Arboriculture & Urban Forestry 2020. 46(1):27–43

ARBORICULTURE & URBAN FORESTRY
Scientific Journal of the International Society of Arboriculture

Street Tree Diversity in Massachusetts, U.S.A.

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Abstract. Pests, disease, and climate change pose major challenges to street tree survival, and diversity in tree species and genera is widely considered to promote the sustainability of municipal street tree populations. Conversely, the lack of sufficient diversity in street tree population was judged a contributing factor in the death and removal of thousands of street trees in Worcester, Massachusetts, that state's second most populous city, due to an infestation of the Asian longhorned beetle (ALB, *Anoplophora glabripennis*). Therefore, reducing the dominance of prevalent street tree species and genera and increasing tree species and genera diversity are considered vital to sustainable street tree management and to the preservation of the ecosystem services and social benefits that street trees provide. This paper assesses street tree diversity in Massachusetts by analyzing a nonrandom sample of collated municipal street tree inventory data stratified by plant hardiness zones. Consistent with results previously found for Connecticut, New Jersey, New York, and Pennsylvania, results in Massachusetts indicate that a relatively small number of species and genera dominate the composition of most municipal street tree populations, including in particular *Acer* spp. (maple), one of the ALB's favorite host genera. There is accordingly a need for greater species and genus diversity in municipal street tree populations statewide. While there may be a trend towards increased street tree diversity and reduction in the dominance of *Acer* spp., considerable work remains to be done.

Keywords. *Acer* spp.; Asian Longhorned Beetle; Diversity Indices; Ecosystem Services; Worcester.

INTRODUCTION

Massachusetts, one of the original thirteen states that declared independence from Great Britain in 1776, has played a unique role in the history of urban and community forestry in the United States. The first official public shade tree in the American colonies was planted there in 1646 (Steiner 2016). To upgrade the appearance of the Boston Common following the construction of municipal buildings around it, double rows of trees were planted on all sides in the mid-19th century to create formal promenades for strolling, one of the first examples of trees being used for that purpose (Favretti 1982). In 1899, as a response to widespread woodland clearing, the Massachusetts state legislature passed a law requiring each municipality to appoint a tree warden responsible for the care and protection of community trees, acknowledging the importance of urban forest management (Ricard 2005). More recently and far less propitiously, in 2008, the Asian longhorned beetle (ALB, *Anoplophora glabripennis*), native to China and Korea and one of the world's worst invasive species (Simberloff and Rejmánek 2011), was found in Worcester, the state's second most populous city. Although the ALB had been found previously in Europe, the northeastern United States, and Canada, the Worcester infestation was of particular concern due to its proximity to the surrounding closed-canopied temperate forests extending from central New England west to southeastern Canada and the Great Lakes region, and because *Acer* spp. (maple), its primary host genus, was a prevalent and economically important component of those forests (Dodds and Orwig 2011).

The ALB infestation in Worcester raised concerns about insufficient tree diversity. Species and genus diversity are considered significant contributors to the resilience of urban trees to stressors such as pests, disease, and climate change and their continued provision of ecosystem services (Manes et al. 2012). Conversely, a vulnerability to stressors related to a lack of diversity can result in large numbers of trees requiring removal in a short period of time, which may not only impair streetscape aesthetics, but also strain municipal budgets and those departments responsible for tree management (Ball et al. 2007; MacDonagh 2015). However, competing with the imperative for diversity is an aesthetic preference for planting monocultures of the same tree species along streets, avenues, and boulevards (Trowbridge and Bassuk 2004). This practice, which dates back to sixteenth century Europe (Couch 1992), contributed to the overplanting of *Ulmus americana* (American elm) as a street tree in the United States. Despite the lessons ostensibly learned from the devastation wrought by Dutch elm disease (DED, *Ophiostoma* spp.), the overplanting of urban tree species continues to be operative today. For example, Vander Vecht and Conway (2015) found *Acer* spp. to comprise 33.1% of all street trees in Toronto, Canada; and an analysis of managed municipal tree populations in the state of Montana, United States found the percentage of *Fraxinus* spp. (ash) to be at least 40% in eighteen municipalities east of the Continental Divide and to be 70% in two of those municipalities (Montana Department of Natural Resources and Conservation 2017). The overplanting of urban tree species is not simply a North American phenomenon; it also occurs worldwide. For example, Thaiutsa et al. (2008) found 42% of street trees in Bangkok, Thailand to be *Pterocarpus indicus* (Amboyna wood); and Tang et al. (2016) randomly sampled six districts in the center of Beijing, China and found most roads to have only one tree species and *Styphnolobium japonicum* (Japanese pagoda tree) to account for more than 50% of sampled trees.

When the ALB was found in Worcester, *Acer* spp. was the most prevalent street tree genus, comprising 79.7% of all city street trees, and *Acer platanoides* (Norway maple) was the most prevalent street tree species, comprising 60.8% of all city street trees (Freilicher et al. 2008). Recognizing the threat posed by the ALB to both urban and nonurban forests, the Massachusetts Department of Conservation and Recreation (DCR), the United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS), and the United States Forest Service (USFS) partnered in an intensive ALB eradication effort which resulted in the removal of more than 35,000 publicly and privately managed Worcester trees (Kotsopoulos 2017). Although the ALB is a polyphagous pest that attacks other tree genera besides *Acer* spp., including *Aesculus* spp. (horsechestnut), *Populus* spp. (poplar), *Betula* spp. (birch), and *Ulmus* spp. (elm)(Hu et al. 2009), it is reasonable to assume that, if Worcester's street tree population had been more diverse, the number of tree removals would have been fewer and the impact of the ALB infestation less severe.

Street trees are typically located in the public street right-of-way. Although comprising a minority of all urban trees (Dwyer et al. 2000), they often receive special attention due to their public function, and together with park trees are the components of the urban forest which municipalities are most able to manage directly. To sustainably manage street trees, assessing the diversity of the street tree population is essential (Raupp et al. 2006; Sjöman et al. 2012). This assessment is usually facilitated through a street tree inventory, whether a complete, partial, or sample inventory. Because the Worcester Department of Public Works and Parks had conducted a citywide street tree inventory between 2005 and 2006, the city was able to select tree species and genera that would not only be resistant to the ALB, but would also increase the diversity of the street tree population when it replaced ALB tree removals (Freilicher et al. 2008; Freilicher 2011).

Street tree management occurs at numerous geographic scales (e.g., parcel, block, neighborhood, municipality, state, country, etc.) by many different actors (e.g., property owner, arborist, tree board, nongovernmental citizen group, public utility, government official, etc.)(Clark et al. 1997; Mincey et al. 2013). This multiplicity of scales and actors makes altering the structure of urban tree populations, such as increasing street tree diversity, a challenging endeavor. In the United States, the USFS partners with individual states in developing statewide plans that delineate management goals and strategies for each state's urban forest, including its street tree component, and municipal management plans are encouraged to be consistent with the statewide plan (Hauer et al. 2008). In Massachusetts, the DCR is charged with administering the state's Urban and Community Forestry Program and advocates greater street tree diversity for municipal streetscape plantings (Massachusetts DCR 2017). However, what is true at the municipal level is also true at the statewide level: implementing increased diversity depends on identifying species and genera that may be overplanted and species and genera that are less prevalent. To this end, some states in the United States have conducted statewide street tree assessments employing a wide range of techniques to obtain the information needed to make effective management decisions (Cowett and Bassuk 2014). One technique used in these assessments has been to collate street tree inventory data from those municipalities in a state possessing an inventory. However, because most municipalities in a state typically do not possess a street tree inventory, and the collated inventories represent a nonrandom sample of the statewide street tree population, additional steps have been taken to correct for possible selection bias (Cowett and Bassuk 2014; McPherson et al. 2016).

