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Tracking Changes to Urban Trees over 100 Years in Ithaca, NY, USA

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Abstract. Municipally managed urban trees provide environmental, social, and economic benefits. Continued provision of these benefits depends on the health and sustainability of these trees, which depends in turn on tree managers having the type of information usually found in a tree inventory. The city of Ithaca, New York, USA possesses 7 inventories of its street and park trees dating back to 1902. This paper uses the data contained in these inventories to assess the health and sustainability of the city's street and park tree populations. Attention is given to the structure of these populations with emphasis placed on species and genera diversity and DBH size class distributions. Prior to 1987, the city's municipal tree population was dominated by a few species, such as Norway maple (*Acer platanoides*), and genera such as maples (*Acer*) and elms (*Ulmus*), and the DBH size class distribution was skewed unsustainably towards older trees. From 1987 onwards, new plantings have significantly increased species and genera diversity, and the DBH size class distribution suggests sufficient younger trees to account for tree mortality and removals. These changes did not occur quickly due to the persistent legacy effect of past planting preferences and practices, but required a consistent effort by municipal tree managers over many years. As a result, based on an analysis of the most recent tree inventory conducted in 2019, the city's street and park trees and the benefits they provide look to be on a more sustainable footing, although challenges still remain.

Keywords. Legacy Effect; Norway Maple; Species Diversity; Tree Inventory; Urban Tree Management.

INTRODUCTION

Urban trees provide environmental, social, and economic benefits (Vogt 2020). These benefits include, but are not limited to, environmental benefits such as air quality improvement (Irga et al. 2015) and carbon storage and sequestration (Tang et al. 2016); social benefits such as better cardiovascular health (Karden et al. 2015) and greater traffic safety (Harvey and Aultman-Hall 2019); and economic benefits such as reduced energy costs (Nowak et al. 2017) and higher property values (Donovan et al. 2019). Municipally managed trees, such as street and park trees, often comprise a minority of urban trees and the benefits they provide (Dwyer et al. 2000). They have, however, been a longstanding focus of urban forestry due at least in part to their high visibility and because, unlike trees on private property, these are the trees over which urban foresters most often have direct control (Clark et al. 1997; Nowak and O'Connor 2001). Provision of the benefits provided by street and park trees has become a focus of municipal tree management in the United States (Silvera Seamans 2013; Young 2013). Continued provision of these benefits depends on the health and sustainability of street and park tree populations, which depend in turn on municipal tree managers having accurate information for tree care and maintenance (Cumming et al. 2008).

The tree inventory, in which data are collected for individual trees in a municipal tree population, has long been considered an essential urban tree management tool (Tate 1985). It facilitates an understanding of tree population structure, such as tree density, species composition and diversity, and age distribution, which is essential for creating a plan to sustainably manage urban trees (Nowak et al. 2008). An inventory provides a snapshot in time and can quickly become outdated, since urban tree populations are dynamic and constantly change due to natural and anthropogenic factors (Roman et al. 2013; Nowak et al. 2016). Understanding such change enables municipal tree managers to understand not just the way things were, but how they will be tomorrow (Rowntree 1998). Accordingly, the inventory should either be continuous, with data updated constantly, or the inventory should be repeated at regular intervals, such as every 5 to 10 years (Baker 1993). Many municipalities, however, do not reinventory trees on a regular basis or at all, in part due to cost (Bassett and Lawrence 1975; Hauer and Peterson 2016). Additionally, when an inventory is repeated, there are often differences in inventory variables, data collection methods, and personnel, which may limit the ability to make comparisons between the data sets (Crown et al. 2018).

The city of Ithaca, New York in the United States possesses 7 inventories of its municipally managed urban trees dating back to 1902, with the most recent inventory conducted in 2019. This paper utilizes the data contained in these inventories to analyze long-term change in the structure of Ithaca's municipally managed tree population in order to understand not just the way things were, but how they will be tomorrow. Particular emphasis is given to the diversity of tree species and genera as a critical management factor in promoting the health and sustainability of Ithaca street and park trees and preserving the environmental, social, and economic benefits they provide.

METHODS

Study Area

Ithaca is a city with a population of 30,999 and a land area of 13.96 km^2 (United States Census Bureau 2018) situated at the southern end of Cayuga Lake in the Finger Lakes region of New York State in the northeastern part of the United States (42.4406° lat, -76.4967° long)(Figure 1). It is located in the Mixed Wood Plains of the Eastern Temperate Forests ecoregion of North America, which is characterized by mixed coniferous-deciduous forests and a humid continental climate marked by warm summers and cold, snowy winters (CEC 2009). Mean annual precipitation is 947.42 mm (37.30 in)(NRCC 2020), and its USDA Plant Hardiness Zone is Zone 6A (-23.3 to -20.6 °C, -10 to -5 °F)(USDA 2012). Incorporated as a village in 1821 and chartered as a city in 1888 (Dieckmann 2004), Ithaca was initially known as a manufacturing center thanks to the water-powered mills facilitated by its glacially carved topography and has since become recognized as an educational center with Cornell University, Ithaca College, and Tompkins Cortland Community College located in or near the city (Kammen 2008). It was often called "Forest City" in the nineteenth century because, although visible from the surrounding hills, it was "almost hid by the gold and cardinal-tinted leaves on the tall trees lining its streets" (Kurtz 1883). Trees continue today to line Ithaca's streets, and its street and park trees are managed by a City Forester who, in coordination with a Shade Tree Advisory Committee comprised of residents and city officials, supervises a Forestry Section within the Public Works Department (Denig 2014).

Data Sets

Data were collated for 7 tree inventories of municipally managed trees in Ithaca, New York, conducted

Figure 1. Location of Ithaca, New York, USA.

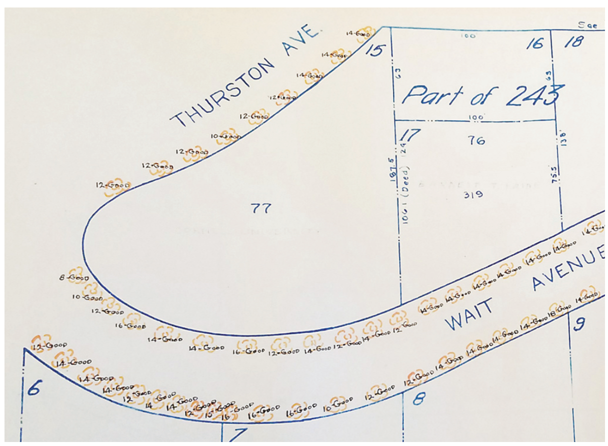

Figure 2. Sample map from the Ithaca tree inventory 1928–1947. Elms are color coded orange.

between 1902 and 2019. The 1902 inventory was conducted by the Cornell University Agricultural Experiment Station in conjunction with an article on the value of street trees in the United States and Europe (Murrill 1902). Street trees were surveyed, but not park trees. At some point between 1928 and 1947 (the exact date is unknown), City Forester Richard Baker conducted an inventory comprised almost entirely of street trees (a few park trees were also surveyed), in which symbols identifying tree locations were drawn on 180 maps of city streets, along with notations for genus, trunk diameter, and condition (Figure 2). The 1928 to 1947 time frame derives from occasional notations on the series of maps which mostly pertain to tree removal dates. The tree symbols bear close resemblance to symbols illustrating a 1920 map drawn by civil engineer Carl Crandall for the Village of Cayuga Heights, which borders Ithaca to the north. Baker became City Forester in 1924, and so the inventory was not conducted before then and was likely conducted at the front end of the 1928 to 1947 time frame, not over the course of 19 years. Baker's inventory was followed by inventories in 1987 and 1996 conducted by graduate students. The 1987 inventory was supervised by the city's Shade Tree Advisory Committee. Data for street trees only were collected on paper and then entered into a computer database for analysis. The 1996 inventory was supervised by City Forester Andrew Hillman, in which data were collected with handheld computers for both street and park trees. These data were later scrubbed by the city's Planning Department and then integrated with the city's geographic information system (GIS). Finally, in 2006, 2013, and 2019, GIS-based inventories were conducted by professional arborists who collected data for both street and park trees.

Ideally, Ithaca's 7 inventories would contain the same data attributes and metrics so that summary data and data for individual trees for all inventories would be directly comparable. Unfortunately, this is not the case. For example, in the 1902 inventory, summary statistics for street-tree species, genus, and condition are the only data currently available, and the inventory's precise geographic extent is unknown. In contrast, the 2019 inventory, along with the 1996, 2006, and 2013 inventories preceding it, contains data on individual street and park trees for many more attributes than species, genus, and condition, and geographic extent can be determined from the latitude and longitude coordinates collected for each tree. Additionally, the 1902 inventory probably does not include trees located in the Cornell Heights district, which was not annexed by the city until 1903; this district contained 218 street trees in the 2019 inventory, or 2.67% of all street trees contained in that inventory. As a result of these differences, the 1902 inventory data do not fully conflate with the 2019 inventory data, and comparisons between the inventories are limited to summary statistics for street tree species, genus, and condition. Similarly, the 1928–1947 inventory contains data for individual trees, and its maps pinpoint tree locations, whereas only summary statistics are available for the 1987 inventory (data were collected for individual trees but cannot be found). However, the 2006, 2013, and 2019 inventories utilize the same data fields and metrics and share the same unique identifier for individual trees. Accordingly, comparisons can effectively be made between these inventories, both on a population level and for individual trees.

