub species present at the site with planted native species listed in bold.

Scientific Name	*Common Name*
Acer negundo	Boxelder
Acer rubrum	**Red maple**
Acer saccharum	**Sugar maple**
Ampelopsis arborea	Peppervine
Campsis radicans	Trumpet creeper
Carya alba	Mockernut hickory
Carya cordiformis	**Bitternut hickory**
Carya ovata	Shagbark hickory
Cornus florida	**Flowering dogwood**
Fraxinus americana	**White ash**
Juniperus virginiana	**Eastern red cedar**
Liquidambar styraciflua	**Sweetgum**
Liriodendron tulipifera	**Tulip poplar**
Nyssa sylvatica	Blackgum
Parthenocissus quinquefolia	Virginia creeper
Pinus strobus	**Eastern white pine**
Prunus serotina	Black cherry
Quercus alba	**White oak**
Quercus bicolor	Swamp white oak
Quercus palustris	**Pin oak**
Quercus prinus	**Chestnut oak**
Quercus rubra	**Red oak**
Quercus svelutina	Black oak
Robinia pseudoacacia	Black locust
Sassafras albidum	Sassafras
Tilia americana	American basswood
Toxicodendron radicans	Eastern poison ivy
Ulmus americana	American elm
Ulmus rubra	Slippery elm
Viburnum dentatum	**Arrowwood viburnum**
Vitis spp.	Grape

dbh. Shrub, vine, and tree seedling (<3 cm dbh) species, stem count, and height were collected from four 25-m^2 quadrats located 3 m from the plot center in each cardinal direction. For multi-stemmed shrubs, only the height of the tallest stem was recorded. Within each of these four quadrats, a 1-m^2 quadrat was established in the corner closest to the plot center and used to record percent cover of each herbaceous species. Species diversity of trees ≥3 cm dbh was calculated using the Shannon–Wiener diversity index (H'): $H' = -\sum p_i \log_e p_i$, where p_i is the relative abundance of trees of species i.

We assessed the vertical structure and species composition of the canopy over the plot by modifying a method developed by Aber (1979). A 120-mm lens was attached to a Nikon F2 35 mm camera and calibrated so that distances could be measured by focusing the lens. A special multiple cross hair focusing screen was used to create a grid of 16 sampling points within the camera's field of view. The camera was set on a tripod 1.5 m above the ground in the center of each 25-m^2 quadrat as well as at plot center; the lens was pointed straight up and used to measure the distance to the leaf covering each of the 16 points in the viewfinder. The species of the tree or vine in focus at each point was also recorded to determine the relative importance of native and exotic species in the canopy structure. These data were used to calculate FHD using the following formula: $\mathrm{FHD} = -\sum q_i \log_e q_i$, where q_i is the proportion of the total foliage which lies in the ith of the chosen horizontal layers (in this case, 2-m layers from camera height to the top of the canopy).

At the center of each 25-m^2 quadrat as well as at plot center, we measured canopy transparency as the relative index of the amount of light that reaches the forest floor in each plot. Transparency was measured using digital photographs taken vertically through the canopy from a height of 1 m. No zoom was used, and automatic camera settings were used for all photographs to standardize lighting under different conditions. Digital images (JPG files) were processed using an open-source program called Cell Profiler v. 2 (Lamprecht et al. 2007). A custom "pipeline" was created to convert color photos to binary light–dark images using a transparency threshold. The output black and white images were then used to calculate percent transparency for each photograph.

