Urban trees worldwide have low species and genetic diversity, posing high risks of tree loss as stresses from climate change increase

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Abstract

Popular trees that are known to grow well in a region are often the first ones people choose to plant in the landscapes that surround them. Historically, this has resulted in over-planting particular species, such as the American elm (*Ulmus americana*). This species had little genetic variation in its natural resistance to Dutch elm disease (*Ophiostoma ulmi*), leading to the death of most American elms. In many areas, the species of trees that are well suited to urban conditions are somewhat limited; those suitable as street trees are even more limited. Analyses of urban tree inventories worldwide show the problem of overplanting still exists in many cities, with the average abundance of the most common species being about 20% worldwide, while being over 40% in some cities. The current ability to clone trees with desirable characteristics means that many tree species planted today have even less genetic variation than those planted from seeds in previous decades. Climate change will bring new growing challenges for urban trees. Trees that grew well under environmental conditions of the past may no longer be suitable in the future. Coupling these factors places cities in danger of rapidly losing large numbers of urban trees, with grave environmental and human consequences, including increased urban heat island temperatures and more heat-related human deaths.

Keywords: biodiversity, diseases, Dutch elm disease, insects, relative abundance, street trees, tree inventories, urban forests

INTRODUCTION

Selecting a tree to plant involves many considerations, such as its size, appearance, and growing requirements. People who plant landscape trees often imagine that the trees will be there decades or even centuries after the planters have died. They are considering the future. They usually chose a tree species that they are familiar with and that is known to grow well where it is being planted. This often results in a few popular tree species dominating in particular areas. This is especially true in cities, where unnatural and harsh conditions, such as heavily compacted soils, excessive temperatures, and dry soils restrict the number of species that will grow well (Wittig and Becker, 2010). In degraded urban landscapes, highly adapted, early succession species are often required for successful establishment (McKinney, 2006). Adding additional restrictions, such as fitting specific design considerations or functioning as a street tree, compound the problem by further restricting the pool of species that may be suitable for a given location.

There are risks associated with planting large numbers of the same species of plants in a limited area. A single pest or environmental onslaught could kill the dominant species, leaving the area devastated. The classic example used to illustrate this risk is the overplanting of elm trees, particularly the American elm (*Ulmus americana*) and the subsequent appearance of Dutch elm disease (*Ophiostoma ulmi*) (Wilson, 1975; Jones, 1981). Elm trees were particularly popular as urban street trees, because they grew quickly, tolerated harsh conditions (e.g., drought), and had a form that people liked (Lohr and Pearson-Mims, 2006). These trees lacked resistance or tolerance to the previously unknown Dutch elm disease. The narrow genetic base of the popular cultivars of elm and large populations of the beetle that spread the pathogen because of plentiful access to the trees likely contributed to the development of the problem (Gibbs, 1978). Millions and millions of elm trees in North America and Europe died when they became infected.

Santamour (1990), a research geneticist with the United States National Arboretum, was particularly concerned about this problem. He recommended that we plant no more than 10% of any single tree species, no more than 20% of any single genus of trees, and no more than 30% in any single family. This rule of thumb became known as the 10-20-30 rule, and many city planners and urban foresters have been aware of it and recommending it for years (Clark et al., 1997; Davey Resource Group, 2008; San Jose, 2014). When the 10-20-30 rule was first proposed, the risks of major devastating problems that might kill or damage all or nearly all of a particular tree species were lower than they are today. A number of major threats have emerged or increased, including climate change, globalization and urbanization (McKinney, 2006; Tubby and Webber, 2010; Lohr and Relf, 2014). These are all increasing the risks of catastrophic disasters. An additional risk has been posed by the ease of cloning and the promotion of what are seen as superior cultivars with desirable traits (Morton and Gruszka, 2008). Thus, trees in cities today not only have little biodiversity (different species), but little genetic diversity (differences within a species).

The purpose of this research was to compare the relative abundance (percentage of total individuals) of most common urban tree species in cities throughout the world and by continent to the recommendation of no more than 10% of any one species, 20% on any genus, and 30% of any family and to demonstrate the feasibility of achieving set benchmarks.

MATERIALS AND METHODS

Tree inventories from 108 cities around the world were collected from published journal articles and government reports (Kendal et al., 2014). Most inventories were from North America and Europe, but lists from Asia, South America, Africa, and Australia were also obtained. Data from the studies were entered as relative abundance or converted to relative abundance if presented as tree counts. Relative abundance of the most common taxon has been shown to be a good predictor of diversity and a useful and simple measure of diversity for urban forest managers (Kendal et al., 2014). Statistics for the overall relative abundance of the most common tree species, genus, and family were calculated. These included the mean, 25th percentile and 10th percentile. Means by continent were also calculated.

To further understand the results at the species level and to determine the feasibility of achieving the recommended benchmarks (Santamour, 1990), we selected examples to show what specific cities have achieved for the relative abundance levels of the most common tree species. Individual inventories were reviewed to select representative examples near each of the statistical summary points and above and below them. The specific examples were selected to represent both wide global distribution and climatic variation using Köppen climate groups (Peel et al., 2007).