Table 1 lists the 7 tree inventories and the differences between them. A distinction has been made between street and park trees. The Bray-Curtis Index (Bray and Curtis 1957; Table 2) was utilized to assess the similarity/dissimilarity of the composition of Ithaca street and park trees for both species and genera. An index value of 0 indicates the same species and genus composition, and a value of 1 indicates no shared species or genera. An index value of 0.667 was found for Ithaca street and park tree species, and a value of 0.630 was found for street and park tree genera, reflecting more dissimilarity than similarity in street and park tree composition. These findings are consistent with findings made by previous studies that the dynamics and population structures of street and park trees are significantly different and suggestions that street and park trees may require separate management strategies (Welch 1994; Nielsen et al. 2007; North et al. 2018). Data were not collected for the city's park trees until 1996, except for a few trees in the 1928–1947 inventory which have not been included in this study. The parks themselves vary from large, primarily landscaped recreational areas adjacent to waterfront, to smaller, more urbanized areas contained within the city's street grid. Planted, cultivated trees contained in these park areas were inventoried in the 1996, 2006, 2013, and 2019 inventories. Trees inventoried as park trees include those

Table 1. Municipal tree inventories in Ithaca, NY, USA, from 1902 to 2019.

	1902	1928–1947	1987	1996	2006	2013	2019
Data level	Summary only	Individual records	Summary only	Individual records	Individual records	Individual records	Individual records
Inventory personnel	Unknown	City forester	Students	Students	Certified arborists	Certified arborists	Certified arborists
Number of trees	5621	5195	5303	9859	11,028	10,695	10,895
Street and/or park	Street trees only	Street trees only	Street trees only	Street and park trees	Street and park trees	Street and park trees	Street and park trees
Species and/or genus	Species and genus	Genus only	Species and genus	Species and genus	Species and genus	Species and genus	Species and genus
Trunk diameter (DBH)	No DBH	Individual DBH	DBH profiles	Individual DBH	Individual DBH	Individual DBH	Individual DBH
Tree locations	Unknown	Drawn on maps	Unknown	Street address and GPS points	Street address and GPS points	Street address and GPS points	Street address and GPS points

Table 2. Measures of tree species and genera diversity.

Bray-Curtis Index	$\sum \frac{\lvert n_{ik} - n_{jk} \rvert}{(n_{ik} + n_{jk})}$	where n_{ik} are the number of individuals of taxon k at site i, and n_{jk} the number at site j	similarity/dissimilarity of communities
Simpson Diversity Index (SDI)	$\sum_i \left(\frac{n_i}{n}\right)^2$	where n_i is number of individuals of taxon i	more sensitive to species and genera evenness
Shannon-Wiener Diversity Index (H)	$-\sum_i \frac{n_i}{n} \ln \frac{n_i}{n}$	where n_i is number of individuals of taxon i	more sensitive to species and genera richness and to sample size
Evenness	e^H/S	where S is number of taxa	quantifies the similarity of species and genera frequencies
Inverse SDI	1/SDI	where SDI is the Simpson Diversity Index statistic	measures diversity rather than dominance
Effective Diversity	e^H	where H is the Shannon-Wiener Diversity Index statistic	not logarithmic, unlike the Shannon-Wiener Diversity Index (H), and therefore more directly comparable

growing in the city cemetery, which dates back to the 1790s, and at the nine-hole municipal golf course. Natural woodland areas within the city were not inventoried.

Data Analysis

Many previous studies have utilized tree inventory data to analyze the structure of municipally managed tree populations at specific points in time, both for an individual municipality (Richards 1983; Maco and McPherson 2003; Yang et al. 2012) and for groupings of multiple municipalities (Thomsen et al. 2016; Koch et al. 2018; Cowett and Bassuk 2020). Less common are studies that have utilized tree inventory data collected at multiple points in time to evaluate the change in the structure of these tree populations. Dawson and Khawaja (1985) assessed changes in species composition, basal area, and tree density of street trees from inventories conducted in two Urbana, Illinois neighborhoods in 1932 and 1982. Gartner et al. (2002) analyzed sample street tree inventory data collected from 44 Missouri towns in 1989 and 1999 to investigate changes in tree age, density, condition, and species composition. Lockwood and Berland (2019) evaluated changes in tree density, genus diversity, and basal area from complete street tree inventories conducted in Center Township, Indiana in 2002 to 2003 and 2013 to 2016.

This study analyzes the structure of Ithaca's street- and park-tree populations at multiple points in time based on the 7 tree inventories conducted between 1902 and 2019. Variables analyzed are conditioned by differences between the data sets and, in particular, between the inventories conducted prior to 1996 and those conducted in 1996 and thereafter. For example, planting space data were not collected for the 1902, 1928–1947, and 1987 inventories, and therefore stocking levels (i.e., the number of existing street trees divided by the number of available planting spaces) cannot be ascertained for those dates. Additional limitations in the data impacting analysis are described below.

The relative abundance percentages of species and genera in relation to the population as a whole (i.e., species and genus composition) were calculated for each inventory where feasible. For example, percentages for street and park trees at both the species and genus level were calculated for the 2019 inventory, but street tree genera percentages only were calculated for the 1928–1947 inventory, since species-level data and park-tree data were generally not collected for that inventory. Relative abundance percentages not only speak to the prevalence or scarcity of an individual tree species and genus, but they are also commonly used to evaluate the susceptibility of an urban tree population to pests and disease. For example, after street tree populations containing large numbers of American elm (*Ulmus americana*) were decimated by Dutch elm disease (DED, *Ophiostoma* spp.) beginning in the 1930s, Santamour (1990) hypothesized that the resilience of a tree population to pests and disease would be enhanced if no tree species exceeded 10%, no tree genus exceeded 20%, and no tree family exceeded 30% of a population. Santamour's 10-20-30 rule has achieved wide acceptance, in part because it is easy to comprehend and calculate. However, it has also been criticized for many reasons, including the absence of evidence to validate its thresholds (Kendal et al. 2014), the threat posed by a polyphagous pest, such as the Asian longhorned beetle (ALB, *Anoplophora glabripennis*), that attacks more than one tree species or genus (Laćan and McBride 2008), and differences in the ability of tree species to cope with stressful urban conditions (Raupp et al. 2006). Notwithstanding these criticisms, Santamour's 10-20-30 rule has been judged a reasoned approach to urban forest planning (Laćan and McBride 2008) and a useful measure of diversity for urban forest managers (Kendal et al. 2014).

In addition to relative abundance frequencies, diversity indices are often used to assess the potential resilience of an urban tree population because they consider additional factors such as the number of trees in the population and species and genus richness (i.e., the number of species and genera). Diversity statistics were calculated where feasible for each tree inventory at species and genus levels for street and park trees (Table 2). Simpson's Diversity Index (SDI) (Simpson 1949) and the Shannon-Wiener Diversity Index (Shannon 1948) are two diversity indices often used in urban forest research. Simpson is sometimes preferred to Shannon-Wiener because it is more sensitive to population evenness (i.e., how evenly the members of a population are distributed between all the species and genera in the population) and gives less weight to rare species and genera; Shannon-Wiener is sometimes preferred to Simpson because it is more sensitive to species and genera richness and to sample size (Colwell 2009). A species diversity *t*-test (Hutcheson 1970) was utilized to assess the statistical significance of change ($p < 0.05$) for Shannon-Wiener Index values between the inventories. Population evenness (Buzas and Gibson 1969) and statistics for the inverse of Simpson's Diversity Index (1/SDI) were also calculated. Simpson's Diversity Index measures dominance, meaning that the greater the SDI statistic, the greater the dominance level; with the Inverse SDI, the greater the Inverse SDI, the greater the diversity level (Sun 1992; Sreetheran et al. 2011). Finally, statistics for effective diversity were calculated from the Shannon-Wiener Index statistics (Jost 2006). Because the Shannon-Wiener Index is logarithmic, the exponential of the Shannon-Wiener Index statistic, or e^H where H is the Shannon-Wiener statistic, produces diversity statistics which are not logarithmic and are therefore more directly comparable. Diversity and evenness statistics and the diversity *t*-test were calculated with PAST Paleontological Statistics software Version 4.2 (Hammer et al. 2001).

The size structure of street and park trees was assessed by DBH, which is trunk diameter measured at breast height (1.37 m or 4.5 ft). The population dynamics of urban forests differ from those of non-urban forests (Halpin and Lorimer 2017). Differences are particularly acute for urban trees intentionally planted in park and streetscape settings (Roman et al. 2014; Smith et al. 2019). Additionally, DBH is an imperfect surrogate indicator for tree age, since growth rates vary both within and between tree species, and smaller growing trees such as Kwanzan cherry (*Prunus serrulata*) will never attain the size of larger growing trees such as a northern red oak (*Quercus rubra*)(Welch 1994). Nevertheless, urban forestry has borrowed from non-urban forestry the model in which a descending size class distribution from smaller to larger DBH size classes suggests a sustainable tree population in which there are sufficient young trees to compensate for tree mortality; conversely, a flat shaped distribution or a distribution with a hump in the mid-sized DBH classes suggests an aging and unsustainable tree population (Richards 1979; McPherson and Rowntree 1989). For those inventories where DBH data were collected, street and park trees were aggregated into 8 DBH classes: 0 to 15.2 cm (0 to 6 in), 15.2 to 30.5 cm (6 to 12 in), 30.5 to 45.7 cm (12 to 18 in), 45.7 to 61.0 cm (18 to 24 in), 61.0 to 76.2 cm (24 to 30 in), 76.2 to 91.4 cm (30 to 36 in), 91.4 to 106.7 cm (36 to 42 in), and > 106.7 cm (> 42 in). Data for DBH were not collected in the 1902 inventory. The 1987 inventory contains DBH data aggregated at a finer scale than the 8 size classes above; these data were reworked to conflate with the 8 size classes. Relative size class distributions of prevalent tree species and genera were also generated, except for the 1928–1947 inventory, where distributions for street tree genera only could be generated.

