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Historical ecology of Inwood Hill Park, Manhattan, New York

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FITZGERALD, J. M. (Department of Biology, Lehman College, City University of New York, 250 Bedford Park Boulevard West, Bronx, NY, 10468) AND R. E. LOEB (Department of Biology, DuBois Campus, The Pennsylvania State University, DuBois, PA 15801). Historical ecology of Inwood Hill Park, Manhattan, New York. J. Torrey Bot. Soc. 135: 281–293. 2008.—Colonial period agriculture and vegetation clearance practices during the American Revolution destroyed the pre-Columbian forest of Inwood Hill Park, Manhattan, New York. Native species plantings in early estates spread to form the park's forest, and post-1850 estates introduced non-native species. Parks Department management practices from 1930 to 1985 reduced forest cover, filled wetlands, and caused the number of non-native and invasive shrub and vine species to nearly triple. *Liriodendron tulipifera* L. and *Lindera benzoin* (L.) Blume have been identified as the dominant species in the Valley Forest since 1930. *Prunus serotina* Ehrh., *Sassafras albidum* (Nutt.) Nees. and *Viburnum acerifolium* L. have continued to form fire-adapted stands in the East Ridge and Slopes Forest. In 2003, the highest density for *Prunus serotina* occurred in the repeatedly disturbed stands of the West Ridge and Slopes Forest. *Alliaria petiolata* (Bieb.) Cavara & Grande, an invasive species, was present only in the Ridge Tops Forest in 1985 and has become the dominant non-native herb species in all of the forests. The invasive shrub and vine species *Celastrus orbiculatus* Thunb., *Lonicera japonica* Thunb., *L. maackii* (Rupr.) Maxim., and *Rosa multiflora* Thunb. have become the dominants in the cleared areas of the Ridge Tops Forest. Sixteen woody invasive species are displacing native species across the park. Soil eroding into the salt marsh has caused the dominance of upland disturbance species. Replacing invasive species with native species has had mixed success because of limited funding to maintain plantings in the dry, impoverished soils of the park and areas treated with herbicides. Assessment methods for the restoration projects and for monitoring long-term species changes are recommended.

Key words: comparative floras, forest restoration, historical ecology, invasive plants, urban forests, urban park vegetation.

Inwood Hill Park contains one of the very few forests of large growth mature trees found in a densely populated city. New York City's urban park forests are complex ecosystems formed by the interaction of often destructive anthropogenic activities and natural processes. Documenting long-term forest changes in urban parks provides an opportunity to analyze the effects of intense, repeated human disturbances on woodlands. Moreover, maintaining an urban park forest with native species requires research on long-term species changes to protect the forest from invasive species (Loeb 1989).

Assessment of species introductions and losses can be made by comparing data from historical records. However, an analysis can be done only with the data from the time periods that are available, which does not allow for examination of forest development as a continuous process (Loeb 1998). Within the limitations of existing records, the objective for this historical ecology of Inwood Hill Park is to document the changes in the forests and wetland from the time of European contact to the present. A second objective is to describe species changes in the forest and wetland communities over the past 80 years. As an integral component of both objectives, this study reports the apparent effects of the New York City Parks Department management, especially in regard to invasive species.

Materials and Methods. The 70 ha Inwood Hill Park is in New York County, NY (40° 52′ 15″ N and 74° 55′ 45″ W). The park borders are Dyckman Street on the south, the Hudson

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River on the west, Harlem Ship Canal (formerly Spuyten Duyvil) on the north, and Payson and Seaman Avenues on the east (Fig. 1). Manhattan schist forms the ridges while Inwood marble underlies the central valley (Schuberth 1968). The soils are deeper in the valley and thinner on the ridge tops and slopes. Soil erosion is an ongoing problem, particularly on the steep slopes. Previous analysis of soil samples indicated that domesticated animal wastes may be enriching the nitrogen levels (Loeb 1986), but nitrogen cycling processes in urban soils may be modified by trampling, atmospheric ozone, and hydrocarbons in the soil (White and McDonnell 1988).

Historical records in libraries and archives were searched for information to assess long-term vegetation change. Institutions visited were: Bronx County Historical Society, Lehman College Special Collections, New York Botanical Gardens, New York City Archives, New York City Parks Department, New York Historical Society, and New York Public Library. The documents search focused on identifying reports of species presence and vegetation disturbances.

Examining vegetation in an urban park requires researchers to decide whether to study sites that have been modified as part of parks department managed vegetation restoration projects. Quadrat placement was guided by an interest in comparing the results with a previous research project (Loeb 1986). Sample site selection criteria included: 1) little evidence of disturbance by park users and 2) no vegetation disturbance by New York City Department of Parks and Recreation Natural Resources Group (NRG) restoration efforts. The number of quadrats placed in the forest communities was limited by extensive herbicidal treatment for invasive species. In late fall 2001 through April 2003, woody plants were surveyed in 10×10 m quadrats as follows: 11 in the Valley Forest, 8 in the East Ridge and Slopes Forest, 8 in the East and West Ridge Tops Forest, and 18 in the West Ridge and Slopes Forest (Fig. 1). The ground layer was surveyed with a 2×4 m quadrat that was nested in each 10×10 m quadrat at the corner which was marked with the permanent stake. The salt marsh was measured with five 2×4 m quadrats from spring 2003 to fall 2003. Nomenclature follows Gleason and Cronquist (1991). Voucher specimens were not collected because taking plant materials from New York City parks is prohibited. A Vernier caliper was used to measure the diameter at breast height (1.37 m; dbh) of woody stems $\geq$ 2.0 cm to $\leq$ 3.0 cm, and a diameter tape was used to measure woody stems $>$ 3.0 cm. The four arboreal size classes were seedlings ($<$ 2.0 cm dbh), sapling (2.0–$<$ 10 cm dbh), subcanopy trees (10–$<$ 30 cm dbh), and canopy trees ($\geq$ 30 cm dbh).