RESULTS AND DISCUSSION

The mean value of relative abundance of the species of the single most common tree in the cities examined in this study was 20% (Table 1). This is twice as high as Santamour's recommended benchmark of no more than 10% (Santamour, 1990). Even cities at the 25th percentile, with a relative abundance of 13%, exceeded this benchmark. Only cities at the 10th percentile met the benchmark, coming in at 9%. The range showed that cities could exceed the benchmark, with the lowest relative abundance for species being only 5%, but cities could also have more than 50% of their trees being a single species. The mean value of relative abundance of the genus of the single most common tree in the cities examined in this study was 26% (Table 1), somewhat higher than the recommended benchmark of no more than 20%. Cities at both the 25th and 10th percentiles readily met this benchmark (16 and 13%, respectively). Similar results were found for meeting the benchmark at the family level. This suggests that even more aggressive benchmarks than those proposed by Santamour should be set at the genus and family level to meet 'best practice' patterns of diversity.

Table 1. Summary statistics for the relative abundance of the species, genus, and family of the most common urban tree across the 108 cities included in this study. Statistic for most common urban tree Relative abundance (%)

	Species	Genus	Family
Range: highest value	52	78	78
Range: lowest value	5	8	9
Mean value	20	26	32
Standard deviation	10	13	14
25th percentile	13	16	21
10th percentile	9	13	17

The mean value of relative abundance of the most common species in cities by continent revealed that no continent achieved the recommended benchmark of 10% (Table 2). Australia was the closest, with a mean of only 12%. North America and Asia were about double the recommended level, while Africa was more than three times the recommended level (only three cities from Africa were included in the analysis, so these results should be interpreted with caution). The mean for the most common genus was at or only slightly above the recommended level of 20% in South America, Australia, and Asia. In North America and Africa, it was 30% or more. For the mean relative abundance of the most common family, all continents, except Australia, were near the recommended level of 30%. Australia has a family mean of 44%.

Table 2. Relative abundance and standard deviation (SD) of the species, genus and family of the most common urban tree by continent. Continent Relative abundance (%) (mean ± SD)

	Species	Genus	Family
Africa	33±16	32±16	32±16
Asia	21±9	22±9	28±9
Australia	12±4	22±8	44±19
Europe	24±10	25±12	29±10
North America	20±9	30±16	32±15
South America	17±7	20±9	33±16

There were some interesting differences in urban forest diversity between the continents. Australia had cities with high species diversity but low diversity at the family level. Many urban trees in Australian cities are native, and this reflects the taxonomic diversity of native vegetation, where most non-rainforest tree species are in only two families (Myrtaceae and Fabaceae) (Groves, 1981). In contrast, cities in Europe had low species diversity but relatively high diversity at the family level; only a few species from each of many different families are commonly planted in European cities (e.g., *Acer platanoides*: Aceraceae, *Betula pendula*: Betulaceae, *Robinia pseudoacacia*: Fabaceae, *Platanus × acerifolia*: Platanaceae, *Pinus pinea*: Pinaceae, *Fraxinus excelsior*: Oleaceae). North American cities had relatively high diversity at the genus level, reflecting the dominance of a few genera such as *Acer, Quercus, Fraxinus, Eucalyptus,* and *Lagerstroemia*.

Helsinki is an example of city with a relative abundance of the most common species (*Tilia × europaea*) that is extremely high (44%), more than twice the mean (Table 3). Helsinki has a continental climate, which is typified by winter temperatures well below freezing. Kendal et al. (2014) showed that cities with continental climates were likely to have a higher species relative abundance than ones with temperate climates, reflecting natural patterns of diversity and the challenging environment that street trees in cooler cities face.

An example of a city with a species relative abundance near the 20% mean is Beijing, with 21% *Styphnolobium japonicum* (Table 3). This city also has a continental climate. Leicester and Ballarat are examples of cities with temperate climates, which have winter temperatures that rarely go below freezing. They represent cities with lower species relative abundances than typical continental cities. Leicester has a mean abundance near the 25th percentile, and Ballarat has one below the 10th percentile.

Table 3. Examples of the most common urban forest tree species, the relative abundance (Abun.) of that species, and the Köppen climate group for selected cities around the world.