i-Tree (www.itreetools.org) is a suite of freely available software tools developed by the United States Forest Service to assess the benefits and values derived from trees and forests (Nowak et al. 2018). i-Tree Eco (2019) can be used to estimate the monetary benefits (i.e., annual US dollar values) provided by urban trees. It requires at a minimum species and DBH data for each tree. These data also enable the computation of importance values (i.e., the sum of the percentage of relative abundance and the percentage of leaf area) associated with a tree species in an urban tree population. Since larger-growing tree species can be expected to have more leaf surface area than smaller-growing tree species, and many benefits provided by urban trees correlate with leaf surface area, larger-growing tree species are typically associated with greater monetary benefits than smaller-growing tree species and with greater importance values (McPherson et al. 2007). For example, Sydnor and Subburayalu (2011) found in Brooklyn, Ohio that a larger-growing tree species (honeylocust, *Gleditsia triacanthos*) provided 7.5 times the estimated benefits that a smaller-growing tree species (Lavalle hawthorn, *Crataegus* × *lavallei*) provided. i-Tree Eco version 6 was utilized to estimate in 2020 US dollars (i.e., as calculated in 2020, unadjusted for inflation) the gross monetary benefits provided by and the importance values associated with Ithaca street trees for the 1928–1947, 1996, 2006, 2013, and 2019 inventories and with Ithaca park trees for the 1996, 2006, 2013, and 2019 inventories. For the 1928–1947 inventory, in which data were collected mostly at the genus level, species was substituted for genus (e.g., *Acer* species for *Acer* genus). Monetary benefits and importance values could not be estimated for the 1902 and 1987 inventories because species, genus, and DBH data were not available for individual trees.

Finally, to better understand the current status of and future prospects for city trees and the benefits they provide, the 2019 inventory was assessed in greater depth. Street tree stocking level and density statistics were calculated and then compared to statistics for New York State (Cowett and Bassuk 2014), California (McPherson et al. 2016), and the United States (Hauer and Peterson 2016). Street trees and park trees in the 0 to 15.2 cm (0 to 6 in) DBH class were analyzed for diversity and species and genus composition and then compared to the diversity and species and genus composition of all street and park trees. Finally, condition and maintenance ratings were associated with the species composition of all street and park trees.

RESULTS

Species and Genus Composition

Street Trees

Sugar maple (*Acer saccharum*) was the most prevalent street tree species in the 1902 inventory (37.45%), but comprised just 4.80% of all street trees in the 2019 inventory (Table 3). American elm (*Ulmus americana*) was the second most prevalent street tree species in the 1902 inventory (28.91%), and elm (*Ulmus* spp.) the second most prevalent street tree genus in the 1928–1947 inventory (30.88%). However, following the onset of Dutch elm disease in the 1930s, only 5 elms, or 0.09% of all street trees, were found in the 1987 inventory; those numbers subsequently increased with the planting of DED-resistant elm species and cultivars, and 311 elms, or 3.80% of all street trees, were found in the 2019 inventory. Norway maple

Table 3. Street- and park-tree species and genera composition from 1902 to 2019.

Street tree species	1902		1928–1947		1987			
	Sugar maple	37.45%	NA	NA	Norway maple	34.62%		
	American elm	28.91%	NA	NA	Sugar maple	19.91%		
	White willow	10.71%	NA	NA	Honeylocust	9.20%		
	Horsechestnut	8.01%	NA	NA	Silver maple	6.26%		
	Red maple	3.68%	NA	NA	Red maple	5.47%		
Street tree genera	**1902**		**1928–1947**		**1987**			
	Maple	44.81%	Maple	50.86%	Maple	67.40%		
	Elm	29.35%	Elm	30.88%	Honeylocust	9.20%		
	Willow	10.82%	Horsechestnut	5.85%	Oak	2.77%		
	Horsechestnut	8.01%	Catalpa	2.56%	Apple	2.68%		
	Ash	1.85%	Ash	1.46%	Planetree	2.62%		
Street tree species	**1996**		**2006**		**2013**		**2019**	
	Norway maple	22.54%	Norway maple	19.95%	Norway maple	14.39%	Norway maple	12.44%
	Sugar maple	9.25%	Sugar maple	9.02%	Honeylocust	7.09%	Honeylocust	7.31%
	Honeylocust	6.59%	Honeylocust	5.86%	Crabapple	5.80%	Crabapple	6.76%
	Crabapple	5.38%	Crabapple	5.35%	Sugar maple	5.65%	Sugar maple	4.80%
	London planetree	3.68%	London planetree	3.70%	London planetree	3.79%	London planetree	3.92%
Street tree genera	**1996**		**2006**		**2013**		**2019**	
	Maple	44.76%	Maple	41.65%	Maple	31.24%	Maple	27.70%
	Honeylocust	6.59%	Oak	5.98%	Oak	9.27%	Oak	9.84%
	Apple	5.39%	Honeylocust	5.86%	Honeylocust	7.09%	Honeylocust	7.31%
	Oak	5.18%	Apple	5.44%	Apple	5.90%	Apple	6.98%
	Planetree	3.93%	Planetree	3.89%	Planetree	3.96%	Planetree	4.10%
Park tree species	**1996**		**2006**		**2013**		**2019**	
	Crabapple	12.21%	Crabapple	12.02%	Crabapple	6.39%	Crabapple	8.22%
	Eastern white pine	6.73%	Eastern white pine	6.76%	Eastern hemlock	6.39%	Eastern hemlock	5.89%
	Green ash	5.24%	Green ash	5.03%	Eastern white pine	5.82%	Eastern white pine	4.81%
	Eastern hemlock	5.24%	Eastern hemlock	5.03%	Green ash	4.96%	Green ash	4.33%
	Norway spruce	4.36%	Norway spruce	4.18%	Norway spruce	4.59%	Norway spruce	4.15%
Park tree genera	**1996**		**2006**		**2013**		**2019**	
	Maple	14.17%	Maple	13.90%	Maple	14.14%	Maple	14.18%
	Apple	13.69%	Apple	13.44%	Oak	7.95%	Apple	8.96%
	Pine	9.41%	Pine	9.33%	Pine	7.91%	Oak	7.59%
	Willow	7.85%	Willow	7.98%	Spruce	7.70%	Spruce	6.70%
	Spruce	7.09%	Spruce	6.87%	Apple	7.05%	Pine	6.00%

(*Acer platanoides*) comprised 0.87% of all street trees in the 1902 inventory, but was the most prevalent street tree species in 1987 (34.62%); it remained the most prevalent street tree species in subsequent inventories, but its relative abundance steadily declined after 1987, comprising 12.44% of all street trees in 2019. Maple (*Acer* spp.) was the most prevalent street tree genus in the 1902 inventory, comprising 44.81% of all street trees, and has remained the most prevalent street tree genus in subsequent inventories (Table 3). However, as a percentage of all street trees, maple prevalence peaked at 67.40% in the 1987 inventory and has declined in each inventory since then, comprising 27.70% of all street trees in 2019. For all inventories from 1902 onwards, and notwithstanding the changes in species and genus composition since then, the most prevalent street tree species exceeded Santamour's 10% rule for species, and the most prevalent street tree genera exceeded his 20% rule for genus. Whereas the 5 most prevalent street tree species comprised 88.76% of all street trees in 1902 and 75.47% of all street trees in 1987, they comprised 35.22% of all street trees in 2019, which equates to a 60.32% reduction from 1902 and a 53.33% reduction from 1987 (Table 4). Similarly, whereas the 5 most prevalent street tree genera comprised 94.84% of all street trees in 1902 and 84.67% of all street trees in 1987, they comprised 55.93% of all street trees in 2019, which equates to a 41.03% reduction from 1902 and a 33.94% reduction from 1987 (Table 4).

Park Trees

Crabapple (*Malus* spp.) was the most prevalent park tree species (12.21% of all park trees) in the 1996 inventory, the first inventory in which data were collected for park trees, and has continued to be the most prevalent park tree species in subsequent inventories, comprising 8.22% of all park trees in 2019 (Table 3). Maple (*Acer* spp.) was the most prevalent park tree genus in the 1996 inventory, comprising 14.17% of all park trees, and has remained the most prevalent park tree genus in subsequent inventories, comprising 14.18% of all park trees in 2019 (Table 3). The percentage of crabapple relative to all park tree species in the 1996 and 2006 inventories exceeded Santamour's 10% rule for species, but did not exceed the 10% rule in the 2013 or 2019 inventories. The percentage of maple relative to all park tree genera did not exceed Santamour's 20% rule for genus in the 1996 inventory nor in any subsequent inventory. Whereas the 5 most prevalent park tree species comprised 33.79% of all park trees in 1996, they comprised 27.40% of all park trees in 2019, which equates to an 18.91% reduction from 1996 (Table 4). Similarly, whereas the 5 most prevalent park tree genera comprised 52.20% of all park trees in 1996, they comprised 43.43% of all park trees in 2019, which equates to a 16.81% reduction from 1996 (Table 4).