Data Analysis

All variables were analyzed at the plot level ($N = 48$). Shrub, vine, and tree seedling counts within each subplot were averaged to calculate the count per hectare within each plot. The percent exotic herbaceous cover of each subplot was also averaged together for each plot. Treatment effects on tree species diversity; abundance of all and targeted exotic shrub stems per hectare; basal area of all, native, and exotic tree species per hectare; FHD; canopy transparency; and stem count of planted native, other native, and exotic tree species per hectare were each analyzed using a one-way analysis of variance (ANOVA) using the "aov" function in R v2.15.2 (R Core Team, Vienna, Austria). To determine if there were significant differences ($\alpha = 0.05$) between each treatment, Tukey's HSD post hoc test was performed using the "TukeyHSD" function in R. We used linear regression to determine whether canopy transparency influenced exotic herbaceous cover or exotic shrub stem count. When needed, data were normalized using the log transformation to ensure that the assumptions of the statistical models were met. The stem counts per hectare of planted and other native tree species that were retained (3–10 cm dbh) or regenerating (<3 cm dbh) were highly skewed due to the large number of plots with no native trees under 10 cm dbh. Because we were unable to transform to the data to meet assumptions of normality and homoscedasticity, treatment effects on the retention and regeneration of planted and other native stem count per hectare were analyzed using a nonparametric Kruskal–Wallis rank sum test using the "kruskal.test" function in R. Multiple comparisons were performed using Bonferroni corrected Mann–Whitney–Wilcoxon tests using the "wilcox.test" function in R.

Results

Species Diversity

Tree species diversity tended to be greater in restored areas (C, CP, and CPM) than in control plots receiving no management