Statewide street tree diversity has been assessed previously in Massachusetts. Cumming et al. (2006) assessed street tree diversity from a sample of 1,124 trees collected from 296 randomly selected plots distributed between six geographic areas (Berkshires, Boston Area, Cape Cod, Central, Northshore, and Southshore). Freilicher (2010) assessed street tree diversity based on data contained in street tree inventories conducted in nine municipalities, six of which were in the Boston area. Cumming et al. (2006) and Freilicher (2010) both found that *Acer* spp. (maple) and *Acer platanoides* (Norway maple) were the most prevalent street tree genus and species statewide.

This paper takes another look at street tree diversity in Massachusetts. Building on an earlier paper assessing street tree diversity in New Jersey, New York, and Pennsylvania (Cowett and Bassuk 2017), it employs a methodology, utilized in that paper, in which street tree inventories were obtained from municipalities in the state. Because these inventories comprised a nonrandom sample with the potential for selection bias that could reduce the accuracy of any findings, inventory data were stratified and weighted with auxiliary information before being analyzed for the abundance, dominance, and evenness of street tree species and genera. An assessment was then made as to statewide street tree species and genus diversity and managing the Massachusetts street tree population for greater resilience and continued provision of ecosystem services and social benefits.

METHODS

Massachusetts is located in the New England region in the northeastern United States. It has a surface area of 27,336 km^2, making it the seventh smallest state, but it is the third most densely populated state, with a population of 6.86 million people, and the most populous state in the New England region (United States Census Bureau 2017a). There are two principal metropolitan areas: Greater Boston in the east, where approximately two-thirds of the state's population lives, and the Springfield metropolitan area in the west. The state's climate is humid continental (Köppen Dfb) and typified by warm, humid summers and cold, snowy winters. About 60% of the state is forested and falls within two USFS Ecological Provinces: the Eastern Broadleaf Forest (Oceanic) Province (Lower New England Section) and the Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow Province (Green, Taconic, Berkshire Mountains Section)(Bailey 2016). USFS Forest Inventory and Analysis (FIA) estimates show that central and transition hardwood forests, dominated by *Quercus* (oak) species, cover more area than any other forest type, and northern hardwood forests, dominated by *Fagus grandifolia* (American beech), *Betula alleghaniensis* (yellow birch), and *Acer saccharum* (sugar maple), cover the next largest area (United States Forest Service 2010).

Street tree inventory data were obtained from thirty Massachusetts municipalities (Figure 1). All municipalities from which data were obtained are cities or towns, both of which are incorporated bodies with legally defined boundaries. There are 351 cities and towns in Massachusetts (MassGIS 2017). Therefore, street tree inventory data were obtained from 8.6% of Massachusetts cities and towns, and the municipalities in the sample contain 28% of all persons statewide (United States Census Bureau 2016). Massachusetts's Urban and Community Forestry Program divides the state into two administrative regions, central-western Massachusetts (Worcester County west) and eastern Massachusetts (east of Worcester County)(Harper et al. 2017). Ten inventories were obtained from central-western Massachusetts (6.2% of cities and towns in the region) and twenty inventories were obtained from eastern Massachusetts (10.5% of cities and towns in the region). The thirty inventories contain 213,845 street trees, with a mean of 7,128 street trees and a median of 4,216 street trees.

Relative abundance percentages of street tree species and genera were calculated for each inventory. Such percentages are frequently used to assess the diversity of a street tree population and to establish recommended ceilings for species and genera prevalence. For example, Santamour (1990) posited in the wake of Dutch elm disease that, to guard against

Figure 1. Street tree inventories obtained in Massachusetts.

large-scale urban tree losses to insect or disease, no tree species should exceed 10%, no tree genus should exceed 20%, and no tree family should exceed 30% of a municipal tree population. Santamour's 10-20-30 rule has become a widely accepted proxy for diversity and can be calculated easily. However, it has also been criticized for a lack of scientific or empirical evidence to validate its percentages as effective thresholds (Kendal 2014), a failure to consider losses from a polyphagous pest such as the ALB that attacks more than one tree species or genus (Laćan and McBride 2008), an overemphasis on species diversity rather than genus or family diversity since pests generally operate at the genus and family levels (Subburayalu and Sydnor 2012), and for overlooking differences between tree species in their ability to adapt to stressful urban conditions (Raupp et al. 2006). More stringent ceilings for species and genera prevalence have been recommended by Barker (1975), Bassuk et al. (2009), and Ball (2015). Nevertheless, despite its limitations, Santamour's 10-20-30 rule represents a reasoned approach to urban forest planning (Laćan and McBride 2008) and can be a useful measure of diversity for urban forest managers (Kendal et al. 2014).

To correct for potential selection bias due to nonrandom sampling, these data were stratified and weighted with auxiliary information. In assessing the structure, function, and value of California street trees, McPherson et al. (2016) stratified a nonrandom sample of street tree inventory data by *i-Tree* climate zones. Similarly, in assessing street tree diversity in New Jersey, New York, and Pennsylvania, Cowett and Bassuk (2017) stratified a nonrandom sample of street tree inventory data by the 2012 USDA Plant Hardiness Zones. For this paper, street tree inventory data were stratified by the 2012 USDA Plant Hardiness Zones (USDA Plant Hardiness Zone Map 2012). Zone boundaries are based on 5.556° Celsius (10° Fahrenheit) temperature differentials for average annual minimum winter temperature for a thirty year period. Zones 4, 5, 6, and 7 are contained within Massachusetts,