The previous study of Inwood Hill Park occurred during April and May 1985. The vegetation was sampled with a transect from the playgrounds on the east to the rink on the west side of the park. The transect area was not a forest restoration site and showed little evidence of park user disturbance. Five 2×4 m quadrats were placed in the salt marsh. The seven plant communities identified in 1985 were Salt Marsh, Valley Forest, Slope Forest, North-facing Forest, Successional Forest, Successional Field, and Lawn (Loeb 1986). Salt Marsh and Valley Forest communities also were identified in the current research. The quadrats in the Slope Forest and the North-facing Forest identified in 1985 were located in the areas sampled for the East Ridge and Slopes Forest and West Ridge and Slopes Forest of the current research, respectively. The Ridge Tops Forest contains the location of the 1985 Successional Forest quadrats. To permit quantitative comparison with the 1985 results, the sampling results for the current study were converted to density per ha (dph).

The number of plantings for restoration projects came from the NRG web site. Observations concerning the effects of NRG forest restoration projects were included in the discussion of the forest and wetland communities.

Results. HISTORICAL ECOLOGY. *Pre-European Contact through 1900.* Native Americans, specifically the Manhattans, lived in the caves of Inwood Hill well before European contact (Fig. 2). A village excavated at Seaman Avenue and Isham Street was interpreted to have horticulture, including *Zea mays* L. fields, as the primary subsistence base (Bolton 1924). However, archaeologists disagree as to whether Native American cultivation of *Zea mays* occurred before the arrival of Europeans. Fossil pollen evidence of prehistoric *Zea mays* has been found in Mishow Marsh,