Diversity Indices

Street Trees

Statistics were generated at species and genus levels for Simpson's Diversity Index, the inverse of the Simpson's Diversity Index (Inverse SDI), the Shannon-Wiener Diversity Index, distribution evenness, and Jost's effective diversity (Table 5). The 1902 inventory was comprised of 5,621 street trees, 48 species, and 29 genera; the 2019 inventory was comprised of 8,194 street trees, 185 species, and 65 genera. Between the 1902 and 2019 inventories, the Inverse SDI increased from 4.09 to 27.15 for species and from 3.27 to 9.40 for genus; the Shannon-Wiener Diversity Index increased from 1.83 to 4.04 for species and from 1.51 to 2.97 for genus; distribution evenness increased from 0.13 to 0.31 for species and from 0.16 to 0.30 for genus; and effective diversity increased from 6.26 to 56.88 for species and from 4.54 to 19.57 for genus. A diversity index *t*-test (Hutcheson 1970) found statistically significant differences ($p < 0.05$) in the Shannon-Wiener Diversity Index between an inventory and the successive inventory for street tree species for all inventories and for street tree genera for the 1987 through 2019 inventories (Table 6). For all inventories conducted between 1902 and 2019, with the exception of the 1928–1947 inventory, for which no species-level data are available, species diversity was found to be

Table 4. Cumulative frequency of the 5 most prevalent tree species and genera from 1902 to 2019.

Street trees	1902	1928–1947	1987	1996	2006	2013	2019
Sum top 5 species	88.76%	NA	75.47%	47.44%	43.89%	36.72%	35.22%
Δ from prior inventory	NA	NA	-14.97%	-37.14%	-7.48%	-16.35%	-4.08%
Sum top 5 genera	94.84%	91.61%	84.67%	65.85%	62.83%	57.46%	55.93%
Δ from prior inventory	NA	-3.41%	-7.57%	-22.23%	-4.58%	-8.55%	-2.65%
Park trees	**1902**	**1928–1947**	**1987**	**1996**	**2006**	**2013**	**2019**
Sum top 5 species	NA	NA	NA	33.79%	33.01%	28.16%	27.40%
Δ from prior inventory	NA	NA	NA	NA	-2.29%	-14.71%	-2.69%
Sum top 5 genera	NA	NA	NA	52.20%	51.52%	44.75%	43.43%
Δ from prior inventory	NA	NA	NA	NA	-1.31%	-13.13%	-2.96%

Table 5. Diversity statistics for tree species and genera from 1902 to 2019.

Street tree species	1902	1928–1947	1987	1996	2006	2013	2019
Number of species	48	NA	80	137	152	180	185
Number of trees	5621	NA	5303	7361	8423	8255	8194
Simpson_SDI	0.24	NA	0.18	0.07	0.06	0.04	0.04
Shannon-Wiener_*H*	1.83	NA	2.39	3.51	3.69	3.99	4.04
Evenness	0.13	NA	0.14	0.24	0.26	0.30	0.31
Inverse SDI	4.09	NA	5.61	13.36	16.05	24.33	27.15
e^H	6.26	NA	10.94	33.31	39.92	53.89	56.88
Street tree genera	**1902**	**1928–1947**	**1987**	**1996**	**2006**	**2013**	**2019**
Number of genera	29	27	45	60	59	64	65
Number of trees	5621	5195	5303	7361	8423	8255	8194
Simpson_SDI	0.31	0.36	0.47	0.22	0.19	0.12	0.11
Shannon-Wiener_*H*	1.51	1.46	1.50	2.51	2.63	2.90	2.97
Evenness	0.16	0.16	0.10	0.20	0.23	0.28	0.30
Inverse SDI	3.27	2.79	2.14	4.61	5.24	8.07	9.40
e^H	4.54	4.29	4.50	12.26	13.86	18.08	19.57
Park tree species	**1902**	**1928–1947**	**1987**	**1996**	**2006**	**2013**	**2019**
Number of species	NA	NA	NA	114	119	140	142
Number of trees	NA	NA	NA	2498	2605	2440	2701
Simpson_SDI	NA	NA	NA	0.04	0.04	0.03	0.03
Shannon-Wiener_*H*	NA	NA	NA	3.79	3.84	4.08	4.08
Evenness	NA	NA	NA	0.39	0.39	0.42	0.42
Inverse SDI	NA	NA	NA	26.12	27.13	37.16	37.08
e^H	NA	NA	NA	44.17	46.43	58.85	59.26
Park tree genera	**1902**	**1928–1947**	**1987**	**1996**	**2006**	**2013**	**2019**
Number of genera	NA	NA	NA	56	56	56	59
Number of trees	NA	NA	NA	2498	2605	2440	2701
Simpson_SDI	NA	NA	NA	0.07	0.07	0.06	0.06
Shannon-Wiener_*H*	NA	NA	NA	3.02	3.05	3.19	3.24
Evenness	NA	NA	NA	0.37	0.38	0.43	0.43
Inverse SDI	NA	NA	NA	13.78	14.12	16.64	17.38
e^H	NA	NA	NA	20.53	21.03	24.17	25.64

positively correlated more with the evenness of the species distribution than with the number of species or with the number of street trees for both the Inverse SDI and effective diversity; for the Shannon-Wiener Diversity Index, it was found to be positively correlated more with the number of species than with the number of street trees or with the evenness of the species distribution (Table 7). For all inventories conducted between 1902 and 2019, with the exception of the 1928–1947 inventory, genus diversity was found to be positively correlated more with the evenness of the genera distribution than with the number of genera or with the number of street trees for both the Inverse SDI and effective diversity; for the Shannon-Wiener Diversity Index, it was found to be positively correlated more with the number of street trees than with the number of genera or with the evenness of the genera distribution (Table 7). At the species level, the percentages of Norway maple and sugar maple street trees relative to all street trees were found to be negatively correlated with all diversity indices, meaning species diversity increased as the percentages of Norway maple and sugar maple decreased. Conversely, the percentages of crabapple and London planetree (*Platanus* × *acerifolia*) relative to all street trees were found to be positively correlated with all diversity indices, meaning species diversity increased as the percentages of crabapple

Table 6. Diversity index *t*-test (Hutcheson 1970) for tree species and genera.

Street tree species	1902	1928–1947	1987	1996	2006	2013	2019
Shannon-Wiener_*H*	1.8343	NA	2.3924	3.5057	3.6873	3.9872	4.0414
Variance	0.000301	NA	0.000457	0.000338	0.000286	0.000251	0.000240
t:	NA	NA	-20.267	-39.482	-7.2704	-12.941	-2.447
df:	NA	NA	10355	11513	15428	16631	16443
p(same):	NA	NA	1.35E-89	7.533E-320	3.76E-13	4.03E-38	0.014416

Street tree genera	1902	1928–1947	1987	1996	2006	2013	2019
Shannon-Wiener_*H*	1.5134	1.4734	1.5027	2.5062	2.6289	2.8952	2.9735
Variance	0.000235	0.000371	0.000576	0.000399	0.000330	0.000260	0.000236
t:	NA	1.623	-0.95038	-32.135	-4.5399	-10.964	-3.5174
df:	NA	10112	10072	11293	15381	16478	16419
p(same):	NA	0.10462	0.34194	6.95E-217	5.67E-06	7.12E-28	0.000437

Park tree species	1902	1928–1947	1987	1996	2006	2013	2019
Shannon-Wiener_*H*	NA	NA	NA	3.7884	3.838	4.0751	4.0816
Variance	NA	NA	NA	0.000572	0.000553	0.000544	0.000483
t:	NA	NA	NA	NA	-1.4777	-7.158	-0.2014
df:	NA	NA	NA	NA	5095.9	5042	5079.3
p(same):	NA	NA	NA	NA	0.13954	9.36E-13	0.84039

Park tree genera	1902	1928–1947	1987	1996	2006	2013	2019
Shannon-Wiener_*H*	NA	NA	NA	3.0222	3.0457	3.1852	3.2442
Variance	NA	NA	NA	0.000500	0.000474	0.000453	0.000406
t:	NA	NA	NA	NA	-0.75214	-4.5846	-2.0117
df:	NA	NA	NA	NA	5091.1	5044.4	5084.1
p(same):	NA	NA	NA	NA	0.452	4.66E-06	0.044309

and London planetree increased. At the genus level, the percentage of maple street trees relative to all street trees was found to be negatively correlated with all diversity indices, meaning genus diversity increased as the percentage of maple decreased. Conversely, the percentage of oak (*Quercus* spp.) street trees relative to all street trees was found to be positively correlated with all diversity indices, meaning genus diversity increased as the percentage of oak increased.

Park Trees

Statistics were generated at species and genus levels for Simpson's Diversity Index, the Inverse SDI, the Shannon-Wiener Diversity Index, distribution evenness, and Jost's effective diversity for park trees in the 1996, 2006, 2013, and 2019 inventories (Table 5). The 1996 inventory was comprised of 2,498 park trees, 114 species, and 56 genera; the 2019 inventory was comprised of 2,701 park trees, 142 species, and 59 genera. Between the 1996 and 2019 inventories, the Inverse SDI increased from 26.12 to 37.08 for species and from 13.78 to 17.38 for genus; the Shannon-Wiener Diversity Index increased from 3.79 to 4.08 for species and from 3.02 to 3.24 for genus; distribution evenness increased from 0.39 to 0.42 for species and from 0.37 to 0.43 for genus; and effective diversity increased from 44.17 to 59.26 for species and from 20.53 to 25.64 for genus. A diversity index *t*-test (Hutcheson 1970) found statistically significant differences ($p < 0.05$) in the Shannon-Wiener Diversity Index between an inventory and the successive inventory for park tree species for the 2006 and 2013 inventories and for park tree genera for the 2006 through 2019 inventories (Table 6). Species diversity was found to be positively correlated more with the number of species than with the evenness of the species distribution or with the number of park trees for both the Shannon-Wiener Diversity Index and effective diversity; for the Inverse SDI, it was found to be

Table 7. Correlations for Shannon-Wiener Diversity Index, Inverse SDI (Inverse of Simpson's Diversity Index), and Effective Diversity (e^H), and number of species and genera, number of trees, and distribution evenness for street and park trees (Pearson's r, $p < 0.05$).