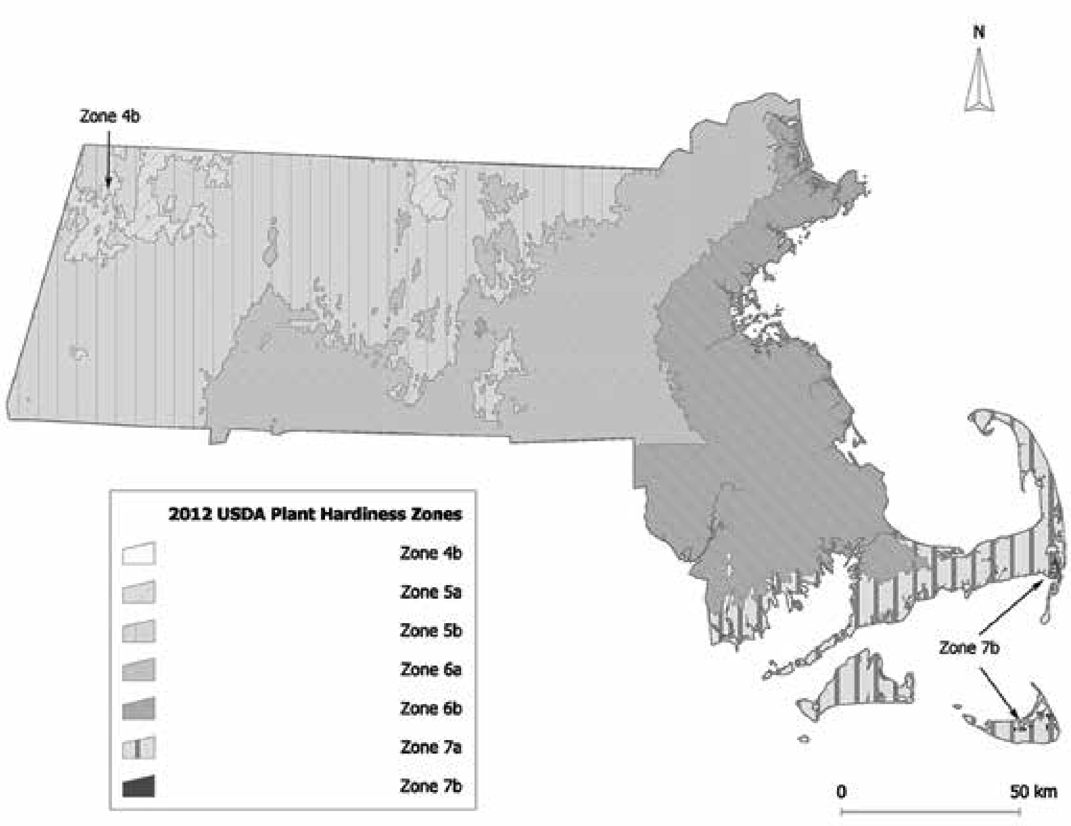

Figure 2. 2012 USDA Plant Hardiness Zones for Massachusetts.

although Zone 4, located in the northwestern part of the state, consists of only 1.89 square kilometers, or 0.009%, of the entire state area.

For each municipality from which street tree inventory data were obtained, the municipality's inner centroid, a center point located within municipal boundaries, was geometrically calculated using Geographic Information Systems (GIS) software. Based on the centroid's longitude and latitude coordinates, each municipality was assigned to a plant hardiness zone. Three inventories were located in Zone 5, twenty-seven inventories were located in Zone 6, and zero inventories were located in Zones 4 and 7. Zone 6 was subdivided into its "a" and "b" components (e.g., 6a and 6b) in which boundaries are based on 2.778° Celsius (5° Fahrenheit) temperature differentials (Figure 2). Ten inventories were located in Zone 6a and seventeen inventories were located in Zone 6b. Means for the relative abundance percentages of street tree species and genera in inventoried municipalities were calculated, and the means for the most prevalent species and genera were regressed on the zones in a one-way analysis of variance (ANOVA). Significant effects ($\alpha = 0.05$) that satisfied statistical assumptions for normality of residuals and homoscedasticity were found for many, but not all of the most prevalent species and genera.

Auxiliary information used for weighting purposes by McPherson et al. (2016) and Cowett and Bassuk (2017) was a measure of street length contained within the strata derived from United States Census TIGERLine datasets. For this paper, following the methodology used by Cowett and Bassuk (2017), TIGERLine All Roads GIS shapefiles (United States Census Bureau 2017b) for Massachusetts were obtained. Street types unlikely to contain municipally managed trees, such as highways, service roads, trails, and alleys were deleted. Streets contained within Census Places, Census Urbanized Areas, and Census Blocks with a population density of at least 96.5 persons per square kilometer (250 persons per square mile) were selected (Figure 3). The percentage of selected street length contained within Zones 5b, 6a, and 6b, the zones within Massachusetts from which street tree inventory data were obtained, was calculated as a percentage of the selected statewide whole (Table 1). These percentages were used to create weights according to the formula:

$$[(w1 \times m1) + (w2 \times m2) + (w3 \times m3)] / (w1 + w2 + w3)$$

Where $m1$, $m2$, and $m3$ denote the group means (i.e., the means for species and genus composition in each zone), and $w1$, $w2$, and $w3$ denote the weights for each group (i.e., the relative percentage of summed selected street length in each zone). These weights were then used to calculate statewide relative abundance percentages of street tree species and genera.

Table 1. Summed selected street length contained within the 2012 USDA Plant Hardiness Zones in Massachusetts.

2012 Plant hardiness zone	Street length (meters)	Percent statewide total
Zone 4b	0	0.00%
Zone 5a	608,874	0.87%
Zone 5b	8,632,237	12.37%
Zone 6a	26,667,085	38.21%
Zone 6b	26,676,845	38.22%
Zone 7a	7,102,094	10.18%
Zone 7b	100,533	0.14%

Diversity indices were calculated as well for each inventory. Such indices have often been used to assess street tree diversity and consider factors such as population size and species and genera numbers (i.e., species and genera richness) in addition to their relative abundance. Statistics were calculated for Simpson's Diversity Index (Simpson 1949) and the Shannon-Wiener Diversity Index (Shannon 1948). While these indices have both been used in assessing street tree diversity, Simpson is sometimes preferred because it better reflects the distribution evenness of a population, and Shannon-Wiener is sometimes preferred because it is more sensitive to sample size (Colwell 2009). To further assess how evenly the trees in each inventory were distributed between all the species and genera in the inventory, statistics for distribution evenness (Buzas and Gibson 1969) were calculated at

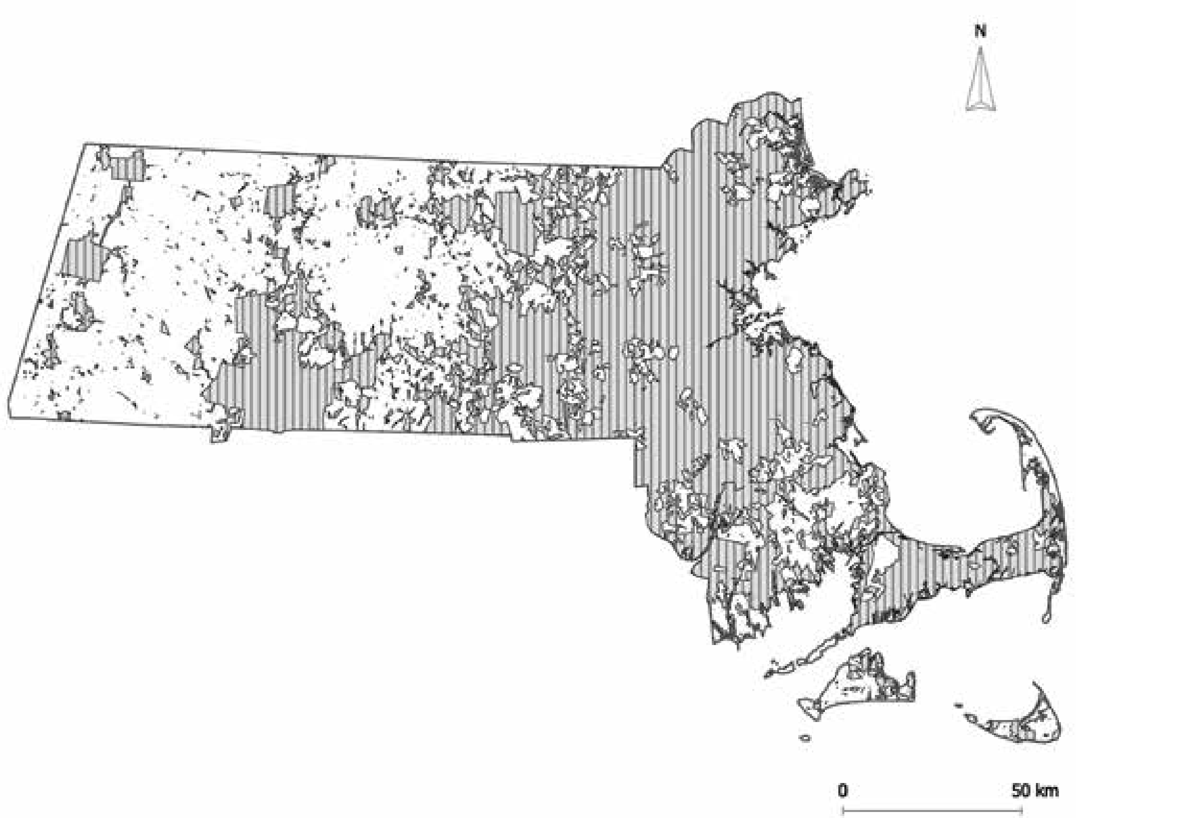

Figure 3. Shaded areas represent 2010 US Census Places, Census Urbanized Areas, and Census Blocks with a population density of at least 96.5 persons per square kilometer (250 persons per square mile) in Massachusetts.