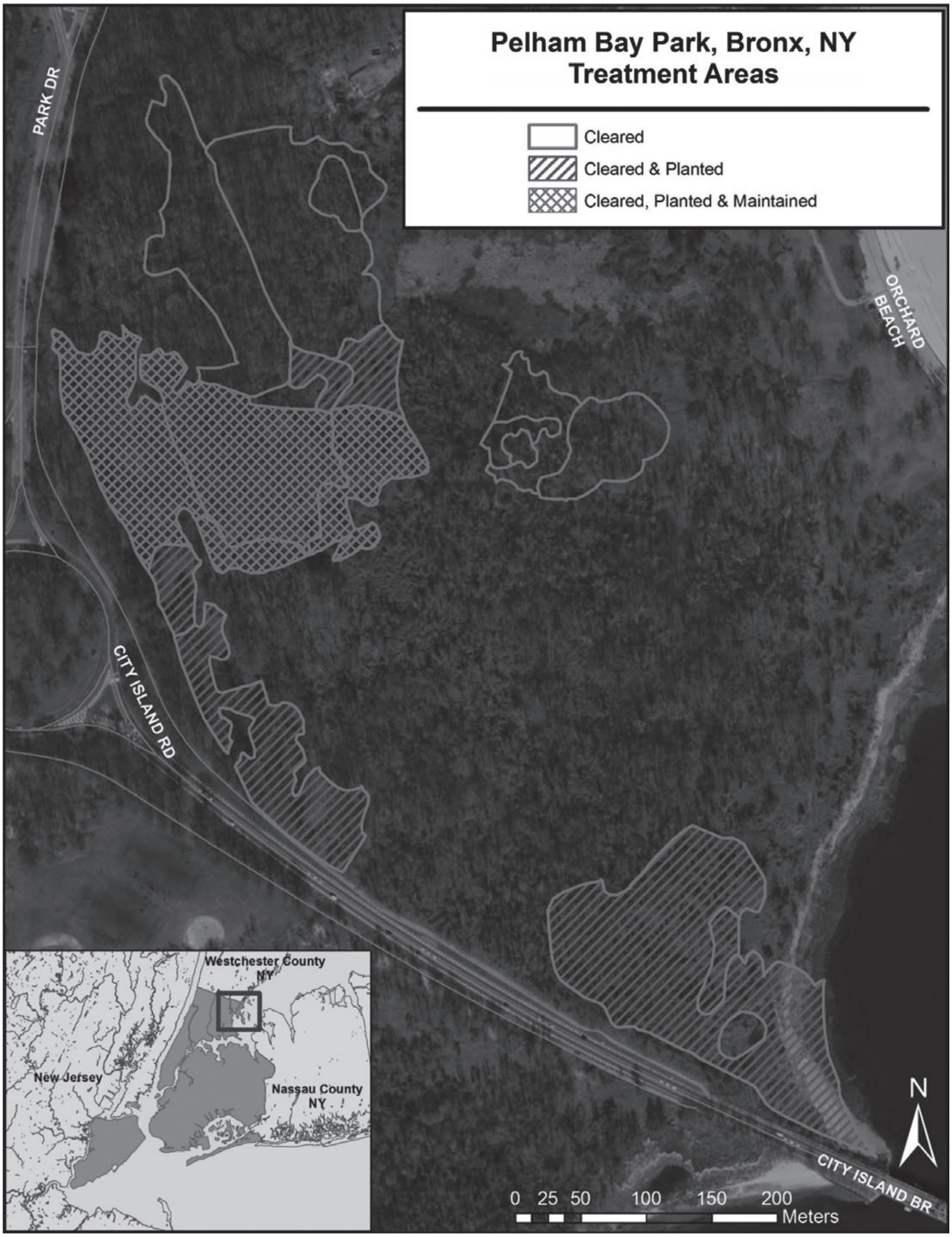

Figure 2. Map of three distinct treatment areas for Rodman's Neck area of Pelham Bay Park, Bronx, NY. Treatments are defined as follows: cleared — chemically and mechanically cleared of exotic vegetation; planted — native trees and shrubs planted at 1-m spacing; and maintained — mechanical removal of invasive plants after planting of native trees and shrubs.

($p < 0.0001$; Table S2 of Appendix S1; Fig. 3A). Relative to control plots, tree species diversity was 181% higher in the CP plots and 190% higher in the CPM plots. Although stem count of all exotic shrubs and vines did not differ significantly among the treatments, the stem count of targeted exotic shrubs and vines did vary significantly ($p < 0.05$; Table S2 of Appendix S1; Fig. 3B), with a greater number of targeted exotics in the C plots than in the CP (Tukey adj. $p < 0.05$) and CPM plots (Tukey adj. $p < 0.05$). However, stem count of targeted exotic shrubs and vines in the control plots did not differ from any of the restored plots. As a way to assess the retention of planted native trees, which were rare before the restoration, we examined the stem