	Number of species/genera	Number of trees	Evenness
Street tree species			
Shannon-Wiener_*H*	0.9937	0.9436	0.9814
Inverse SDI	0.9620	0.8813	0.9717
e^H	0.9893	0.9351	0.9956
Street tree genera			
Shannon-Wiener_*H*	0.9348	0.9767	0.9091
Inverse SDI	0.7789	0.8467	0.9489
e^H	0.9091	0.9489	0.9585
Park tree species			
Shannon-Wiener_*H*	0.9992	0.1608	0.9931
Inverse SDI	0.9952	0.1150	0.9975
e^H	0.9990	0.1573	0.9939
Park tree genera			
Shannon-Wiener_*H*	0.7433	0.3330	0.9814
Inverse SDI	0.7046	0.2770	0.9906
e^H	0.7568	0.3473	0.9773

positively correlated more with the evenness of the species distribution than with the number of species or the number of park trees (Table 7). Genus diversity was found to be positively correlated more with the evenness of the genera distribution than with the number of genera or with the number of park trees for all diversity indices (Table 7). At the species level, the percentage of crabapple park trees relative to all park trees was found to be negatively correlated with all diversity indices, meaning species diversity increased as the percentage of crabapple decreased. At the genus level, the percentages of apple (*Malus* spp.) and pine (*Pinus* spp.) park trees relative to all park trees were found to be negatively correlated with all diversity indices, meaning genus diversity increased as the percentages of apple and pine decreased. Conversely, the percentage of oak park trees relative to all park trees was found to be positively correlated with all diversity indices, meaning genus diversity increased as the percentage of oak increased.

Size Class Distributions

Street Trees

The DBH size class distributions of street trees for the 1996, 2006, and 2013 inventories display profiles approximating the reverse J shape from smaller to larger DBH size classes, suggestive of a sustainable tree population (Figure 3). The DBH size class distributions for the 1928–1947, 1987, and 2019 inventories deviate from the reverse J shape profile. In the 1987 and 2019 inventories, there are too few trees in the 0 to 15.2 cm (0 to 6 in) DBH size class. In the 1928–1947 inventory, there are too few trees in the 0 to 15.2 cm (0 to 6 in) and 15.2 to 30.5 cm (6 to 12 in) DBH size classes. The DBH size class distributions of Norway maple reveal a population that is getting older as the percentages of trees in the 0 to 15.2 cm (0 to 6 in) DBH size class are increasingly insufficient to compensate for tree mortality; conversely, the DBH size class distributions of London planetree reveal a more youthful population than Norway maple, thanks to the large percentages of trees in the 0 to 15.2 cm (0 to 6 in) DBH size class in the 1996 and 2006 inventories (Table 8).

Park Trees

The DBH size class distributions of park trees for the 1996, 2006, and 2013 inventories display profiles approximating the reverse J shape from smaller to larger DBH size classes, suggestive of a sustainable tree population (Figure 4). The DBH size class

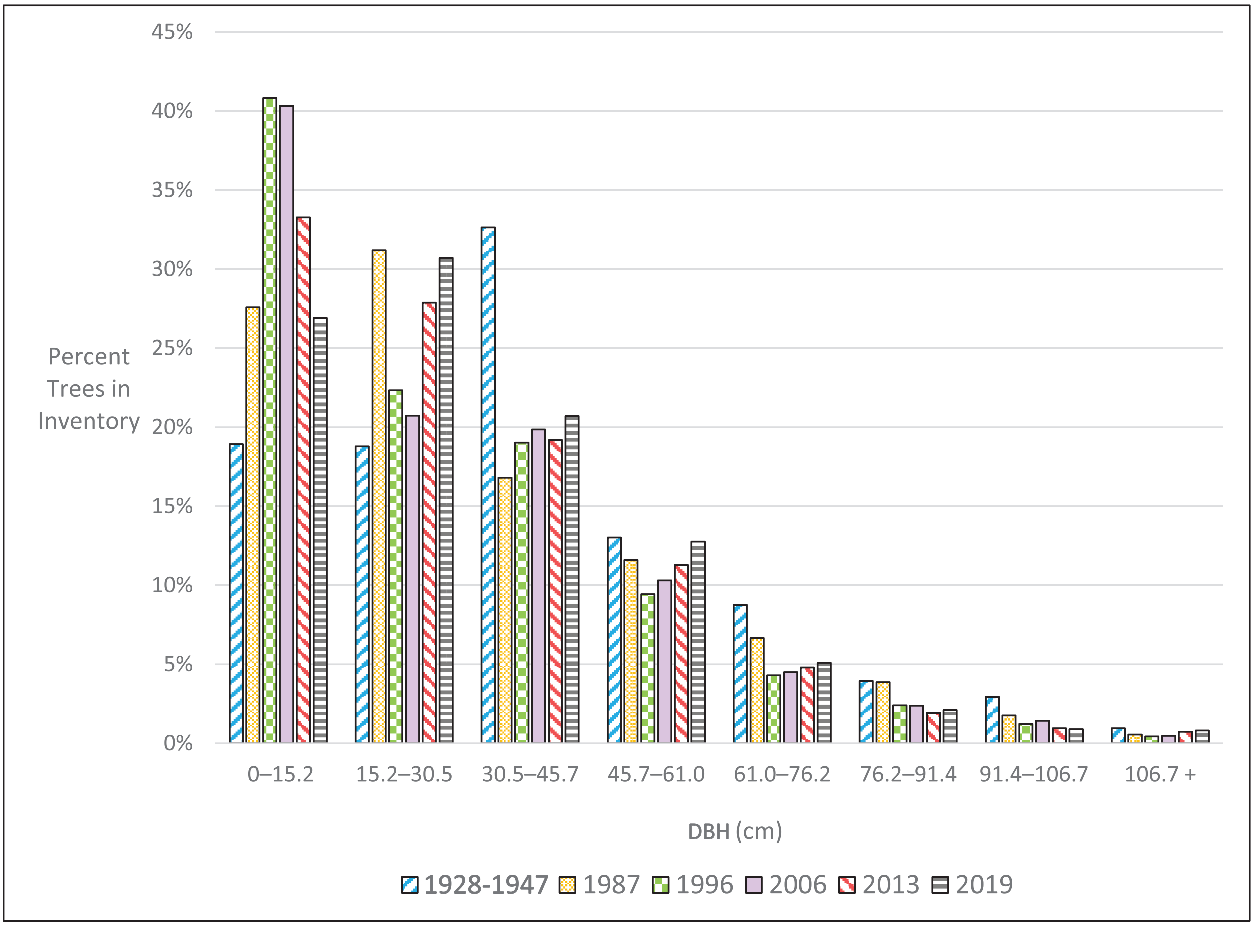

Figure 3. DBH size class distributions of street trees 1928–1947 to 2019.

distribution for the 2019 inventory deviates from the reverse J shape profile; there are too few trees in the 0 to 15.2 cm (0 to 6 in) and 15.2 to 30.5 cm (6 to 12 in) DBH size classes.

i-Tree Benefits and Importance Values

Street Trees

Monetary benefits provided by street trees in 2020 US dollars were estimated to be $111.38 per tree in 1928–1947, $75.37 per tree in 1996, $80.46 per tree in 2006, $78.75 per tree in 2013, and $85.14 per tree in 2019. Estimated leaf surface area per street tree declined from 3,155 ft^2 (293 m^2) in 1928–1947 to 2,028 ft^2 (188.5 m^2) in 1996 and increased to 2,198 ft^2 (204 m^2) in 2019. The importance value of elms declined from 74.0 in 1928–1947 to 1.9 in 1996 and increased to 8.3 in 2019. In 1996, the 3 street tree species with the largest importance values were maples: Norway maple's importance value was 60.1, sugar maple's importance value was 26.8, and silver maple's importance value was 12.9. By 2019, the importance values for these maple species had decreased: Norway maple's importance value was 38.2, sugar maple's importance value was 11.4, and silver maple's importance value was 6.1. London planetree was the street tree species in 2019 with the second largest importance value at 11.9.

Park Trees

Monetary benefits provided by park trees in 2020 US dollars were estimated to be $128.35 per tree in 1996, $124.74 per tree in 2006, $145.64 per tree in 2013, and $180.60 per tree in 2019. Estimated leaf surface area per park tree increased from 2,393 ft^2 (222 m^2) in 1996 to 3,019 ft^2 (280.5 m^2) in 2019. For all inventories between 1996 and 2019, the 6 park tree species with the largest importance values were crabapple,

Table 8. DBH size class distributions of Norway maple (*Acer platanoides*) and London planetree (*Platanus × acerifolia*) from 1987 to 2019.