species and genus levels. All diversity index statistics were calculated using PAST Paleontological Statistics software Version 3.0 (Hammer et al. 2001). The inverse of Simpson's Diversity Index (1/SDI) was also calculated, since Simpson's Diversity Index (SDI) measures dominance, and the greater the Inverse SDI, the greater the diversity level; an Inverse SDI value of 10 equates with Santamour's 10% rule for species, and an Inverse SDI value of 5 equates with Santamour's 20% rule for genera (Sun 1992; Sreetheran et al. 2011).

Finally, relative size class distributions of Massachusetts street trees were assessed by dbh, diameter at 1.37 m (4.5 ft). In forestry, a descending distribution from smaller to larger dbh size classes approximating a reverse J shape suggests a sustainable tree population where sufficient young trees exist to compensate for tree mortality, whereas a flat shaped distribution or a distribution with a hump in the midsized dbh classes suggests an aging tree population that is not sustainable (Halpin and Lorimer 2017). The population dynamics of urban forests, and in particular street trees, differ from the population dynamics of nonurban forests, but some measures devised for nonurban forests, such as relative size class distributions, have been applied to the structural analysis of street tree populations (Richards 1983; McPherson and Rowntree 1989; Roman et al. 2014). Therefore, for each street tree inventory, trees were aggregated into eight 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 and greater (42 in and greater). Counts for each dbh class were converted to a statewide percentage of all inventoried trees by dbh class and to a mean percentage by inventory of all inventoried trees by dbh class. Relative size class distributions of prevalent street tree species and genera were also generated. Additionally, trees in the 0 to 15.2 cm (0 to 6 in) class were analyzed for species composition and diversity, and comparisons were then made to the species composition and diversity of all street trees statewide.

RESULTS

Species and Genus Composition

Acer platanoides (Norway maple) was found to be the most prevalent street tree species with a weighted statewide mean of 23.9% (Table 2), and *Acer* spp. (maple) was found to be the most prevalent street tree genus with a weighted statewide mean of 41.4% (Table 3). *Acer rubrum* (red maple) was found to be the second most prevalent street tree species with a weighted statewide mean of 7.7%, and *Quercus* spp. was found to be the second most prevalent street tree genus with a weighted statewide mean of 12.5%. The results for *Acer platanoides* and *Acer* spp. exceeded Santamour's 10% rule for species and his 20% rule for genus. Twenty-eight of thirty municipalities (93.3%) exceeded the 10% rule for species. In most but not all cases, this was due to the percentage of street trees that were *Acer platanoides*, but the

Table 2. Statewide relative abundance percentages for street tree species in Massachusetts.

Species	Weighted	Unweighted	Δ
Acer platanoides	23.94	23.84	0.11
Acer rubrum	7.66	7.70	(0.04)
Acer saccharum	6.44	5.84	0.59
Quercus rubra	6.01	5.94	0.07
Malus species	3.82	3.46	0.36
Tilia cordata	3.72	3.92	(0.20)
Gleditsia triacanthos	3.71	4.06	(0.35)
Pyrus calleryana	3.57	4.16	(0.59)
Pinus strobus	3.38	3.31	0.07
Quercus palustris	2.27	2.30	(0.03)
Fraxinus americana	2.26	1.92	0.34
Acer saccharinum	1.75	1.52	0.23
Quercus alba	1.73	1.65	0.08

Table 3. Statewide relative abundance percentages for street tree genera in Massachusetts.

Genus	Weighted	Unweighted	Δ
Acer	41.41	40.53	0.88
Quercus	12.46	12.25	0.21
Tilia	4.72	5.04	(0.32)
Pinus	4.38	4.25	0.12
Fraxinus	4.01	3.89	0.13
Malus	3.98	3.60	0.38
Gleditsia	3.71	4.06	(0.35)
Pyrus	3.62	4.22	(0.60)
Prunus	3.26	3.60	(0.35)
Ulmus	2.36	2.49	(0.13)
Platanus	1.79	1.96	(0.17)
Picea	1.50	1.37	0.13
Tsuga	1.07	0.97	0.10

Table 4. Mean diversity indices at species and genus levels in Massachusetts.

	Zone 5b	Zone 6a	Zone 6b	Statewide
Species				
Simpson (SDI)	0.1667	0.1371	0.1138	0.1269
Shannon-Wiener	2.5440	2.8776	2.9697	2.8964
Evenness	0.2780	0.2494	0.2309	0.2418
Inverse SDI	7.8419	11.9895	11.4339	11.2599
Genus				
Simpson (SDI)	0.3211	0.2413	0.2146	0.2342
Shannon-Wiener	1.8720	2.1454	2.2358	2.1693
Evenness	0.2322	0.2137	0.2177	0.2178
Inverse SDI	3.6318	4.8660	5.6464	5.1848

percentages of *Acer rubrum*, *Acer saccharum*, *Gleditsia triacanthos* (honeylocust), *Malus species* (crabapple), *Pinus strobus* (eastern white pine), *Pyrus calleryana* (Callery pear), *Quercus rubra* (northern red oak), and *Tilia cordata* (littleleaf linden) exceeded 10% in some municipalities. Thirty of thirty municipalities (100%) exceeded the 20% rule for genus. In most but not all cases, this was due to the percentage of street trees belonging to the *Acer* genus, but the percentages of *Malus* spp. (apple), *Pinus* spp. (pine), and *Quercus* spp. exceeded 20% in some municipalities. The ten most prevalent street tree species comprised 62.5% of all street trees statewide, and the ten most prevalent street tree genera comprised 83.8% of all street trees statewide. The results for *Pinus* spp. (fourth most prevalent street tree genus) and *Pinus strobus* (ninth most prevalent street tree species) are surprising, since pines are not typically planted as street trees. An explanation for their prevalence could be the state's Scenic Roads Act (Massachusetts General Laws 2018) which has caused some municipalities to inventory roads located on municipality outskirts in wooded areas.