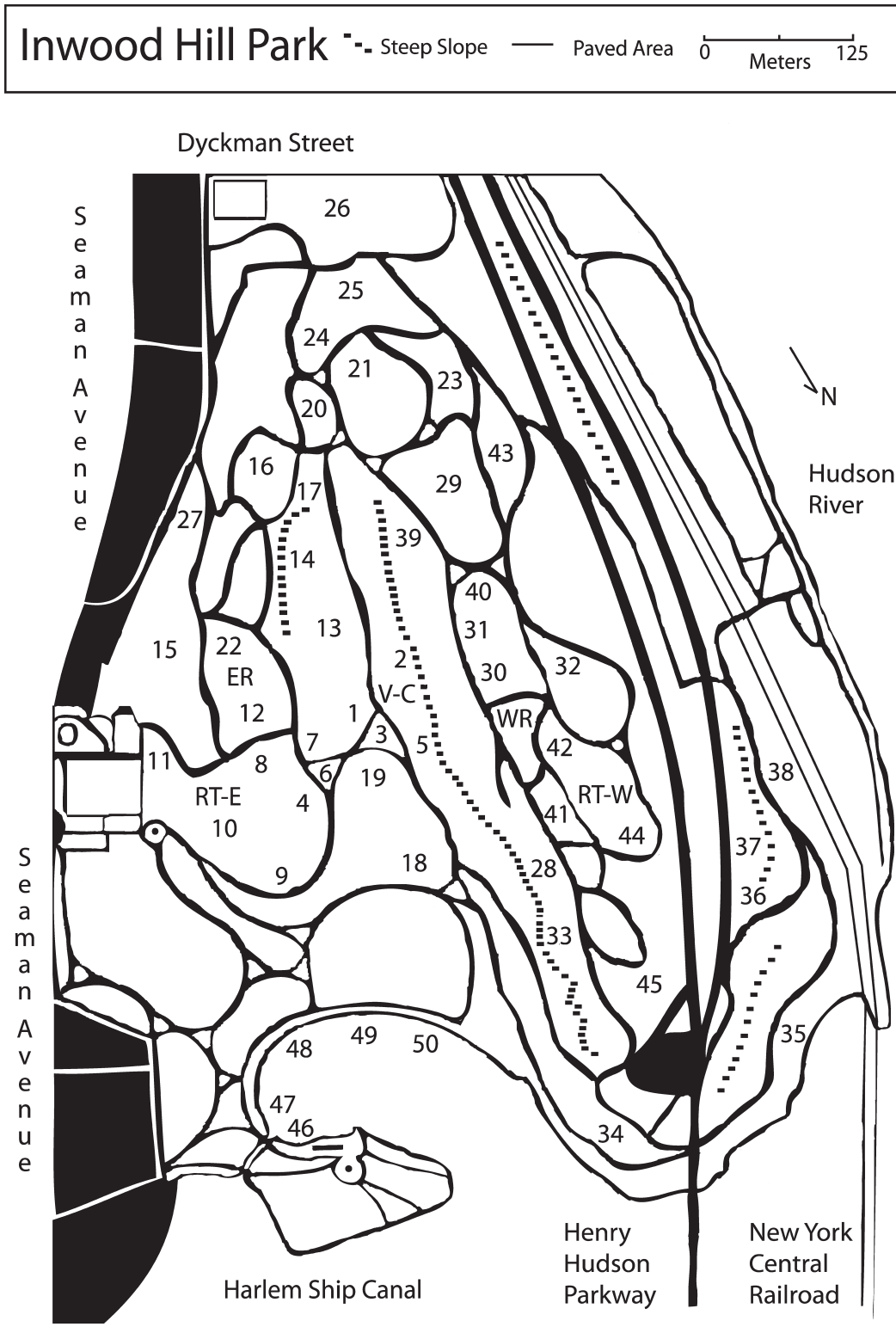

FIG. 1. Map of Inwood Hill Park showing location of quadrats: Valley (1–3, 5, 6, 13, 14, 17–19); East Ridge and Slopes (4, 8, 9, 11, 12, 16, 22, 27); Ridge Tops (10, 15, 20, 21, 32, 42, 44, 45); West Ridge and Slopes (23–25, 26, 28–31, 33–43); and Salt Marsh (46–50).

FIG. 2. Map of Inwood Hill in 1932 showing Native American and historic sites (based upon Bolton 1932).

Hunter Island, Bronx County, NY. Although Spuyten Duyvil marshes were similar to Mishow Marsh, *Zea mays* cultivation would not have succeeded because the soils derived from Inwood Marble are not optimal for *Zea mays* growth (Loeb 1998).

Pre-European settlement witness tree information for Inwood is not available but

surveyors in the nearby east Bronx noted *Betula* spp. L., *Carya* spp. Nutt., *Castanea dentata* (Marsh.) Borkh., *Liriodendron tulipifera* L., *Pinus* spp. L., *Quercus* spp. L., *Q. alba* L, *Q. rubra* L., *Q. velutina* Lam., *Robinia pseudoacacia* L., and *Ulmus* spp. L. (Loeb 1987). The Dutch colonial period landowner Jan Dyckman built and occupied a farm with *Pyrus malus* L. orchards in Inwood soon after 1644 (Bolton 1924) and until 1776.

Early in the American Revolution, Cock Hill Fort at the top of Inwood Hill was taken from the American colonial forces. From 1776 to 1783, Hessian troops were housed in huts along what is now Payson Avenue (Fig. 2). Both the British and American forces practiced vegetation clearing, which caused the loss of the forests covering Manhattan and The Bronx (Loeb 1989), including Dyckman's *Pyrus malus* orchards (Bolton 1924).

Soon after the American Revolution, the estates built in Inwood were predominantly planted with native species because American landscape plant nurseries supplied species native to the United States, except for non-native fruit trees and a few long-cultivated alien species (Adams 2004, Fry 1996, Schrack 1936). For example, in the middle Atlantic region during the period 1770 to 1790, the nurseries commonly offered *Abies balsamea* (L.) Mill., *Acer rubrum* L., *A. saccharum* Marsh, *Aesculus pavia* L., *Betula lenta* L., *Calycanthus floridus* L., *Catalpa* spp. Scop., *Cornus florida* L., *Corylus americana* Marsh., *Juniperus virginana* L., *Lindera benzoin* (L.) Blume, *Liriodendron tulipifera*, *Myrica pensylvanica* Loisel, *Philadelphus coronarius* L., *Picea mariana* (Mill.) BSP., *Pinus strobus* L., *Prunus caroliniana* (Mill.) Ait., *P. glandulosa* Thunb., *Quercus alba*, *Q. coccinea* Muenchh., *Q. velutina*, *Robinia pseudoacacia*, *Sassafras albidum* (Nutt.) Nees, *Tsuga canadensis* (L.) Carriere, and *Viburnum opulus* L. (Adams 2004). Later estates introduced the non-native species available through the nurseries in the latter half of the nineteenth century (Bolton 1924, Clayton 1992).

The earliest record of Inwood's flora was made by W. W. Denslow in September 1867. Denslow reported the presence of the Orchidaceae species: *Corallorhiza maculata* (Raf.) Raf., *C. odontorhiza* (Willd.) Nutt., *Habenaria flava* (L.) R. Br., *H. lacera* (Michx.) Lodd., *Liparis liliifolia* (L.) Rich., *L. loeselii* (L.) Rich., *Orchis spectabilis* L., *Spiranthes lacera* (Raf.) Raf., *S. cernua* (L.) Rich., *S. lucida* (H. Eaton) Ames., and *Tipularia discolor* (Pursh) Nutt. Almost all of the Orchidaceae species had disappeared by the turn of the twentieth century (Denslow 1924, 1927). Only *Epipactis helleborine* (L.) Crantz., a native of Europe, is found in the park today. At the west ridge's northern base there was a stand of *Caulophyllum thalictroides* (L.) Michx. (Anonymous 1936).

1900 to 2007. Although the legal proceedings to establish Inwood Hill Park originated in 1903, title became vested in New York City by a Supreme Court order issued April 21, 1925 (Anonymous 1925a, 1925b). The condemnation proceedings of 1903 caused many estates to be abandoned years before the land was purchased for the park. Little was preserved, especially no botanical descriptions, from these relicts of architectural grandeur and elegant gardens (Anonymous 1926).