Norway maple	1987	1996	2006	2013	2019
0–15.2 cm	28.53%	6.57%	3.57%	0.84%	0.79%
15.2–30.5 cm	35.47%	39.00%	29.64%	14.73%	12.46%
30.5–45.7 cm	18.11%	33.76%	40.48%	44.78%	40.14%
45.7–61.0 cm	11.11%	14.10%	18.93%	28.45%	34.25%
61.0–76.2 cm	4.17%	5.06%	5.54%	8.84%	10.11%
76.2–91.4 cm	1.66%	1.15%	1.43%	1.68%	1.47%
91.4–106.7 cm	0.85%	0.36%	0.42%	0.51%	0.39%
> 106.7 cm	0.11%	0.00%	0.00%	0.17%	0.39%
London planetree	**1987**	**1996**	**2006**	**2013**	**2019**
0–15.2 cm	3.17%	53.87%	49.36%	15.34%	18.69%
15.2–30.5 cm	31.75%	2.95%	10.58%	35.78%	26.79%
30.5–45.7 cm	23.81%	12.18%	9.62%	14.38%	18.07%
45.7–61.0 cm	13.49%	11.81%	9.29%	7.99%	9.35%
61.0–76.2 cm	11.90%	7.38%	8.97%	8.31%	6.85%
76.2–91.4 cm	7.94%	4.80%	5.13%	8.95%	10.90%
91.4–106.7 cm	4.76%	5.17%	4.81%	4.47%	3.43%
> 106.7 cm	3.17%	1.85%	2.24%	4.79%	5.92%

eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), green ash (*Fraxinus pennsylvanica*), Norway spruce (*Picea abies*), and silver maple. Crabapple had the largest importance value in 1996 (16.0), but its importance value declined to 10.9 in 2019 when eastern hemlock had the largest importance value (13.3). The importance value of green ash declined from 14.4 in 1996 to 11.7 in 2019. Similarly, the importance value of silver maple declined from 13.7 in 1996 to 10.8 in 2019.

2019 Inventory

Street tree stocking level in 2019 was found to be 88.9% compared to 87.2% in the 2013 inventory and 85.0% in the 2006 inventory. Hauer and Peterson (2016) reported a national street tree stocking level of 81.5%. Street tree density in 2019 was found to be 58.9 street trees/km compared to 59.2 street trees/km in the 2013 inventory and 60.5 street trees/km in the 2006 inventory. Cowett and Bassuk (2014) reported a weighted statewide mean in New York State of 50.0 street trees/km; McPherson et al. (2016) reported a weighted statewide mean in California of 46.2 street trees/km; and Hauer and Peterson (2016) reported a national average of 47.3 street trees/km (76.1 street trees/mile). The 2 most prevalent street tree species in the 0 to 15.2 cm (0 to 6 in) DBH class were crabapple (12.88%) and honeylocust (5.49%), and the 2 most prevalent street tree genera were apple (13.20%) and oak (12.29%). Norway maple was the most prevalent street tree species for all street trees (12.44%) but comprised 0.36% of street trees in the 0 to 15.2 cm (0 to 6 in) DBH class. The 2 most prevalent park tree species in the 0 to 15.2 cm (0 to 6 in) DBH class were crabapple (16.42%) and gray birch (*Betula populifolia*) (5.28%), and the 2 most prevalent park tree genera were apple (17.55%) and oak (12.83%).

Maple was the most prevalent park tree genus for all park trees (14.18%) but comprised 7.55% of park trees in the 0 to 15.2 cm (0 to 6 in) DBH class. Effective diversity (e^H) for street tree species in the 0 to 15.2 cm (0 to 6 in) DBH class was 60.58, compared to 56.88 for all street tree species, and evenness for street tree species in the 0 to 15.2 cm (0 to 6 in) DBH class was 0.40, compared to 0.31 for all street tree species. Effective diversity (e^H) for street tree genera in the 0 to 15.2 cm (0 to 6 in) DBH class was 24.34, compared to 19.57 for all street tree genera, and evenness

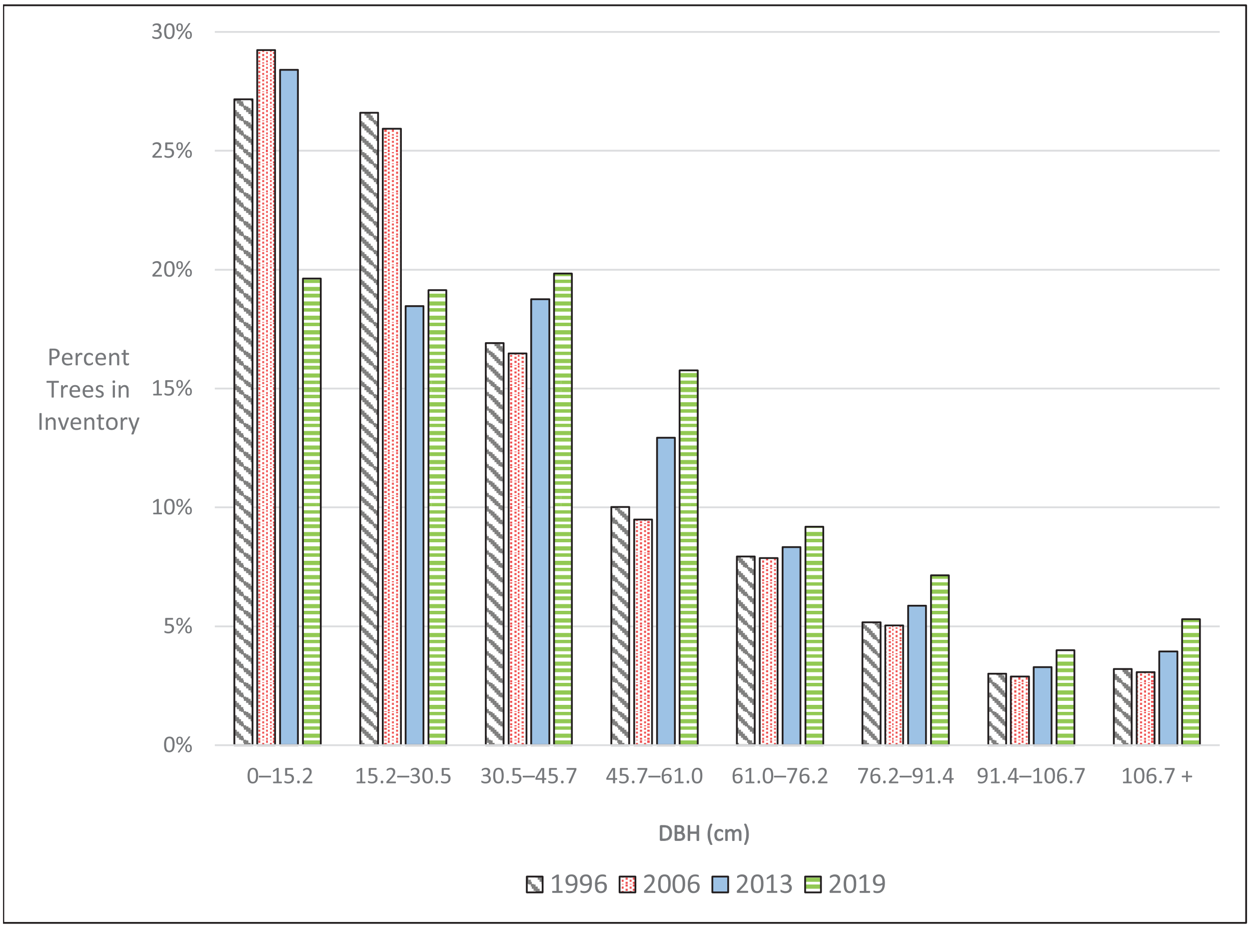

Figure 4. DBH size class distributions of park trees 1996–2019.

for street tree genera in the 0 to 15.2 cm (0 to 6 in) DBH class was 0.42, compared to 0.30 for all street tree genera. As a percentage of street trees receiving poor condition ratings, the 4 most prevalent street tree species were Norway maple (22.78%), sugar maple (15.19%), crabapple (6.33%), and black locust (*Robinia pseudoacacia*)(5.91%). As a percentage of street trees receiving Priority 1 and Priority 2 maintenance ratings, meaning trees should be removed or pruned immediately to promote public safety, the 4 most prevalent street tree species were Norway maple (29.44%), honeylocust (13.55%), sugar maple (10.75%), and silver maple (8.88%). As a percentage of park trees receiving poor condition ratings, the 4 most prevalent park tree species were green ash (13.33%), crabapple (13.33%), silver maple (8.15%), and eastern white pine (7.41%). As a percentage of park trees receiving Priority 1 and Priority 2 maintenance ratings, the 4 most prevalent park tree species were green ash (20.83%), silver maple (12.50%), eastern white pine (6.25%), and white willow (*Salix alba*) (5.73%).

DISCUSSION

Ithaca's earliest tree inventory (Murrill 1902) was conducted in the midst of the City Beautiful movement in the United States. With its confidence in the positive effect of aesthetics on human thought and behavior, this movement advocated for the planting of visually pleasing tree-lined streets as a civic improvement (Wilson 1989). Murrill (1902) referenced "shade trees" as "material aids to the healthfulness and attractiveness of cities and towns." Tree planting was accompanied by the need for tree management "according to the most approved scientific principles and methods," which included "the taking of a tree census…of all the trees of the city" (Solotaroff 1911). Other cities besides Ithaca, such as Hartford, Connecticut (Parker 1907) and Newark, New Jersey (Forest Park Reservation Commission of New Jersey 1915), inventoried municipal trees at that time, although, to the best of our knowledge, the records of many of these inventories have not survived. Ithaca's 1902 inventory, in which sugar maple and American elm comprised 66.36% of the street tree population, reflected prevailing planting practices which included "entire blocks…[to be] planted with one tree [species] alone" (Landreth 1895).