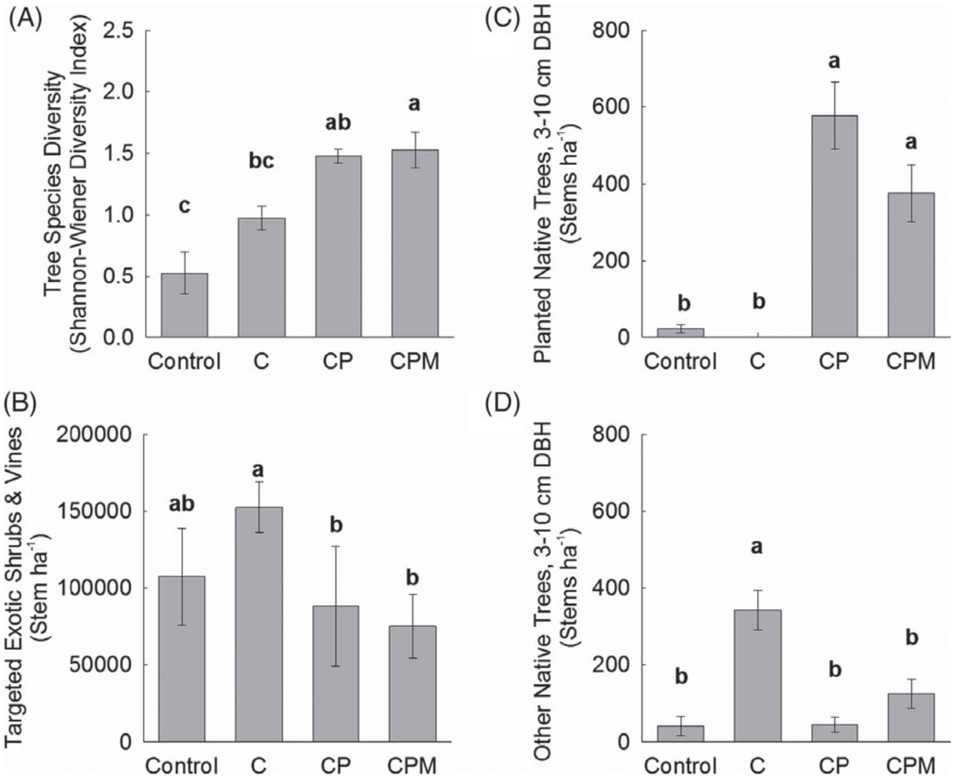

Figure 3. Species diversity and stem density in each treatment (C, cleared of exotic vegetation; CP, cleared + planted native trees and shrubs at 1-m spacing; CPM, cleared + planted + maintained by removal of re-emerging exotic vegetation). Values represent means ± SE ($n = 13$ for control, $n = 12$ for C, $n = 7$ for CP, and $n = 16$ for CPM). (A) Tree species diversity (treatment effect: $p < 0.0001$): letters a through c represent a significant difference (Tukey's HSD, $\alpha = 0.05$). (B) Targeted exotic shrubs and vines (treatment effect: $p = 0.0113$): letters a and b represent a significant difference (Tukey's HSD, $\alpha = 0.05$). (C) Planted native tree stems (treatment effect: $p < 0.0001$). (D) Other native tree stems (3–10 cm dbh; treatment effect: $p < 0.0001$; see Table 2 for list of species): letters a and b represent a significant difference (Bonferroni corrected Mann–Whitney–Wilcoxon test, $\alpha = 0.0083$).

count of planted versus other native trees within the 3–10 cm dbh range. The number of planted native trees (3–10 cm dbh; Table 2, "planted" species listed in bold) varied by treatment ($p < 0.0001$; Table S3 of Appendix S1) and was greater in the CP (+2,520%, $p < 0.001$) and CPM plots (+1,610%, $p < 0.0001$) than control plots (Fig. 3C). The number of other native trees (3–10 cm dbh; Table 2) also varied by treatment ($p < 0.0001$; Table S3 of Appendix S1) and was greater in the C plots than the CP, CPM, or control plots ($p < 0.0001$) (Fig. 3D).

Vegetation Structure

Total tree basal area, basal area of native tree species, and the basal area of exotic tree species varied significantly across the different restoration treatments. Total basal area was greater in all restored plots compared with the control plots (Table S2 of Appendix S1; Fig. 4A), with the highest basal area found in the CP plots (170% greater than control plots, Tukey adj. $p < 0.001$). Relative to the control treatment, the basal area of native trees was greater in the C treatment (+317%, Tukey adj. $p < 0.0001$) and CPM treatment (+221%, Tukey adj. $p < 0.001$; Table S2 of Appendix S1; Fig. 4B). The basal area of exotic trees was greatest in the CP treatment (210% greater than control plots, Tukey adj. $p = 0.001$; Table S2 of Appendix S1; Fig. 4C).

FHD was higher in the C (+65%, Tukey adj. $p < 0.001$) and CPM plots (+56%, Tukey adj. $p < 0.01$) compared with control plots (Table S2 of Appendix S1 ; Fig. 4D). Canopy transparency was significantly lower in the CP and CPM plots compared with control plots (Table S2 of Appendix S1; Fig. 4E). Relative to the control plots, the CP and CPM plots had 28 and 34% lower canopy transparency, respectively (Tukey adj. $p < 0.05$ and $p < 0.0001$).

Ecological Processes

Although there was no evidence that canopy transparency influenced exotic herbaceous cover or exotic shrub stem count (data not shown), we did see evidence of a treatment effect on regeneration. The regeneration of native ($p < 0.001$, Table S3 of Appendix S1; Fig. 5) saplings (<3 cm dbh) varied by treatment. Native saplings were more abundant in the CPM plots than the control plots (+893%, $p < 0.0001$). Exotic sapling abundance did not differ between the restored plots and the control plots.