The Harlem Ship Canal was completed in 1938 after cutting through rock in a freshwater marsh called Dyckman's Meadows (Hermalyn 1993). Most of the wetland vegetation in Spuyten Duyvil was destroyed, including a stand of *Caulophyllum thalictroides* (L.) Michx. at the west ridge's northern base (Anonymous 1936). Parks Commissioner Robert Moses directed the filling of the Inwood Hill Park marsh with debris from subway excavations to form six baseball fields. After the hurricane of 1938 toppled the oldest *Liriodendron tulipifera* tree in the park (Dawson 1938), the remaining marsh was filled for a soccer field.

In 1935, Robert Moses decided to build the Henry Hudson Parkway straight through the west ridge of Inwood Hill Park (Caro 1974). To create the highway right-of-way, Moses ordered the felling of a 160 year old *Liriodendron tulipifera* tree and hundreds of other old *Liriodendron tulipifera* and *Quercus* spp. trees as well as the removal of shrubs and ground layer plants (Anonymous 1935). Under Robert Moses' direction, the Parks Department regularly cleared the ground layer of New York City park forests and planted new species of trees and shrubs (Loeb 1998).

Four reports noting species present in Inwood Hill Park were published soon after the Parks Department became responsible for the park's vegetation. In 1930, Arthur Graves compiled a list of 70 woody taxa growing without cultivation including 20 non-native

species (Graves 1930). The Orchid species which Denslow had recorded in 1867 were extirpated, and *Vaccinium corymbosum* L. was no longer growing naturally in the park. The invasive shrub *Rubus phoenicolasius* Maxim. was reported as ''rare'' in 1930, but today is forming dense stands along Dyckman Street. The 1930 Torrey Botanical Club Inwood Hill Park field trip report noted the non-native trees *Broussonetia papryifera* (L.) Vent., *Morus alba* L., *Paulownia tomentosa* (Thunb.) Steudel., and *Sophora japonica* L. The native shrubs *Corylus americana* and *Sambucus racemosa* L. were reported in 1930 (Anonymous 1930) but were not found in the park during 2001–2003. The 1936 Torrey field trip report indicated that the *Liriodendron tulipifera* trees in the valley and stands of *Quercus* spp. on the hillsides appeared unaffected by the highway construction (Anonymous 1936). In 1937, Small listed 76 species of native trees and shrubs growing naturally, and 33 species of trees and shrubs introduced and planted (Small 1937). Collation of the species observed by Graves, Small, and the field trip groups of the Torrey Botanical Club (Anonymous 1930, Graves 1930, Anonymous 1936, Small 1937) indicates there were a total of 83 tree species, including 32 non-native species in the 1930s. Among the 34 shrubs, there were eight non-native species. Of the seven vines, three were non-native species. Among the species identified in the 1930s, there were 16 trees, five shrubs, and three vines considered to be invasive species in the middle Atlantic region (United States National Parks Service Alien Plant Working Group 2007).

From 1960 through the early 1980s, progressively deepening budget cuts caused the vegetation in New York City parks to be virtually abandoned. Natural reproduction in the park's forests was diminished as regular cutting before 1960 resulted in the virtual loss of ground layer plants and seed bank exhaustion. Human disturbances killed established plantings of non-native shrubs and trees. Soil compaction increased water run-off, which caused expanding swaths of bare rock and eroded soils. Dead and decaying trees, damage to exposed roots, fires, vandalism, and uncontrolled park use created openings for invasive species (Friends of Inwood Hill Park 1986, Loeb 1986).

The 1985 park study indicated there were 21 arboreal species and 35 species of herbs and shrubs (Loeb 1986). A New York City Department of Parks topographic map of the park (New York City Department of Parks and Recreation 1936) which recorded the canopy trees in 1936 was used to confirm the similarity between the forest canopy composition in 1936 and 1985 (Loeb 1986). The loss of *Castanea dentata* in 1908 to the Chestnut Blight undoubtedly contributed to the open character of the forests in 1936. However, the later loss of *Ulmus americana* L. to Dutch Elm Disease was not important because *Ulmus americana* was infrequently noted on the 1936 map.

In 1985, slopes were reconstructed with timber barrier to reduce erosion and replanted; and the drainage system was cleared in the park (Friends of Inwood Hill Park 1986). During 1987 and 1988, 500 trees and shrubs were planted (New York City Department of Parks and Recreation 1990). By 1994, over 3,000 native trees and shrubs had been planted and efforts were underway to restore parts of the forest burned by vandals (Anderson 1994). The plantings from 1994 through 2006 included 36,928 native trees and shrubs and 34,006 native herbaceous plants (New York City Department of Parks and Recreation Natural Resources Group 2007).

During 2001 to 2003, a total of 77 tree species, including 36 non-native species were identified. Among the 52 shrubs, 23 were non-native species. Of the 28 vines, eight were non-native species (Fitzgerald and Cooney 2003). There are 14 trees (eight non-native species) and six shrubs (one non-native) not found in 2001–2003 that were listed for 1930–1937 (Anonymous 1930, Graves 1930, Anonymous 1936, Small 1937). Among the 65 species in the 2001–2003 list but not reported in 1930–1937, there are 11 trees (six non-natives), 33 shrubs (15 non-natives), and 21 vine species (11 non-natives).