Hope et al. (2006) have defined a "legacy effect" as an inherited present day situation due to past events. Because most street trees are intentionally planted and the urban landscape is not created instantaneously, but develops over time, urban tree populations, in the absence of major ecological disturbances, are typically the product of past landscape preferences and practices, which can persist for long periods (Boone et al. 2010; Greene and Millward 2016; Larson et al. 2017). Although the City Beautiful movement waned after World War I, its legacy endured in Ithaca. In the 1928–1947 inventory, monocultural stands of trees can be found on some Ithaca streets (Figure 2). In fact, the diversity of the city's street tree population declined between the 1902 and 1928–1947 inventories, and genera richness (i.e., the number of genera) also decreased (Table 5). Maple and elm, which together comprised 74.16% of all street tree genera in the 1902 inventory, comprised 81.73% of all street tree genera in the 1928–1947 inventory (Table 3). This lack of diversity in the city's street tree population and its dominance by a few tree genera rendered it exceptionally vulnerable to a pest or disease such as Dutch elm disease.

Ithaca's 1987 inventory appears to represent an inflection point in the structure and management of its municipal trees. First, it revealed the decimation of the city's elms by Dutch elm disease. Elms, which totaled 1,650 trees and comprised 29.35% of all trees in the 1902 inventory and totaled 1,604 trees and comprised 30.88% of all trees in the 1928–1947 inventory, totaled just 5 trees and comprised 0.09% of all trees in the 1987 inventory (Table 3). The American elm's loss proved to be the Norway maple's gain. Recognized today as an invasive species which depresses species richness in forests (Webb et al. 2000), Norway maple was one of the few street tree species available in large enough quantities to meet the replanting needs created by Dutch elm disease in the eastern and north-central United States (Nowak and Rowntree 1990). By 1987, it had become Ithaca's most prevalent street tree species, comprising 34.62% of the street tree population, and maple, which had comprised 50.86% of the street tree population in the 1928–1947 inventory, was found even more dominant in the 1987 inventory, comprising 67.40% of all street tree genera (Table 3). Second, the 1987 inventory was accompanied by an unpublished document which included management recommendations predicated on an analysis of the inventory data and, in particular, the impact of Dutch elm disease. After stating that "planting a large percentage of any one species… [increases] the risk of disease or insect infestation which could seriously alter the green character of the city," the document recommended a moratorium on planting Norway maple and that no single street tree species should comprise more than 5% of the street tree population. Finally, in a dramatic departure from the methodology employed in the 1928–1947 inventory, in which data were recorded by hand and stored on 180 maps of city streets, the 1987 inventory incorporated computer technology in the inventory process and especially in data storage and analysis. Data collected in the field on paper forms were entered into a computer database which could then be queried to generate charts and graphs and also be updated with future changes, such as new plantings and removals.

The inventories from 1996 through 2019 further suggest that the 1987 inventory was an inflection point. After 1987 and continuing through 2019, the percentages of Norway maple and maple relative to all street tree species and genera steadily declined (Table 3). At the same time, the number of street tree species and genera, the diversity of the street tree population, and the evenness of the species and genus distributions increased (Tables 5 and 6). The DBH size class distributions for street trees in the 1987 and 1996 inventories reveal that a large number of new plantings occurred prior to those inventories and, for the 1996 inventory at least, these plantings consisted in large part of species other than Norway maple and genera other than maple (Figure 3). While the DBH size class distributions in the 2006, 2013, and 2019 inventories indicate that the pace of new plantings may have slowed after 1996, the cumulative effect of both new plantings and species selection since 1987 has been to increase street tree diversity and to approach, although not achieve, Santamour's 10% threshold for species and his 20% threshold for genera.

Park trees were not inventoried until 1996. Accordingly, there is no way of assessing legacy effects dating back to 1902, such as knowing whether, prior to 1996, the park tree population was dominated by a few species and genera and, if so, the extent of domination. However, results from the 1996 inventory reveal that park trees were not dominated by a few species and genera to the same extent as street trees. For example, the 1996 inventory found that crabapple, the most prevalent park tree species, comprised 12.21% of all park tree species, whereas Norway maple, the most prevalent street tree species, comprised 22.54% of all street tree species (Table 3). The 1996 inventory also found that maple, the most prevalent park tree genus, comprised 14.17% of all park tree genera, whereas maple, the most prevalent street tree genus, comprised 44.76% of all street tree genera (Table 3). Additionally, in 1996, the sums of the 5 most prevalent park tree species and genera were less than the sums of the 5 most prevalent street tree species and genera (Table 4). Moreover, there were substantial differences in the composition of the park tree population, with eastern hemlock, eastern white pine, and Norway spruce found to be prevalent park tree species, unlike in the street tree population.

These findings for Ithaca's park trees in 1996 parallel findings made by Welch (1994) in Boston that the composition of Boston's park tree population was very different than that of Boston's street tree population, and that Boston's park tree population was more diverse than its street tree population. Comparisons with the 2006, 2013, and 2019 inventories provide further insight. From 1996 to 2019, effective diversity (e^H)(Jost 2006) increased for street tree species and genera and for park tree species and genera; while the number of street and park tree species and genera increased, the increase in effective diversity was correlated more with an increase in the evenness of the street and park tree populations than with the increase in the number of species and genera (Table 5). Evenness is important because even if the number of species or genera increases, if a species or genus is represented by only a few trees, then the most prevalent species or genera remain comparatively dominant. For example, even though there was a 66.7% increase in the number of street tree genera between the 1928–1947 and 1987 inventories, there was no statistically significant increase in diversity ($p < 0.05$) due to the dominance of the most prevalent street tree genera (Tables 5 and 6). The increase in population evenness for Ithaca's street trees since 1996 has been substantial and has contributed to reducing the gap in diversity with Ithaca's park trees, but, in 2019, Ithaca's park tree population continued to be more diverse than the population of its street trees.

While greater population evenness has contributed importantly to increased diversity for Ithaca's street and park trees, the number of species and genera has also increased, and its impact should not be discounted. The increase at the species level is especially pronounced with a 35.0% increase in the number of street tree species and a 24.6% increase in the number of park tree species between 1996 and 2019 (Table 5). This increase can be attributed in part to the increase in average minimum winter temperatures revealed in the 1990 and 2012 plant hardiness zones (USARS 1990; USDA 2012). Ithaca was reassigned from Zone 5b (-26 to -23 °C,-10 to -5 °F) in 1990 to Zone 6a (-23 to -20 °C, -10 to -5 °F) in 2012. Warmer average minimum winter temperatures have permitted cold hardy cultivars of species such as southern magnolia (*Magnolia grandiflora*) to survive now in Ithaca, whereas in the past they would not have been hardy. More significantly, however, the increase in the number of street and park tree species reflects an emphasis by municipal tree managers to diversify the municipal tree population. In particular, there has been an effort to seek out and plant tree species not typically available at nurseries nor planted in urban environments. Such plantings have included trees that are difficult to transplant successfully when harvested from the field, including pawpaw (*Asimina triloba*), pecan (*Carya illinoiensis*), shellbark hickory (*Carya laciniosa*), overcup oak (*Quercus lyrata*), swamp chestnut oak (*Quercus michauxii*), and chinkapin oak (*Quercus muehlenbergii*). Many tree species are not good candidates for urban plantings, especially as street trees, due to the many environmental stressors impacting tree health such as drought, compacted soil, de-icing salt, and air pollution (Kargar et al. 2017), and not every introduction of new tree species has been successful. For example, European alder (*Alnus glutinosa*) did not do well because it is not drought tolerant, and water stress is the primary abiotic constraint for trees in urban landscapes (Sjöman et al. 2018).

Increased diversity is not a cure-all for the many challenges facing urban trees, nor does it automatically result in a stable and sustainable municipal tree population, given the urban forest's vulnerability to multiple stressors and disturbances (Richards 1983; Steenberg et al. 2017). For example, with respect to pest vulnerability, for pests such as the emerald ash borer (EAB)(*Agrilus planipennis*) which are primarily host specific, greater tree diversity can typically be expected to be associated with reduced tree loss (Jactel and Brockerhoff 2007). However, for non-host specific, polyphagous pests, such as the Asian longhorned beetle, a less diverse tree population comprised of tree species resistant to such pests could potentially be more sustainable than a more diverse population comprised at least in part of vulnerable tree species (Berland and Hopton 2016). Additionally, since differences in tree growth rates and size translate into significant differences in the benefits provided by trees (McPherson and Peper 2012), increasing diversity by replacing larger growing tree species, such as Norway maple, with smaller growing tree species, such as crabapple, rather than with other larger growing tree species, can reduce the structural potential of the benefits provided by municipal trees (Sydnor and Subburayalu 2011). Finally, whereas native tree species may support a greater abundance and density of birds than non-native trees (Shackleton 2016) and contribute to ecological integrity (Ordóñez and Duinker 2012), and non-native tree species which are non-invasive and resistant to pests, diseases, and droughts may be better suited to harsh growing urban conditions (Riley et al. 2018), an emphasis on native tree plantings may negatively impact the sustainability of urban tree populations, particularly in regions with extreme environmental conditions (Sjöman et al. 2016).