Discussion

Urban environments can play an important role in mitigating global biodiversity loss; therefore, management practices

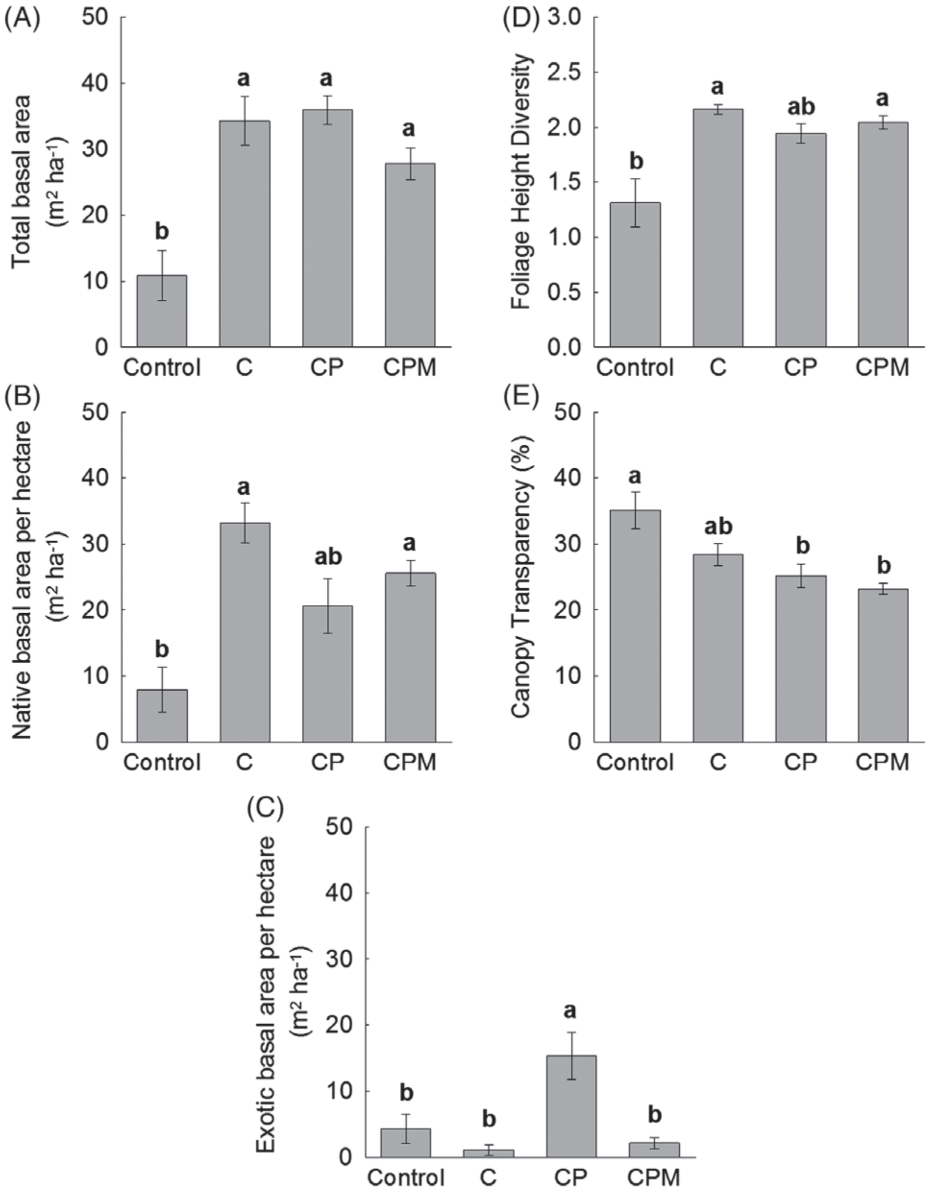

Figure 4. Vegetation structure in each treatment (C, cleared; CP, cleared + planted; CPM, cleared + planted + maintained). Values represent means ± SE ($n = 13$ for control, $n = 12$ for C, $n = 7$ for CP, and $n = 16$ for CPM). Letters a and b represent a significant difference (Tukey's HSD, $\alpha = 0.05$) among the treatments. (A) Total tree basal area (treatment effect: $p < 0.0001$), (B) basal area of all native trees (treatment effect: $p < 0.0001$), and (C) basal area of all exotic trees (treatment effect: $p < 0.0001$) in each treatment. (D) FHD in each treatment (treatment effect: $p = 0.0006$). FHD $= -\sum q_i \log_e q_i$, where q_i is the proportion of the total foliage which lies in the ith of the chosen horizontal layers (in this case, 2-m layers from camera height to the top of the canopy). (E) Percentage canopy transparency in each treatment (treatment effect: $p = 0.0001$).