Diversity Indices

Statistics were generated at species and genus levels for Simpson's Diversity Index, the Shannon-Wiener Diversity Index, distribution evenness, and the inverse of Simpson's Diversity Index (Table 4). For both the Inverse SDI and Shannon-Wiener, a larger value indicates greater diversity, and a smaller value indicates less diversity. Differences in values appear greater for the Inverse SDI than for Shannon-Wiener because the latter index is logarithmic. At both the species and genus levels, and for both the Shannon-Wiener Diversity Index and the Inverse SDI, diversity increased as average annual minimum winter temperature increased. Statistics were also generated for distribution evenness at species and genus levels (Table 5). Species diversity was found to be positively correlated more with the number of species in each municipality than with the evenness of the municipality's species distribution or the number of municipal trees for both the Shannon-Wiener Diversity Index and the Inverse SDI. Genus diversity was found to be positively correlated more with number of genera than with the evenness of the genera distribution or the number of municipal trees for the Shannon-Wiener Diversity Index, and to be positively correlated more with the number of genera and with the evenness of the genera distribution than with the number of municipal trees for the Inverse SDI. The percentage of *Acer platanoides* in a municipal street tree population was found to be negatively correlated with the Shannon-Wiener Diversity Index ($r = -0.8501$) and the Inverse SDI ($r = -0.7887$), meaning species diversity increased as the percentage of *Acer platanoides* decreased. Similarly, the percentage of *Acer*

Table 5. Correlations for Mean Inverse SDI (Inverse of Simpson's Diversity Index) and Shannon-Weiner Diversity Index values, number of species and genera, number of municipality trees, and distribution evenness (Pearson's r, $P < 0.0001$).

	Number species/ genera	Number trees	Evenness
Species diversity			
Shannon-Wiener	0.7532	0.2318	0.0243
Inverse SDI	0.7006	0.1887	0.4049
Genus diversity			
Shannon-Wiener	0.7436	0.2872	0.0017
Inverse SDI	0.5994	0.2799	0.6010

Table 6. Mean diversity indices for younger trees (dbh 0–15.2 cm) and all street trees in Massachusetts.

	Trees dbh 0–15.2 cm	All trees
Simpson (SDI)	0.0804	0.1269
Shannon-Wiener	3.0905	2.8964
Evenness	0.4469	0.2418
Inverse SDI	15.7502	11.2599

spp. in a municipal street tree population was found to be negatively correlated with the Shannon-Wiener Diversity Index (r = -0.8197) and the Inverse SDI (r = -0.8167), meaning genus diversity increased as the percentage of *Acer* spp. decreased. Conversely, the percentages of both *Acer rubrum* and *Quercus rubra* were found to be positively correlated with the Shannon-Wiener Diversity Index (r = 0.1937, r = 0.3748) and the Inverse SDI (r = 0.1464, r = 0.3588), meaning species diversity increased as the percentages of *Acer rubrum* and *Quercus rubra* increased. Similarly, the percentage of *Quercus* spp. in a municipal street tree population was found to be positively correlated with the Shannon-Wiener Diversity Index (r = 0.2550) and the Inverse SDI (r = 0.2459), meaning genus diversity increased as the percentage of *Quercus* spp. increased.

Relative Size Class Distribution

The relative size class distributions of all inventoried street trees statewide, and of street trees by inventory, display profiles that differ from the reverse J shape from smaller to larger dbh size classes, suggestive of a sustainable tree population. Specifically, 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 (Figure 4). Relative size class distributions of prevalent street tree species display contrasting profiles. The distributions of *Acer platanoides*, *Acer saccharum*, and *Quercus rubra*, the first, third, and fourth most prevalent street tree species, reveal humps in the midsized dbh classes; conversely, among the ten most prevalent street tree species, only the distributions of *Acer rubrum* and *Malus species* (crabapple) reveal descending reverse J shape profiles (Figure 5). Similarly, the distributions of *Acer* spp. and *Quercus* spp., the first and second most prevalent street tree genera, reveal humps in the midsized dbh classes; among the ten most prevalent street tree genera, only the distributions of *Malus* spp. (apple), *Prunus* spp. (cherry), and *Ulmus* spp. (elm) reveal descending reverse J shape profiles (Figure 6). For street tree species in the 0 to 15.2 cm (0 to 6 in) class, relative abundance percentages and diversity indices differ from those of all street tree species statewide. *Acer rubrum*, *Pyrus calleryana*, and *Malus species* (crabapple) are the first, second, and third most prevalent street tree species in the 0 to 15.2 cm (0 to 6 in) class, as compared with being the second, ninth, and fifth most prevalent street tree species respectively for all statewide street trees. Additionally, statistics indicate greater diversity and distribution evenness for street tree species in the 0 to 15.2 cm (0 to 6 in) class as compared with street tree species in all dbh size classes statewide (Table 6).

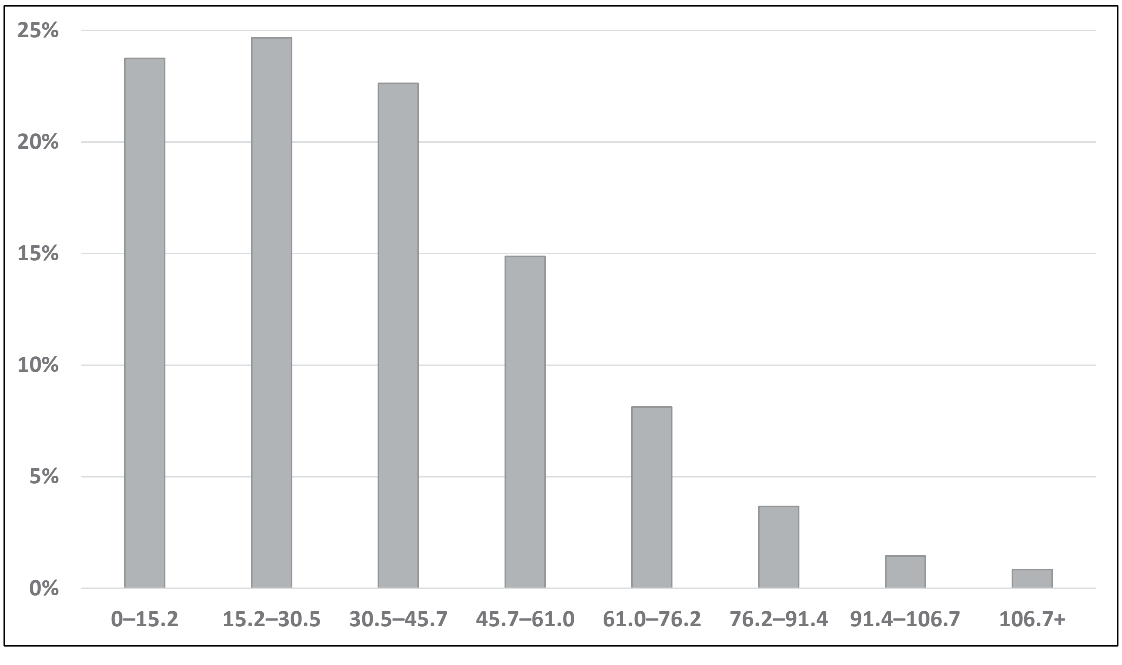

Figure 4. Relative size class distribution of all inventoried street trees in Massachusetts (x-axis = dbh cm).