Therefore, although diversity is rightfully seen as an important contributor to sustainable municipal tree management, such management is more complex than simply increasing the number of tree species and genera in a municipal tree population. It requires accurately estimating the new plantings needed to account for tree mortality and removals (Roman et al. 2014). The large number of new plantings in Ithaca since 1987 has been sufficient to substantially alter the DBH size class distribution of its municipal trees and has likely placed them on a more sustainable long-term footing. It requires regular periodic monitoring to provide the information necessary for effective management (Nowak 2017). Ithaca has conducted 7 inventories of its street trees since 1902 and 4 inventories of its park trees since 1996, and this paper has been able to make findings from those inventories, despite substantial differences between them (Table 1); importantly, the 2006, 2013, and 2019 inventories, by utilizing the same data fields and metrics and sharing the same unique identifier for individual trees, have established a standardized footing for future longitudinal comparisons and analysis, both on a population level and for individual trees, that will contribute to effective management, particularly if inventories continue to be conducted on a regular, periodic basis (Roman et al. 2013). It requires coordinated strategies of action linking actors at many geographic scales, including at the neighborhood level (Mincey et al. 2013). A volunteer citizen pruner program has assisted city crews in maintaining municipal trees for many years and pruned 446 trees in 2019; Ithaca's GIS and Forestry departments have collaborated to create an interactive Tree Tour Map for city residents accessible via the Internet; and Ithaca tree managers have partnered with nurseries to secure tree stock that is more diverse and/or available as bare root plantings (Denig 2014). Finally, it requires funding sufficient for tree planting and maintenance, for developing a long-term management plan, and for hiring and training the staff required to implement the plan by planting and maintaining trees (Clark et al. 1997; Kenney et al. 2011). Municipal funding proposed by Ithaca's mayor and approved by its Common Council, coupled with grants from New York State's Urban and Community Forestry program, allowed the Forestry Section within the Public Works Department to spend \$26.21 per capita and \$70.11 per tree to manage the city's street and park trees in 2019. By comparison, in 2018, for municipalities in the Tree City USA program, the average spent per capita was \$7.77 in New York State, \$10.66 in New Jersey, and \$5.64 in Pennsylvania, with a national average of \$8.40 (Arbor Day Foundation 2019). Additionally, Hauer and Peterson (2016) reported that, in 2014, a municipality of Ithaca's population size (i.e., 25,000 to 49,999) spent on average \$9.75 per capita and \$37.35 per tree to manage municipal trees.

CONCLUSION

Analysis of Ithaca's 7 tree inventories revealed substantial change in the population structure of Ithaca's municipally managed urban trees. This change has taken time because of the legacy effect of past practices and preferences, but progress has been made, especially in reducing the dominance of prevalent tree species and genera and increasing diversity, that will promote tree health and sustainability and help to preserve the environmental, social, and economic benefits they provide. Despite this change and progress, challenges still remain. The city's ash and hemlock trees (2.90% and 1.47% of all street and park trees in 2019, respectively) continue to be threatened by the emerald ash borer and hemlock woolly adelgid (HWA)(*Adelges tsugae*). The Asian longhorned beetle and spotted lanternfly (SLF)(*Lycorma delicatula*) could pose even more serious threats, since both are polyphagous pests, and the ALB's preferred host genus is maple; the ALB has not been found in Ithaca as of yet, but an SLF infestation was discovered in November 2020. Oak wilt disease, which is caused by the fungus *Bretziella fagacearum* and has been found 60 miles (96.5 km) away in Canadaigua, New York, is another concern, particularly since tree diversification in Ithaca has been based in part on increasing the number and variety of oaks being planted. While the increase in average minimum winter temperatures has allowed tree species such as southern magnolia to be planted in Ithaca, it also creates additional stress on urban trees, such as longer periods of drought and more intense precipitation events, which can negatively impact tree health and survivability (Yang 2009; Tubby and Webber 2010). Whether Santamour's 10-20-30 rule or the 5% limit on street tree species recommended by Ithaca's 1987 street tree management plan and Ball (2015) are adopted as benchmarks, additional work needs to be done to further diversify the street tree population and, more specifically, to reduce the number of Norway maple and maple trees. Although street tree density and stocking levels exceed the national averages reported by Hauer and Peterson (2016), more new trees need to be planted and, where possible, consideration should be given to replacing larger growing tree species with other larger growing tree species in order to maximize the benefits provided by urban trees. While the money spent to manage Ithaca's street and park trees has exceeded state and national averages, the COVID-19 pandemic has greatly reduced city revenues and could result in cuts to municipal services and staffing (Anbinder 2020). Finally, street and park trees should continue to be inventoried on a regular, periodic basis, utilizing metrics consistent with previous inventories so as to provide the information necessary for effective resource management and for safeguarding the investment made by the city in its municipal tree population.

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Résumé. Les arbres urbains gérés par les municipalités génèrent des bénéfices environnementaux, sociaux et économiques. Le maintien en continu de ces bénéfices dépend de la santé et de la pérennité de ces arbres, lesquelles dépendent à leur tour du fait que les gestionnaires des arbres disposent du type d'informations que l'on retrouve habituellement dans un inventaire des arbres. La ville d'Ithaca, dans l'état de New-York, États-Unis, dispose de sept inventaires de ses arbres d'alignement et de parcs, remontant jusqu'à 1902. Ce document utilise les données contenues dans ces inventaires pour établir la santé et la pérennité des populations d'arbres en alignement et dans les parcs de la ville. Une attention particulière est accordée à la structure de ces populations en mettant l'accent sur la diversité des genres et des espèces et sur leur répartition par classe de diamètre DHP. Avant 1987, la forêt urbaine municipale était dominée par quelques espèces telle l'érable de Norvège (*Acer platanoides*) et des genres comme les érables (*Acer*) et les ormes (*Ulmus*) tandis que la répartition des classes de diamètre DHP était biaisée incontestablement vers des arbres plus âgés. Depuis 1987, les nouvelles plantations ont considérablement augmenté la diversité des genres et des espèces alors que la répartition des classes de diamètre DHP dénote la présence en abondance d'arbres plus jeunes en réaction à la mortalité et à l'abattage des arbres. Ces changements ne sont pas survenus rapidement en raison de l'effet durable découlant des anciennes préférences et pratiques de plantation, mais ont nécessité un effort constant de la part des gestionnaires des arbres municipaux pendant de nombreuses années. En conséquence, sur la base de l'analyse du dernier inventaire des arbres réalisé en 2019, les arbres en alignement et dans les parcs de la ville, ainsi que les bénéfices qu'ils procurent, semblent constituer une base plus durable, même s'il reste des défis à relever.

Zusammenfassung. Kommunal verwaltete Stadtbäume bieten ökologische, soziale und wirtschaftliche Vorteile. Die fortgesetzte Bereitstellung dieser Vorteile hängt von der Gesundheit und Nachhaltigkeit dieser Bäume ab, was wiederum davon abhängt, dass die Baumverwalter über die Art von Informationen verfügen, die normalerweise in einem Bauminventar zu finden sind. Die Stadt Ithaca, New York, USA, verfügt über 7 Inventare ihrer Straßen- und Parkbäume aus dem Jahr 1902. Dieses Papier verwendet die in diesen Inventaren enthaltenen Daten, um die Gesundheit und Nachhaltigkeit der Straßen- und Parkbäume der Stadt zu beurteilen. Das Augenmerk liegt auf der Struktur dieser Bestände, wobei der Schwerpunkt auf der Arten- und Gattungsvielfalt und der Verteilung der DBH-Größenklassen liegt. Vor 1987 wurde der städtische Baumbestand der Stadt von einigen wenigen Arten wie Spitzahorn (*Acer platanoides*) und Gattungen wie Ahorn (*Acer*) und Ulmen (*Ulmus*) dominiert, und die DBH-Größenklassenverteilung war unnachhaltig zu älteren Bäumen hin verzerrt. Seit 1987 haben Neuanpflanzungen die Arten- und Gattungsvielfalt deutlich erhöht, und die DBH-Größenklassenverteilung lässt auf genügend jüngere Bäume schließen, um die Baumsterblichkeit und Entnahmen zu berücksichtigen. Diese Veränderungen traten aufgrund des anhaltenden Vermächtniseffekts früherer Pflanzungspräferenzen und -praktiken nicht schnell ein, sondern erforderten über viele Jahre hinweg konsequente Anstrengungen der urbanen Baumverwalter. Ausgehend von einer Analyse der jüngsten Bauminventur, die 2019 durchgeführt wurde, scheinen die Straßen- und Parkbäume der Stadt und der Nutzen, den sie bieten können, auf einer nachhaltigeren Grundlage zu stehen, auch wenn es noch Herausforderungen gibt.

Resumen. Los árboles urbanos manejados municipalmente proporcionan beneficios ambientales, sociales y económicos. El suministro continuo de estos beneficios depende de la salud y la sostenibilidad de estos árboles, lo que depende a su vez de que los administradores de árboles tengan el tipo de información que normalmente se encuentra en un inventario de árboles. La ciudad de Ithaca, Nueva York, USA posee 7 inventarios de sus árboles urbanos y parques que datan de 1902. Este documento utiliza los datos contenidos en estos inventarios para evaluar la salud y la sostenibilidad de las poblaciones de árboles de calles y parques de la ciudad. Se presta atención a la estructura de estas poblaciones con énfasis en la diversidad de especies y géneros y distribuciones de clases de tamaño (DBH). Antes de 1987, la población de árboles municipales de la ciudad estaba dominada por algunas especies como el arce de Noruega (*Acer platanoides*) y géneros como los arces (*Acer*) y olmos (*Ulmus*). La distribución de la clase de tamaño DBH se sesgó insustentablemente hacia los árboles más antiguos. A partir de 1987, las nuevas plantaciones han aumentado significativamente la diversidad de especies y géneros, y la distribución de la clase de tamaño DBH sugiere suficientes árboles más jóvenes para compensar la mortalidad y la eliminación de árboles. Estos cambios no se produjeron rápidamente debido al persistente efecto heredado de las preferencias y prácticas de plantación anteriores, pero requirieron un esfuerzo constante por parte de los administradores de árboles municipales durante muchos años. Como resultado, sobre la base de un análisis del inventario de árboles más reciente realizado en 2019, los árboles de la calle y el parque de la ciudad y los beneficios que proporcionan parecen estar en una base más sostenible, aunque todavía quedan desafíos.

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