that preserve and promote urban biodiversity should be pursued (Alvey 2006). Almost 20 years after the initiation of forest restoration in the Rodman's Neck area of Pelham Bay Park, we were able to document measurable effects of tree planting and maintenance activities using metrics recommended by Ruiz-Jaén and Aide (2005). Consistent with our hypotheses, we saw improvements in tree species diversity, greater forest structure complexity, and evidence of the retention and regeneration of native tree species. However, we did not see a decrease in exotic shrub, vines, or basal area in the restored plots, and there was no correlation between canopy closure and the abundance of exotic plants. In addition, we found differences in restoration outcomes depending on the level of intervention. For example, planting and clearing improved tree diversity and canopy closure to a greater extent than clearing alone, and the mechanical removal of invasive plants after the plantings further improved tree species diversity and native tree regeneration.

Across all the restored plots, total and native tree basal area increased significantly compared with control plots, suggesting

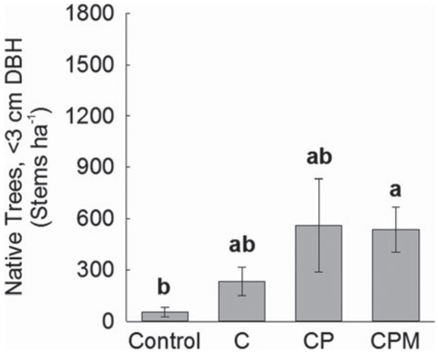

Figure 5. The number of native tree stems (<3 cm dbh) per hectare, in each treatment (C, cleared; CP, cleared + planted; CPM, cleared + planted + maintained). Treatment effect: $p = 0.0004$. Planted native trees listed in bold in Table 2. Values represent means ± SE ($n = 13$ for control, $n = 12$ for C, $n = 7$ for CP, and $n = 16$ for CPM). Letters a and b represent a significant difference (Bonferroni corrected Mann–Whitney–Wilcoxon test, $\alpha = 0.0083$) in the number of tree stems (<3 cm dbh) per hectare among the treatments.

that restoration activity led to increased tree species productivity at our site. Increased FHD on restored plots compared with control plots also indicates that vertical vegetation structure is more complex in restored areas, which improves habitat for bird communities (Anderson & Shugart 1974; Wiens & Rotenberry 1981; Müller et al. 2009; Heyman 2010; Hewson et al. 2011). New York City's urban forests are part of the Atlantic Flyway and provide safe refuge to many avian species during migration, as well as habitat for resident and breeding populations. The eBird website (eBird 2014) has recorded 218 species of birds at Pelham Bay Park, and the National Audubon Society designated the park an "Important Birding Area" in 2005 (National Audubon Society 2012). However, it is worth noting that some birds will spread exotic invasive seeds throughout the forest (White & Stiles 1991; Hutchinson & Vankat 1998; Gosper et al. 2005).

Although scientific literature on urban forest restoration was limited at the time our study site was restored, the body of scientific knowledge on urban ecological restoration has grown in the past two decades, and we found that both the restoration techniques used and our findings are supported by other researchers. For example, Ruiz-Jaén and Aide (2006) found that planting native trees restored many ecological functions in a forest near the San Juan Metropolitan area in Puerto Rico. Similarly, we found that tree diversity in the planted plots (CP and CPM) was significantly higher than that in the control plots. Qualitative vegetation surveys of the study area prior to the start of restoration activities in 1991 indicated that planted tree species were not present in large numbers, so the increase in planted native trees in the 3–10 cm dbh class found in the CP and CPM plots is likely to be the planted trees that survived. We also found that the stem count of targeted exotic shrubs and vines was significantly higher in C plots than in CP or CPM plots. The disturbance created on plots that were only cleared may have opened them up to further invasion and proliferation of exotic shrubs and vines (McLachlan & Bazely 2003). These findings suggest that if the effort is taken to clear invasive plants, planting native vegetation reduces the reemergence of some species of exotic shrubs and vines.