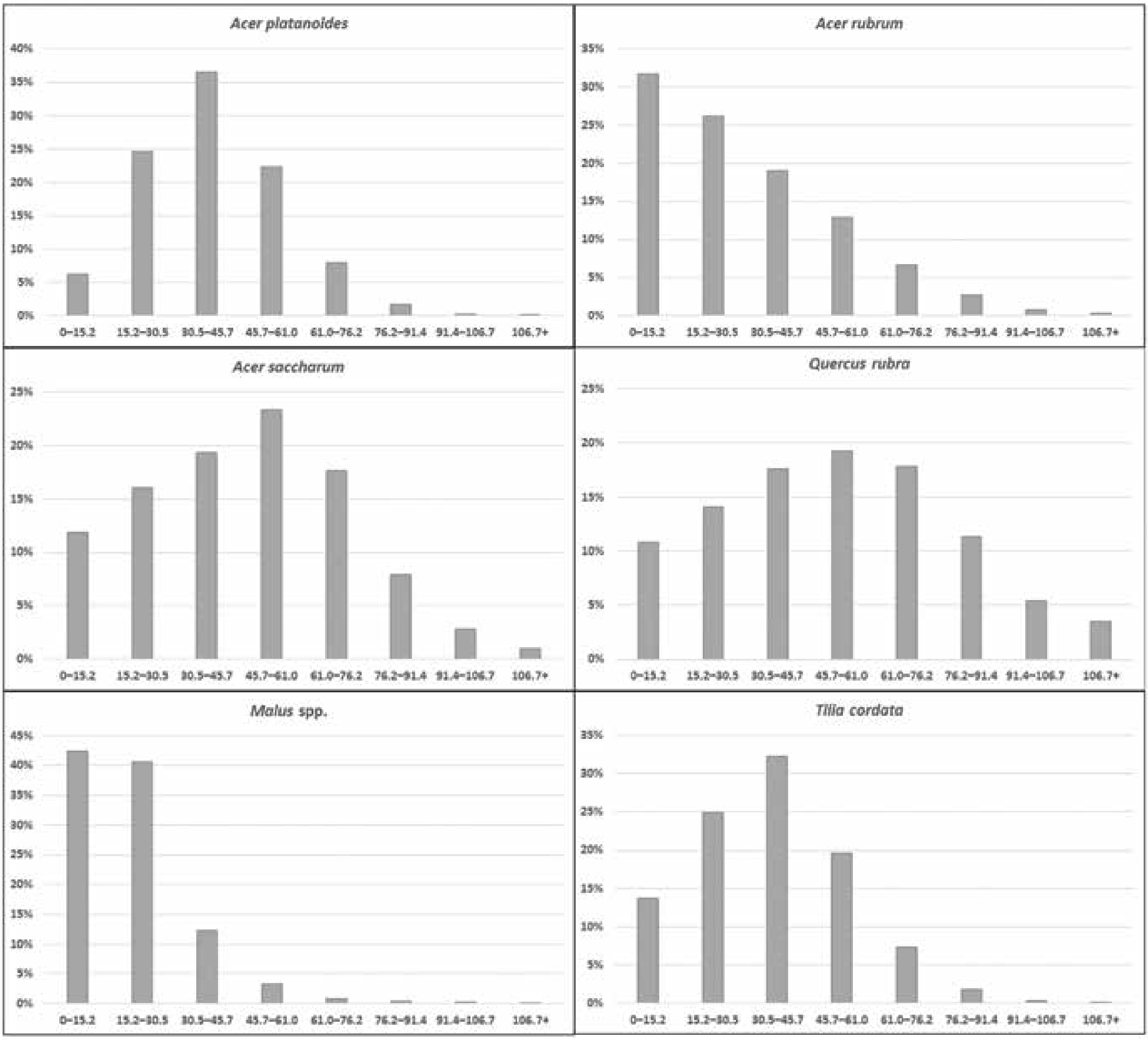

Figure 5. Relative size class distributions of prevalent street tree species in Massachusetts (x-axis = dbh cm).

DISCUSSION

Cumming et al. (2006) and Freilicher (2010) found *Acer platanoides* and *Acer* spp. to be the most prevalent street tree species and genus in Massachusetts. Cumming et al. (2006) also found *Acer rubrum* to be the second most prevalent street tree species and *Quercus* spp. to be the second most prevalent street tree genus and estimated *Acer platanoides* to comprise 34% of all street tree species statewide and *Acer* spp. to comprise 49% of all street tree genera statewide. In Connecticut and New York, two states contiguous to Massachusetts, Ward (2011) found *Acer* spp. to be the most prevalent Connecticut street tree genus, comprising 48% of the statewide street tree population, and Cowett and Bassuk (2017) found *Acer* spp. to be the most prevalent New York street tree genus, comprising 40.9% of the statewide street tree population, and *Acer platanoides* to be the most prevalent New York street tree species, comprising 19.8% of the statewide street tree population. Cowett and Bassuk (2017) also found *Acer* spp. to be the most prevalent street tree genus and *Acer platanoides*

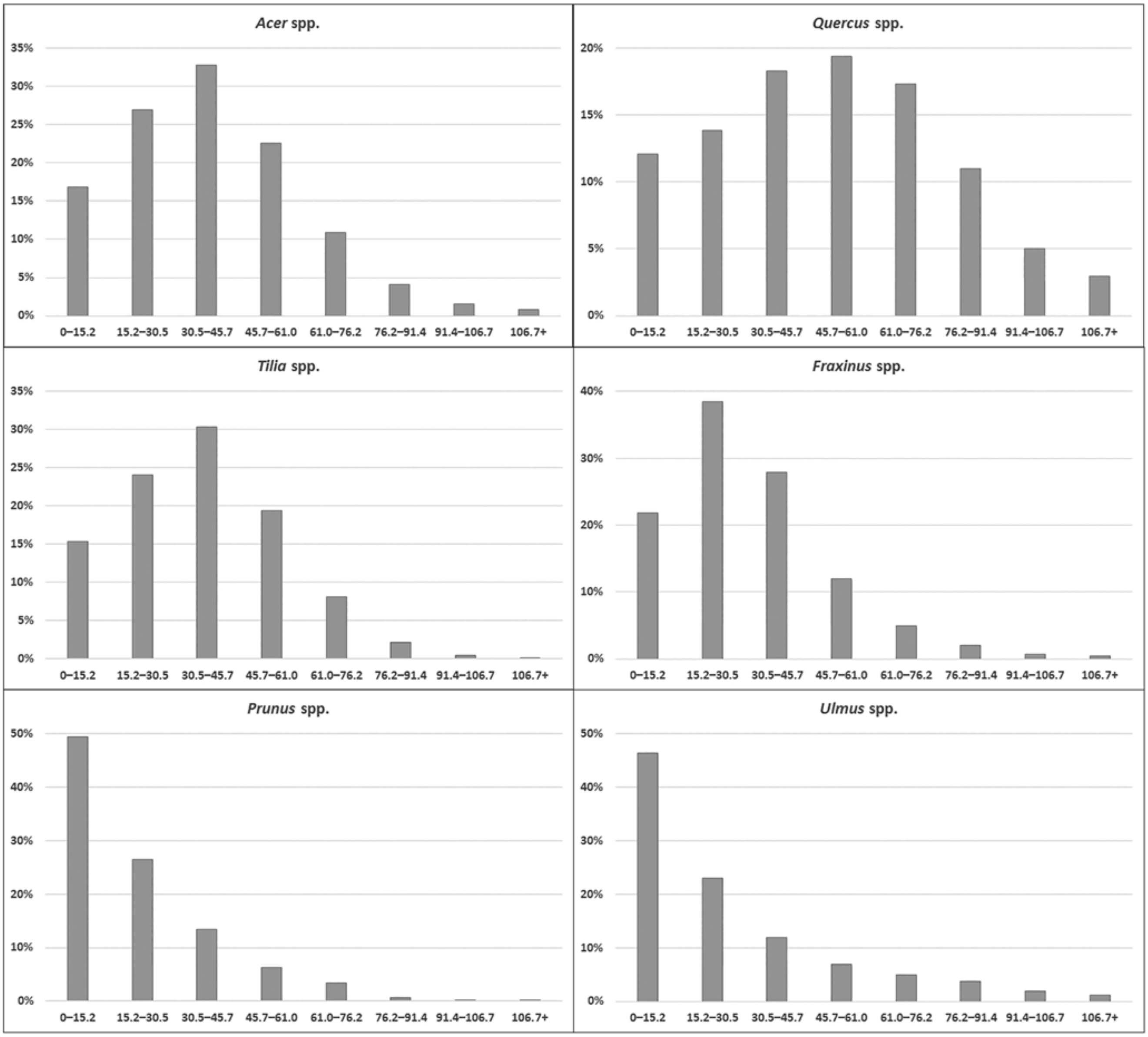

Figure 6. Relative size class distributions of prevalent street tree genera in Massachusetts (x-axis = dbh cm).

to be the most prevalent street tree species in the nearby northeastern states of New Jersey and Pennsylvania.