Although five invasive species were lost from the 1930s to 2001, 16 invasive species became established. In total, there were 13 tree, 14 shrub, and eight vine invasive species identified in 2001–2003. Based on observations from 2001 to 2007, only the populations of *Aesculus hippocastanum* L., *Ailanthus altissima*, *Ampelopsis brevipedunculata* (Maxim.) Trautv., *Celastrus orbiculatus* Thunb., *Hedera helix* L., *Ligustrum vulgare* L., *Lonicera japonica* Thunb., *L. maackii* (Rupr.) Maxim., *L. tatarica* L., *Morus alba*, *Robinia pseudoa-*

Table 1. Density per ha of subcanopy (10–30 cm dbh) and canopy (> 30 cm dbh) tree species found at least two forest types: Valley Forest, East Ridge and Slopes Forest, East and West Ridge Tops Forests, and West Ridge and Slopes Forests.

Species	Valley Forest		East Ridge		Ridge Tops		West Ridge	
	10–30	> 30	10–30	> 30	10–30	> 30	10–30	> 30
Acer rubrum.	0	0	13	0	0	0	11	6
Acer saccharum	9	18	0	13	0	0	0	0
Aesculus hippocastanum	0	0	0	0	13	13	0	22
Betula lenta	0	9	0	0	13	0	6	0
Carya cordiformis	9	18	0	0	13	0	22	17
Carya tomentosa	0	0	13	0	0	0	11	0
Celtis occidentalis	9	0	13	0	0	0	17	6
Fraxinus americana	9	18	0	13	50	0	0	0
Liriodendron tulipifera	0	173	13	0	13	25	11	11
Maclura pomifera	0	0	0	0	13	0	6	0
Morus alba	9	0	0	0	0	0	6	0
Paulownia tomentosa	0	9	0	0	13	13	0	0
Pinus nigra	0	0	0	13	0	0	0	6
Prunus serotina	9	9	13	0	63	0	17	0
Quercus alba	9	9	38	38	0	13	6	6
Quercus coccinea	0	0	0	13	50	25	6	0
Quercus prinus	0	0	0	88	13	13	6	28
Quercus rubra	9	64	25	163	125	250	67	233
Quercus velutina	0	0	0	25	0	50	17	44
Sassafras albidum	0	0	13	0	0	0	17	6
Ulmus americana	0	9	0	0	0	0	6	0

cacia, *Rhodotypos scandens* (Thunb.) Makino., *Rosa multiflora* Thunb., *Rubus phoenicolasius*, *Solanum dulcamara* L., and *Wisteria sinensis* (Sims) Sweet are expanding.

Modern Vegetation Communities. The woody plants found in the 45 forest quadrats comprised 77 species in 54 genera and 24 families. Dividing by growth form, 44 tree, 26 shrub, and seven vine species existed. The tree species common to all four forests (Tables 1 and 2) were *Acer rubrum*, *A. saccharum*, *Carya cordiformis*, *Celtis occidentalis*, *Cornus florida*, *Fraxinus americana*, *Liriodendron tulipifera*, *Morus alba*, *Prunus serotina*, *Quercus alba*, *Q. rubra*, and *Sassafras albidum*. *Prunus serotina* for the seedling and sapling size classes (Table 2) and *Quercus rubra* for the subcanopy and canopy tree size classes had the greatest dph in all of the forests except the Valley Forest (Table 1). Total dph for seedlings (< 2 cm) and saplings (2–10 cm) of just the species in Table 2 was more than triple the total dph in 1985 for all species represented in the smaller size class (0–20 cm).

The shrubs *Rosa multiflora*, *Viburnum acerifolium*, *V. dentatum*, and vine *Celastrus orbiculatus* were present in all of the forests. The highest dph for all of the shrubs occurred for *Lindera benzoin* in the Valley Forest (Table 3). Total dph for the shrub and vine species in Table 3 is nearly twice the total dph for all shrub and vine species identified in 1985.

There were 96 herbaceous and graminoid species representing 76 genera and 41 families. *Alliaria petiolata*, *Aster divaricatus*, *Circaea lutetiana*, *Eupatorium rugosum*, *Parthenocissus quinquefolia*, *Polygonum cespitosum*, *P. virginianum*, *Smilacina racemosa*, and *Solidago caesia* were present in all four forest communities. The total dph for the 41 species identified in two or more of the forest communities (Table 4) is more than three times the total dph for all the herbaceous and graminoid species reported in the 1985 forest communities.

The salt marsh community sample contained 64 species from 58 genera and encompassing 27 families. Of the 13 species found in more than half of the quadrats (Table 5), three were halophytes and the remaining 10 are commonly found in disturbed environments of the park.

Discussion. Historical Ecology. The ecological history of Pelham Bay (Loeb 1998), Seton Falls (Loeb 1989), Van Cortlandt (Profous and Loeb 1984), and Wave Hill (Yost et al. 1991) parks in the Bronx have many commonalities with Inwood Hill Park:

Table 2. Density per ha of seedlings (< 2 cm dbh) and saplings (2–10 cm dbh) for tree species found at least two forest types: Valley Forest, East Ridge and Slopes Forest, East and West Ridge Tops Forests, and West Ridge and Slopes Forests.