Planting also lowered canopy transparency, indicating that the goal of increasing canopy closure is being met at our site. The C plots did not have significantly lower transparency values than control, indicating that the decreased transparency on the planted plots (CP and CPM) was likely influenced by the native trees that were planted almost 20 years ago. However, despite decreases in canopy transparency, the abundance of targeted exotic shrubs and vines was not different between control plots and the CP or CPM plots. Because we found no correlation between canopy transparency and exotic herbaceous cover or exotic shrub stem count, we discovered that closing the forest canopy does not prevent exotic species from establishing at our site, which is contrary to the hypothesis formulated when the restoration activities took place.

To the best of our knowledge, there were no major forest disturbances after restoration plantings were complete that would explain the establishment of exotic species, aside from the continued invasive removal in CPM plots and regular park use by urban residents. However, closing the canopy only excludes shade-intolerant invasive species, but still allows for shade-tolerant invasive species to establish (Meiners et al. 2002) such as *Lonicera japonica* (Schierenbeck 2004) and *Polygonum perfoliatum* (Kumar & DiTommaso 2005), which were found in the study site. In addition, the restoration emphasized installation of native trees while very little understory planting took place. For example, *Viburnum dentatum* comprised less than 1% of total vegetation planted. Because communities with greater functional diversity tend to be more resistant to invasion (Naeem et al. 2000; Diaz & Cabido 2001; Pokorny et al. 2005), planting more native shrubs and herbaceous species in addition to native trees may have led to greater reductions in the establishment of exotic shrubs and vines at our site.

Although clearing invasive species and planting native trees improved tree species diversity, native tree retention, and canopy closure, repeated removal of invasive vines further increased tree species diversity and the native tree regeneration. Native tree regeneration is a key component of a self-sustaining forest ecosystem, and there were more native tree saplings (<3 cm dbh) in the CPM treatment than in the control treatment. The C and CP plots were not significantly different from control plots, which again highlight the importance of maintenance in native forest regeneration in urban areas. In addition, we found that CP plots had significantly higher exotic tree basal area than control plots and did not have significantly higher native basal area than control plots. This result may be largely due to a stand of *Populus alba* trees present in five of the seven CP plots in the southern end of the site. The limited treatment of the poplar stand during the restoration with no evidence of maintenance may have been counterproductive and resulted in increased vegetative reproduction (Edgin 2004). These clonal trees make up 37% of the total basal area in the CP plots and may have prevented a significant increase in native basal area in plots where they were present.

In a study of an urban forest, Vidra et al. (2007) found that both supplemental planting of native species and repeated removal of invasive species were required in order to achieve a more diverse native plant community. Although native tree species are more abundant on planted plots than control plots, our findings show that there is a definite need for continued maintenance at this site. The last management activity took place on the CPM plots in 2001, and we saw that the abundance of exotic invasive vines and shrubs did not differ between control and any of the restored areas. It is likely that unless further targeted removal of exotic invasive species takes place, these species will become dominant again. Rayfield et al. (2005) also compared simple and complex restoration strategies and found that the complexity of the technique does not guarantee a return to pre-disturbance communities. Thus, more research is required to determine the optimal levels of intervention required to continue to move a site like this along the restoration trajectory.

This study provides a relatively long-term view of the outcomes that can be achieved using a common set of tools available to urban restoration practitioners (clearing, planting, exotic invasive plant removal, and continued maintenance). The most promising outcome is achieved by using multiple strategies including continued maintenance. We found patterns of increased species diversity, vegetation structural diversity, and canopy cover consistent with those of Ruiz-Jaén and Aide's (2005) evaluation of urban forest restoration success. Overall, our results suggest that the goal of a sustainable forest ecosystem dominated by native trees and understory plants is not achievable without continued human intervention on highly degraded urban restoration sites. However, this study does suggest that urban land managers can have a positive sustained effect on urban forest composition and structure over the course of two decades.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Soils sample collection, basic soil characteristics and statistical tables.

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