This paper's results regarding the dominance of *Acer platanoides* and *Acer* spp. in statewide street tree species and genus composition are not only consistent with the findings made in Connecticut, New Jersey, New York, and Pennsylvania, but they confirm the findings made by Cumming et al. (2006) and Freilicher (2010) in Massachusetts. This paper similarly found *Acer rubrum* to be the second most prevalent street tree species and *Quercus* spp. to be the second most prevalent street tree genus. However, the relative abundance percentages for these species and genera were found to be substantially lower in this paper than in Cumming et al. (2006). Because most of the street tree inventory data collated for this paper were collected in the last few years, approximately ten years after the results reported by Cumming et al. (2006), it is tempting to infer that the two papers provide a longitudinal comparison of the statewide street tree population revealing change in that population. Given the dominance of *Acer platanoides* and *Acer* spp. in the statewide street tree population, reductions in their dominance would be particularly noteworthy to state and municipal officials charged with street tree management. Such reductions would be consistent with and possibly reflect the efficacy of policies adopted at state and local levels to reduce reliance on one street tree species or genus and to increase diversity. A notable example of these policies was the 2006 decision by the Massachusetts Department of Agricultural Resources (MDAR) to place *Acer platanoides* on its prohibited plant list and thereby ban its sale and importation in the state (MDAR 2018).

Assessing structural change in a tree population is based ideally on repeated observations for the same trees in the same study area or, in the case of street trees, on the same street segments over time (Roman et al. 2014; Roman et al. 2016; Halpin and Lorimer 2017). For example, the New Jersey Forest Service (2000) compared data taken in 1994 and 1999 from the same 432 randomly selected one quarter mile-long street segments to find an increase in street tree numbers, but a decline in street tree condition, and the Missouri Department of Conservation compared data taken in 1989 and 1999 from the same 272 randomly selected streetscape plots to find increases in street tree numbers and species diversity (Gartner et al. 2002). Such longitudinal data better account for tree mortality than inferring tree mortality from relative size class dbh distributions (Harcombe 1987). Cumming et al. (2006) and this paper collected statewide street tree data at different points in time, but did not collect longitudinal data for the same trees. The two papers also employed different sampling methodologies. Findings made by Cumming et al. (2006) were based on 296 randomly selected roadway plots containing 1,124 trees located within United States Census defined urban areas, whereas findings in this paper are based on a nonrandom sample of thirty street tree inventories containing 213,845 street trees stratified by the 2012 USDA Plant Hardiness Zones and weighted by selected street length located within Census Places, Census Urbanized Areas, and Census Blocks with a population density of at least 96.5 persons per square kilometer (250 persons per square mile). An additional limitation of this paper is the lack of data for Zone 7a, most of which is located in Cape Cod, Martha's Vineyard, and Nantucket, and comprises 10.2% of the selected Massachusetts street length referenced above. Because the relative abundance percentages for *Acer* spp. were found to increase as average annual minimum winter temperature declined, and the relative abundance percentages for *Quercus* spp. were found to increase as average annual minimum winter temperature increased, it is possible that the inclusion of data from Zone 7a would reduce the statewide percentage for *Acer* spp. and increase the statewide percentage for *Quercus* spp. While such a result would be consistent with the findings made by Cowett and Bassuk (2017) for New York and Pennsylvania, its impact on these statewide percentages would likely be minor.

Therefore, it is possible that the differences in relative abundance percentages found in Cumming et al. (2006) and this paper for prevalent street tree species and genera such as *Acer platanoides* and *Acer* spp. reflect differences in data collection and sampling methodologies rather than structural change in the statewide street tree population. However, while limitations must be acknowledged, it is nonetheless also possible that the differences in relative abundance percentages accurately connote structural change in the Massachusetts street tree population. Two additional finding suggest this might in fact be the case. First, in collating data for this paper, street tree inventory data were obtained from two municipalities for 2007 and 2017. Analysis of this data reveals that, for these ten years in the two municipalities, the relative abundance percentage for *Acer platanoides* declined 14.6% in the first municipality and 19.5% in the second, and the relative abundance percentage for *Acer* spp. declined 10.0% in the first municipality and 23.2% in the second. Second, while relative size class distributions should not be relied on solely to confirm structural change in a tree population, they are suggestive of the trajectory of future population dynamics. Pronounced humps in the mid-sized dbh classes of the distribution profiles for *Acer platanoides* and *Acer* spp. indicate that in the long term, the statewide relative abundance percentages of *Acer platanoides* and *Acer* spp. are on track to decline.

This paper also found that street tree species and genus diversity increases as the percentages of *Acer platanoides* and *Acer* spp. in a municipal street tree population decrease. Therefore, structural change in the Massachusetts street tree population, whereby reliance on any one street tree species or genus was reduced, could signify progress in increasing street tree species and genus diversity. Notwithstanding the possibility of such progress, considerable work remains to be done. Street tree species and genus diversity was found to be correlated more with the number of species and genera (i.e., species and genus richness) than with the evenness of the species and genera distribution. In other words, prevalent street tree species and genera remain dominant. 93.3% of the municipalities from whom street tree inventory data were obtained for this paper exceed Sanatmour's 10% rule for species, and 100% of the municipalities exceed his 20% rule for genus, not to mention the more stringent thresholds recommended by Barker (1975), Bassuk et al. (2009), and Ball (2015).

When equated with tree numbers, the work required to increase street tree diversity and meet thresholds such as Santamour's is daunting. For example, the median number of street trees for municipalities from which street tree inventory data were obtained was 4,216, and the median percentage of *Acer* spp. for these municipalities was 38.8%. For a municipality with 4,216 street trees, of which 38.8% are *Acer* spp., reducing the percentage of *Acer* spp. from 38.8% to 20.0% would require the addition of 3,970 non-*Acer* street trees, or nearly doubling the number of trees in the street tree population. This figure does not account for tree mortality and removals, including variable mortality rates for different tree size classes, such as for newly planted trees. Nevertheless, the fact remains that increasing diversity to meet thresholds such as those proposed by Santamour, especially for a large municipality with thousands, if not tens of thousands of existing street trees, requires a substantial financial investment.