	Valley Forest		East Ridge		Ridge Tops		West Ridge	
Species	< 2	2–10	< 2	2–10	< 2	2–10	< 2	2–10
Acer platanoides	36	0	213	13	0	0	100	22
Acer pseudoplatanus	0	0	100	0	0	0	75	33
Acer rubrum	191	118	1238	575	0	13	338	117
Acer saccharum	73	55	238	113	100	125	63	128
Aesculus hippocastanum	18	0	50	0	0	0	188	39
Ailanthus altissima	55	9	113	38	0	50	363	211
Betula lenta	9	0	50	113	213	163	200	106
Carya cordiformis	291	73	213	25	875	463	788	217
Carya tomentosa	55	0	25	13	0	50	113	28
Catalpa bignonioides	0	0	0	25	0	25	0	0
Celtis occidentalis	64	100	88	13	0	25	113	50
Cercis canadensis	0	9	0	0	0	0	138	0
Cornus florida	9	9	13	38	0	13	0	22
Crataegus spp.	0	9	0	0	0	0	13	0
Fagus grandifolia	18	0	38	50	0	0	75	44
Fraxinus americana	145	36	163	63	925	538	775	228
Liriodendron tulipifera	100	9	138	0	0	0	125	33
Morus alba	0	18	100	63	0	38	113	17
Prunus serotina	136	36	1800	375	998	938	2425	922
Pyrus baccata	0	0	0	0	0	25	0	17
Quercus alba	0	0	138	13	125	0	175	22
Quercus coccinea	0	0	50	0	50	0	0	0
Quercus prinus	18	0	125	13	138	13	100	0
Quercus rubra	100	9	388	13	488	0	500	67
Quercus velutina	0	0	75	0	38	0	175	11
Sassafras albidum	64	18	838	200	763	500	525	211

vegetation destruction during the American Revolution, estate development in the nineteenth century, landscape clearing and replanting after park formation, roadway construction isolating a section of park, cessation of landscape maintenance from 1960 to 1984, and recent implementation of vegetation restoration projects. A comparison of the Pelham Bay Park flora in 1946–1947 to 1994–1998 indicates a loss of 40 native species and a gain of 114 non-native species, excluding an increase of 47 planted species (DeCandido and Lamont 2004).

Older parks outside of the New York City area also have ecological histories similar to Inwood Hill Park. Researchers examining Thorden Park, Syracuse, New York, (Zipperer and Zipperer 1992) concluded that the forest had an over-mature even-age structure and that there was a need for replacement of plantings with native species, including *Acer* spp., *Fraxinus* spp., *Populus* spp., and *Quercus* spp. The study of Franklin Park, Columbus, Ohio (Quigley 2002) showed that very few of the newly planted trees were growing vigorously and that soil fertility may be less of a limiting factor than poor soil structure due to compaction. Soil compaction contributes to the losses of new plantings in Inwood Hill Park, since rainfall too often turns into runoff that precludes the water from entering the forest soils. The restoration of the woodland adjacent to the Washington National Cathedral involved placement of technology to enhance water infiltration into the soil and reduce down slope movement of water within the soil (McIntyre 2006).

New York City Parks Department plantings and maintenance practices caused the number of non-native and invasive shrub and vine species to nearly triple from 1937 to 2003. In sharp contrast with the past, Inwood Hill Park has been a showcase for the Parks Department's efforts in erosion control and natives species restoration since 1985 (New York Department of Parks and Recreation Natural Resources Group 2007). Many of these projects have been financed by grants which have a limited funding period that does not support a suitable long-term maintenance program to assure the survival of plantings. Another maintenance concern arose when

Table 3. Density per ha of shrub and vine species found at least two forest types: Valley-Clove forest (Valley), East Ridge and Slopes forest (East), East and West Ridge Tops forests (Ridge), and West Ridge and Slopes forests (West).

Species	Forest			
	Valley	East	Ridge	West
Shrubs				
Hamamelis virginiana	91	363	0	72
Lindera benzoin	5200	363	0	883
Lonicera maackii	0	113	413	1261
Rhus typhina	0	0	125	111
Rosa multiflora	364	575	238	450
Rubus allegheniensis	0	38	0	117
Rubus occidentalis	0	0	113	211
Rubus phoenicolasius	0	469	469	972
Viburnum acerifolium	109	4600	875	933
Viburnum dentatum	218	100	575	628
Viburnum prunifolium	91	0	0	100
Vines				
Ampelopsis brevipedunculata	0	75	50	144
Celastrus orbiculatus	36	100	788	589
Lonicera japonica	0	938	3438	5000
Toxicodendron radicans	0	0	125	183
Vitis labrusca	18	100	0	22
Wisteria sinensis	0	0	50	6

large areas of the west ridge were left unattended for nearly three years after treatment with herbicides to reduce invasive species was completed. The invasive species *Ailanthus altissima*, *Alliaria petiolata*, *Artemisia vulgaris*, *Celastrus orbiculatus*, *Lonicera japonica*, *L. maackii*, *Microstegium vimineum*, and *Rubus phoenicolasius* colonized the herbicide treated areas as well as sites where plantings have died because of insufficient watering.