City	Abund. (%)	Species	Climate	Citation
Helsinki, Finland	44	*Tilia × europaea*	Continental	Sjomann et al., 2012
Port Alfred, RSA	43	*Erythrina caffra*	Temperate	Kuruneri-Chitepo and Shackleton, 2011
Bangkok, Thailand	42	*Pterocarpus indicus*	Tropical	Thaiutsa et al., 2008
Beijing, PRC	21	*Styphnolobium japonicum*	Continental	Yang et al., 2005
Leicester, UK	14	*Crataegus monogyna*	Temperate	Davies et al., 2011
Philadelphia, USA	10	*Prunus serotina*	Continental	Nowak et al., 2007
Bandung, Indonesia	9	*Swietenia macrophylla*	Tropical	Abendroth et al., 2012
Ballarat, AU	7	*Aesculus hippocastanum*	Temperate	Kendal et al., 2012

Winter temperature does appear to be a factor that affects the ease of obtaining diversity in city trees, with fewer choices likely being available in cities with temperatures regularly below freezing. Clearly that is not the only factor influencing the relative abundance of the most common tree species, as shown by the example of Port Alfred (Table 3), which has a temperature climate, but also has one of the highest rates of species relative abundance with 43% Erythrina caffra and by the example of Philadelphia, which has a continental climate, but a low relative abundance with 10% Prunus serotina. Cities in tropical climates can also be used to demonstrate the extremes in relative abundances possible under similar climatic conditions, with Bangkok having a relative abundance of 42% and Bandung having only 9%.

These findings suggest that many cities world-wide are at great risk of losing major portions of their green infrastructure when an environmental, pest, or human-caused disaster that a single species or genus of tree is susceptible to occurs. A current example is the emerald ash borer (Agrilus planipennis). It arrived in North America in 2002 and is quickly killing millions of ash trees (Fraxinus spp.). This insect can kill ash trees in just a few years, and ash trees comprise more than 35% of the urban forest in some communities (Ball et al., 2007). The negative impacts that can occur to human health when large numbers of trees are killed in a short time frame was documented with this loss of ash trees. By comparing deaths rates in counties before and after invasion by the borer to similar counties where the borer had not yet invaded, Donovan et al. (2013) documented an increase of more than 20,000 deaths from respiratory and cardiovascular disease over a five-year period that could be attributed in part to emerald ash borer. Presumably reduced air quality contributed to the increase in respiratory deaths and increased human stress contributed to the cardiovascular problems. Losses of large portions of the urban green infrastructure would also cause an increase in the urban heat-island effect, resulting in increased risk of heatrelated human deaths (Kim, 1992; O'Neill et al., 2009).

If we continue to overplant tree species, particularly when a limited number of cultivars are selected, other catastrophes like those from Dutch elm disease and emerald ash borer are inevitable and in fact are already occurring. One example is ash dieback (Hymenoscyphus pseudoalbidus) in Europe, which is killing trees in urban areas on a similar scale to Dutch elm disease, but at a much faster pace (Bakys et al., 2009). These results also show that overplanting of a single species or clone of trees in cities need not occur. Even cities with extreme, continental climates are able to reach the level recommended by Santamour (1990). These results could be used by cities to set their own benchmarks based on their current situation and striving for improvements in their species diversity mixes to reduce the risk of losses.

Results from this study show that climate has an effect on patterns in the urban forest and that planning and management also play important roles. Green policies and management practices that encourage increasing diversity must be carefully developed to result in acceptable adaptation strategies for climate change rather than unachievable results. For example, the City of Melbourne, Australia, has an elaborate urban forest strategy, in which one of the main objectives is the diversification of the tree species palette (City of Melbourne, 2012). They proposed increasing diversity to no more than 5% of one tree species, no more than 10% of one genus and no more than 20% of one family. This is not the natural pattern in cities with climates similar to Melbourne or in the natural forest in Australia, so achieving this benchmark might be hard to implement and might imply the addition of ill-adapted species. Many cities in Canada also have developed urban forest strategies or management plans including the diversification of their forests, especially as a protective measure against pest and diseases (Canadian Urban Forest Research Group, 2012). This encourages reducing mono-plantings, an objective that might be more achievable than setting specific or strict benchmarks. Ann Arbor, Michigan, developed an urban and community forestry plan to ensure that new trees would lead to an increase in the diversity of the urban forest and increase its resiliency to changing pressures (City of Ann Arbor, 2014). These examples show that from the policy side there is a desire to achieve diversity, especially as a protection against pest and diseases, however since many plans are quite recent, some years need to pass to be able to see how these policies translate into implementation and effectiveness. Diversity of species, genera, and families might not be enough protection from pest and diseases for urban forests; policies to ensure genetic diversity within species should also be considered.

CONCLUSIONS

The need for resiliency in urban forests is growing as challenges associated with climate change, globalization, urbanization, and loss of genetic diversity and biodiversity grow. Catastrophic losses of urban trees from Dutch elm disease, emerald ash borer, and other problems has been a wake-up call for some cities, but others still appear to ignore or be unable to address the risks. In the cities examined in this study, the mean relative abundance of the most common tree species was 20%, which is twice what has been recommended for nearly 25 years (Santamour, 1990). For some cities it was more than 40%. Different imbalances are found in different places, with family diversity being low in Australia, genus diversity low in North America, and species diversity being low in Europe. While some cities have achieved recommended levels, much more needs to be done in many cities around the world to ensure that the co-benefits of urban trees, both in terms of environmental benefits such as reduced urban heat island effect and human health effects such as reduced respiratory illnesses, are sustained into the future.

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