Even if a municipality decides to make the financial investment to increase street tree diversity, additional challenges must be overcome, many of which have been discussed previously in Polakowski et al. (2011) and Lohr (2013), including: inhospitable growing conditions typically associated with the public street right-of-way; stressors associated with climate change such as drought and extreme weather events; pests and diseases in addition to the ALB, including the emerald ash borer (*Agrilus planipennis*), hemlock woolly adelgid (*Adelges tsugae*), oak wilt (*Ceratocystis fagacearum*), and most recently spotted lanternfly (*Lycorma delicatula*); growth and branching habits of tree species poorly suited for streetscapes; the legacy of monocultures and aesthetic preference for visual uniformity in street tree plantings; preferences by property owners, developers, and municipal officials for certain tree species and insufficient understanding about diversity's importance; lack of nursery availability for less prevalent street tree species and genera; and insufficient genetic and cultivar diversity in available nursery stock and existing street tree plantings. Moreover, a non-host specific, polyphagous pest such as the ALB creates additional problems since, as Berland and Hopton (2016) have pointed out, a less diverse street tree population comprised of ALB resistant tree species and genera will be less vulnerable to the ALB than a more diverse street tree population comprised of ALB host tree species and genera. In other words, increasing tree diversity without considering local pest pressure will not inherently facilitate street tree population sustainability, a challenge that becomes still more complex when multiple hosts and pests are involved (Laćan and McBride 2008). Given the circumstances involved, it may be imperative to not limit street tree diversification to native tree species and to consider planting nonnative tree species, especially if certain nonnative species are judged to be pest, disease, and drought resistant and capable of coping with inhospitable growing conditions (Sjöman et al. 2016; Riley et al. 2018). To secure consistent access to less prevalent tree species and genera, New York City entered into long-term contracts with nurseries to grow desired tree species and genera (Stephens 2010), and some municipalities, including several in Massachusetts, started their own nurseries, although many closed or scaled back operations after the municipality found the nursery to be too much work and/or to have produced poor quality trees (City of Northampton, MA 2015).

Therefore, increasing street tree diversity may not be a panacea for the sustainability of the street tree population, and its true value in comparison to other factors, such as site suitability, nursery availability, and aesthetic preferences, may warrant further study (Berland and Hopton 2016). Nevertheless, it remains an important consideration in sustainable street tree management at municipal and statewide scales, and while there may be many challenges in achieving it as a goal, to not address these challenges head on means to risk losing not only the public investment already made in street trees, but the ecosystem services and social benefits trees provide, now and in the future.

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Conflicts of Interest: The authors reported no conflicts of interest.

Résumé. Les insectes, les maladies et les changements climatiques représentent des défis majeurs pour la survie des arbres d'alignement et il est largement convenu que la diversité des espèces et des genres favorise la résilience des populations d'arbres municipaux. À l'inverse, une faible diversité dans la population d'arbres d'alignement a été considérée comme un facteur contribuant à la mortalité et à l'abattage subséquent de milliers d'arbres de rue de Worcester, Massachusetts, la deuxième ville la plus populeuse de l'État, en raison de l'infestation du longicorne asiatique (*Anoplophora glabripennis*). Par conséquent, réduire la prépondérance d'espèces et de genres dominants d'arbres d'alignement et accroître leur diversité est considéré fondamental pour la gestion durable d'arbres sur rues et la préservation des services écosystémiques et des bénéfices sociaux qu'ils génèrent. Le présent article établit la diversité des arbres d'alignement dans le Massachusetts en analysant un échantillonnage non aléatoire de données regroupées d'inventaires d'arbres municipaux stratifiées selon les zones de rusticité végétale. Cohérents avec les résultats obtenus précédemment pour le Connecticut, le New Jersey, New York et la Pennsylvanie, les résultats du Massachusetts établirent qu'un nombre relativement réduit d'espèces et de genres dominaient la composition de la plupart des populations municipales d'arbres en alignement, tout particulièrement les érables, *Acer* spp., un des genres hôtes préférés du longicorne asiatique. Il y a en conséquence un besoin pour une plus grande diversité des espèces et des genres au sein des populations d'arbres en alignement dans tout l'État. Bien qu'il y ait une tendance vers une diversité accrue parmi les arbres sur rues et une diminution de la prépondérance des *Acer* spp., un travail considérable reste à accomplir.

Zusammenfassung. Schädlinge, Krankheiten und Klimaveränderungen können große Herausforderungen für das Überleben von Straßenbäumen bedeuten und die Diversität der Baumarten und Gattungen wird weitgehend angesehen als Förderung der Nachhaltigkeit von kommunalen Straßenbaumpopulationen. Umgekehrt wird der Mangel an ausreichender Diversität in Straßenbaumpopulationen als beitragender Faktor für den Tod und die Entfernung von Tausenden von Straßenbäumen aufgrund einer Infektion mit dem Asiatischen Laubholzbockkäfer (ALB, *Anoplophora glabripennis*) in Worcester, Massachusetts, dem Bundesstaat mit der zweithöchsten Bevölkerungszahl, gesehen. Daher wird die Reduzierung der Dominanz vorherrschender Straßenbaumarten und Gattungen und Vergrößerung der Baumarten- und Gattungsdiversität als lebenswichtig für nachhaltiges Straßenbaummanagement und für die Erhaltung von ökologischen Leistungen und sozialen Vorzügen, die Bäume leisten, erachtet. Dieses Papier untersucht die Straßenbaumdiversität in Massachusetts durch Analyse einer nicht randomisierter Probennahme aus gesammelten Daten von kommunalen Baumkatastern, stratifiziert durch die Klimazonenanpassung der Pflanzen. Übereinstimmend mit früher erfassten Daten aus Connecticut, New Jersey, New York, und Pennsylvania, indizieren die Resultate aus Massachusetts, dass eine relativ kleine Anzahl von Arten und Gattungen die Komposition der meisten Straßenbaumpopulationen dominieren, einschließlich *Acer* spp., eine der von ALB favoritisierten Wirtspflanzengattung. Daher gibt es ein großes Bedürfnis nach größerer Arten- und Gattungsdiversität in Straßenbaumpopulationen bundesweit. Während es möglicherweise einen Trend zur Diversität und Reduktion von der Dominanz von Ahornarten gibt, muss noch viel Arbeit geleistet werden.

Resumen. Las plagas, las enfermedades y el cambio climático plantean importantes desafíos para la supervivencia de los árboles urbanos y se considera ampliamente que la diversidad de especies y géneros de árboles promueve la sostenibilidad de las poblaciones municipales de árboles. Por el contrario, la falta de diversidad suficiente en la población de árboles se consideró un factor contribuyente en la muerte y la eliminación de miles de árboles en Worcester, Massachusetts, la segunda ciudad más poblada de ese estado, debido a una infestación del escarabajo asiático de cuernos largos (ALB, por sus siglas en inglés, *Anoplophora glabripennis*). Por lo tanto, reducir el dominio de las especies y géneros de árboles prevalentes y aumentar la diversidad de géneros y especies arbóreas se considera vital para el manejo sostenible de los árboles urbanos y para la preservación de los servicios del ecosistema y los beneficios sociales que proporcionan los árboles. Este documento evalúa la diversidad de árboles de la calle en Massachusetts mediante el análisis de una muestra no aleatoria de datos de inventario de árboles de calles municipales recopilados, estratificados por zonas de resistencia de la planta. En consonancia con los resultados encontrados anteriormente para Connecticut, Nueva Jersey, Nueva York y Pensilvania, los resultados en Massachusetts indican que un número

relativamente pequeño de especies y géneros dominan la composición de la mayoría de las poblaciones de árboles municipales, incluyendo en particular *Acer* spp. (arce), uno de los géneros de host favoritos de ALB. Por consiguiente, existe la necesidad de una mayor diversidad de especies y géneros en las poblaciones municipales de árboles urbanos en todo el estado. Si bien puede haber una tendencia hacia una mayor diversidad de árboles y una reducción en el dominio de *Acer* spp., queda mucho trabajo por hacer.