Forest and Wetland Communities. Graves (1930) observed that the Valley Forest dominants were *Liriodendron tulipifera*, *Acer saccharum*, and *Quercus rubra*. *Liriodendron tulipifera* and *Acer saccharum* were the dominants in 1985 (Loeb 1986). Although *Liriodendron tulipifera* remains the first dominant species, *Quercus rubra* has replaced *Acer saccharum* as the second most important tree species. *Prunus serotina* was not a canopy species in any of the park's forests in 1985, but has entered the Valley Forest canopy. There are very few sub-canopy trees in the Valley Forest, the situation which also existed 20 years ago (Loeb 1986). NRG has been replanting the sub-canopy species *Cornus florida* but few have survived due to insufficient watering or the anthracnose virus. Some *Liriodendron tulipifera* saplings have not survived because the root balls were not placed deeply enough in the soils. The dense shrub layer of *Lindera benzoin* in the valley that Graves (1930) described and that was documented as being dominant in 1985 is still present. However, *Rosa multiflora* has started to invade parts of the valley, and *Rubus phoenicolasius*, which was found in 1985 (Loeb 1986), has become a problem species. The herbaceous species with the greatest dph was the invasive *Alliaria petiolata*, followed by the native *Impatiens capensis*; however, neither species was reported for the Valley Forest in 1985 (Loeb 1986). Also, *Aegopodium podagraria* has been spreading rapidly in the Valley Forest, particularly at the foot of the west ridge. Koreans collect *A. podagraria* in the park annually, which has facilitated the spread of *A. podagraria*, displaced native species, and allowed other invasive species to expand into the area.

Acer rubrum dph for saplings and subcanopy trees was greatest in the East Ridge and Slopes Forest. NRG established a planting program 15 years ago to replace the invasive species *Acer platanoides* and *A. pseudoplatanus* with natives, such as *Acer rubrum*. Vandalism and fires have served to stimulate the growth of many stands of *Prunus serotina* and *Sassafras albidum*. In 1985, *Sassafras albidum* stands were near only the tennis courts on the west-facing slope of the east ridge (Loeb 1986).

Table 4. Density per ha of herbaceous species found at least two forest types: Valley-Clove forest (Valley), East Ridge and Slopes forest (East), East and West Ridge Tops forests (Ridge), and West Ridge and Slopes forests (West).

Species	Forest			
	Valley	East	Ridge	West
Alliaria petiolata	15114	3438	5000	10694
Allium vineale	795	1094	0	208
Artemisia vulgaris	0	0	1250	3333
Aster cordifolius	0	781	2344	347
Aster divaricatus	5000	14063	12500	12153
Carex laxifolia	455	313	313	694
Carex pensylvanica	0	0	156	208
Carex vulpinoidea	0	156	0	278
Circaea lutetiana	7727	625	1406	2639
Commelina communis	341	0	781	1528
Dactylis glomerata	0	1094	1250	0
Danthonia spicata	0	1250	6250	0
Desmodium paniculatum	0	0	938	764
Erigeron philadelphicus	114	0	156	0
Eupatorium purpureum	0	0	469	764
Eupatorium rugosum	795	2500	1563	1597
Geum canadense	795	0	625	417
Helianthus divaricatus	682	0	938	1319
Hemerocallis fulva	0	0	1094	2500
Hieracium paniculatum	0	0	625	278
Impatiens capensis	13409	0	0	1181
Juncus tenuis	0	3594	0	694
Luzula multiflora	0	1250	781	0
Oxalis stricta	1364	0	0	208
Parthenocissus quinquefolia	1932	2344	5938	8264
Pilea pumila	227	0	0	208
Plantago lancelota	0	469	313	0
Plantago major	0	625	469	0
Poa pratensis	0	0	1094	208
Polygonatum biflorum	0	2813	1094	1319
Polygonum cespitosum	1591	625	938	903
Polygonum virginianum	7727	313	1875	1181
Rubus flagellaris	341	1875	0	1042
Smilacina racemosa	4545	1563	3281	1597
Smilax rotundifolia	0	469	0	69
Solidago bicolor	0	0	1563	972
Solidago caesia	1023	1250	938	2431
Solidago juncea	0	313	3594	1111
Viola sororia	3409	0	0	1250

Viburnum acerifolium is the dominant native shrub and *Rosa multiflora* is the most important invasive shrub. Although Graves (1930) reported that *Vaccinium corymbosum* was extirpated, the species was found on the east ridge. The NRG planted the native species *Vaccinium angustifolium* Aiton, which has acclimated well in the acidic soils of the ridges (Loeb 1986). Among herbs, the native species with the highest density was *Aster divaricatus*, and *Alliaria petiolata* was the non-native species with the greatest density.

In 1985, *Liriodendron tulipifera*, *Quercus alba*, and *Q. rubra* had equal densities in the larger size class of the Ridge Tops Forest. Although *Prunus serotina* was not represented in the canopy, it was a dominant in the smaller size class (Loeb 1986). The sampling in 2001–2003 revealed *Quercus rubra* had 10 times the density of *Liriodendron tulipifera* and nearly 20 times the density of *Quercus alba*. Among shrubs and vines, *Viburnum acerifolium* and *Celastrus orbiculatus* were the dominant native and non-native species, respectively. In contrast, the 1985 research did not find these two species in this forest. Denuded areas have rapidly growing populations of *Celastrus orbiculatus*, *Lonicera japonica*, *L. maackii*, *and Rosa multiflora*. The native and non-native herbaceous species with the greatest density are *Aster divaricatus* and *Alliaria petiolata*, respectively. In 1985, the density

Table 5. Density per ha of species present in more than half of the salt marsh quadrats.

Species	Density
Amorpha fruticosa	1250
Calystegia sepium	2750
Carex vulpinoidea	1750
Celastrus orbiculatus	3500
Dactylis glomerata	7750
Iva frutescens	4750
Plantago major	4750
Rumex crispus	5750
Solidago sempervirens	8250
Spartina cynosuroides	4500
Taraxacum officinale	5250
Trifolium pratense	8000
Trifolium repens	5000

for the native species *Impatiens capensis* far exceeded all of the *Aster* spp. L. The Ridge Tops Forest sample had the only *Alliaria petiolata* in the park forests sampled in 1985 and now *Alliaria petiolata* is the dominant herbaceous species in all of the forests.

Liriodendron tulipifera, *Quercus prinus*, and *Q. rubra* were the dominants in the North-facing Forest of the west ridge in 1985. *Acer rubrum* and *Prunus serotina* also were present with the latter species having the highest density in the smaller size class (Loeb 1986). In the West Ridge and Slopes Forest, *Prunus serotina* had the greatest density, but *Quercus rubra*, followed by *Q. prinus* and *Q. velutina*, had the greatest density in the canopy size class, and *Robinia pseudoacacia* had the highest density in the subcanopy tree size class. The dominant shrubs were the invasives *Lonicera maackii* and *Rosa multiflora*, and *Aster divaricatus* and *Alliaria petiolata* were the herbs with the largest density. The ornamentals *Fagus sylvatica*, *Lonicera japonica*, *L. maackii*, *L. morrowii*, and *Polygonum cuspidatum* appear to be remnants of former estates. A small population of *Tsuga canadensis* in the west ridge is being encroached upon by *Robinia pseudoacacia* and *Maclura pomifera*. The NRG is clearing this stand and the southwestern portion of the park, which is dominated by *Robinia pseudoacacia*.

In 1986, just four species were found in the salt marsh: *Ammophila breviligulata* Fern., *Iva frutescens*, *Phragmities australis* (Cav.) Trin., and *Spartina alterniflora* Loisel. Only *Iva frutescens* was found in the five plots examined for this research at half the density reported previously (Loeb 1986). Although there were new halophytes found in the current study, the vast majority of the species reported were typical of disturbed non-wetland areas. Erosion has filled the wetland to the point that *Celastrus orbiculatus* is evident throughout the marsh because lateral roots have twined around the rocks that ring the perimeter of the marsh and sent up many stems. A small flooded area of the lawn bordering the salt marsh contains the halophyte *Distichlis spicata* (L.) Greene.

Conclusions. Inwood Hill Park has a colonial period history of vegetation losses culminating with the vegetation clearance practices of the American Revolution that denuded the landscape. Native species reintroductions began when wealthy landowners of the Inwood area returned after the Revolution to build estates landscaped with native species, which became the dominant species in the forests of the ridges and valley of the park. Later estates introduced many non-native species, as did Parks Department plantings. Wetland vegetation was lost when the Harlem Ship Canal was constructed and when recreational fields were created with subway excavation debris. Construction of the Henry Hudson Parkway caused extensive losses in the arboreal and shrub layers. Past Parks Department planting and mowing practices decimated the ground layer of the forest. Since the implementation of species restoration as the vegetation maintenance practice in 1985, the dph of herbaceous (including graminoids), shrub, and arboreal species in the ground layer has more than doubled.

The forest and wetland communities of Inwood Hill Park are more diverse and have a greater structural variation than revealed by previous research. However, canopy trees species losses continue; instead of being replaced by other native species capable of forming a closed forest, alien species are spreading in canopy gaps. Over the past 80 years, the number of non-native and invasive shrub and vine species has nearly tripled, threatening the loss of some native species. Most notably, the invasive shrubs and vines *Celastrus orbiculatus*, *Lonicera japonica*, *L. maackii*, *Rosa multiflora*, and *Rubus phoenicolasius* are spreading across the park. In less than 20 years, the invasive species *Alliaria petiolata* has expanded from one forest to become the dominant non-native herbaceous species throughout all of the park's forests.

Wetland species are being displaced by invasive upland species as erosion fills in the one remaining salt marsh. The Parks Department is conducting restoration projects to reestablish native species in barren areas and in areas dominated by invasive species.

Inwood Hill Park provides opportunities for further research into vegetation dynamics and ecosystem management under the stress of urban conditions. As a complement to long-term ecological research on the forests, regular monitoring of the park's many plantings to assess progress in new herb, shrub, and arboreal layers formation is essential to be certain that the forest will survive. A grid system for the park should be created to show where restoration plantings have occurred, enabling comparisons within sites and among sites that have and have not been planted to determine changes over time. The past and future use of herbicides should be monitored to determine effectiveness over time in controlling invasive species. Experimentation with various treatments to enhance soil conditions should be integrated into restoration projects. Comparisons of different methods to maintain new plantings are vital to guide restoration practice. Although the aforementioned recommendations for future work are focused on the forests, they could also apply to the salt marsh community, which also should be an important area for restoration projects.

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