

Urban Biodiversity and Climate Change

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Summary

Climate change has the potential to affect urban vegetation diversity. The effects of climate change will vary across the globe. Global climate change along with increasing urbanization and its associated heat islands could lead to significantly warmer temperatures in developing regions. The local climate and soils, urban processes, vectors of plant and seed transmission, and vegetation management decisions combine to produce the current biodiversity exhibited in cities. The diversity of urban vegetation composition has changed through time with many cities currently having species richness and Shannon-Wiener diversity index values greater than native forest stands. Vegetation managers can affect future biodiversity and help offset potential environmental changes by understanding these changes and designing vegetation plans to sustain future plant health and diversity, and ensure ecosystem services that help mitigate climate changes.

Keywords

urban forests, species diversity, species richness, urban heat islands, urban tree cover

Introduction

In 2007, the United Nation's Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment report (IPCC, 2007) that, in part,

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assesses the scientific information related to the potential effects of climate change in our world. Given the findings of this report, the intent of this paper is to explore the potential implications of climate change on urban biodiversity and potential actions urban vegetation managers may need to take now to help sustain urban biodiversity and vegetation in the future, given a changing climate.

Climate change

The IPCC report (2007) states that 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising average sea levels'. Eleven of the last twelve years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). Observed long-term changes in climate include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, strengthening wind patterns, and aspects of extreme weather events including droughts, heavy precipitation and heat waves. Some future effects of climate change are projected to be: (i) warmer and fewer cold days and nights; (ii) warmer and more frequent hot days and nights; (iii) increased frequency of heat waves; (iv) increased frequency of heavy precipitation events; and (v) increased area affected by droughts.

These potential changes can vary in effect at the continental and regional scale, with some areas projected to exhibit greater temperature increases than others (e.g. warming is to be greatest over land and at high northern latitudes) and some areas experiencing an increase in precipitation (high latitudes) and others likely having decreased precipitation (most subtropical land regions) (IPCC, 2007). The average surface temperature warming following a doubling of carbon dioxide concentrations is likely to be in the 2–4.5 °C range. These changes in temperature and precipitation, along with increasing levels of carbon dioxide, are likely to lead to natural and cultivated species shifts, which will have implications for urban biodiversity.

Urban biodiversity

Urban biodiversity, the diversity of living organisms in urban areas, is a function of the urban ecosystem, including its plants and animals. Healthy

ecosystems and biological diversity are vital to help cities function properly. Biodiversity helps to ensure a quality of life in urban areas by contributing foodstuffs, medicines, environmental quality, and enriching the spiritual, aesthetic and social life of urban dwellers (UNEP, 2008). This chapter will focus on urban vegetation, particularly on urban trees. Trees are a dominant landscape element in many areas, affecting other aspects of biodiversity, and their composition is often directly affected by urban management decisions. A review of the topic of biodiversity and climate change in urban environments has been conducted (Wilby & Perry, 2006), but limited studies on urban biodiversity and climate change exist.

There are many factors that affect tree diversity in urban areas. The urban environment is composed of a mix of natural and anthropogenic factors that interact to produce the vegetation structure in cities. Natural influences include native vegetation types and abundance, natural biotic interactions (e.g. seed dispersers, pollinators, plant consumers), climate factors (e.g. temperature, precipitation), topographic moisture regimes, and soil types. Superimposed on these natural systems is an anthropogenic system that includes people, buildings, roads, energy use, and management decisions. The management decisions made by multiple disciplines within an urban system can both directly (e.g. tree planting, removal, species introductions, mowing, paving, watering, herbicides, fertilizers) and indirectly (e.g. policies and funding related to vegetation and development) affect vegetation structure and biodiversity. In addition, the anthropogenic system alters the environment (e.g. changes in air temperatures and solar radiation, air pollution, soil compaction) and can induce changes in urban vegetation structure.

Urban tree cover

Variations in urban tree cover across regions and within cities give an indication of the types of factors that can affect urban tree structure and, consequently, biodiversity. One of the dominant factors affecting tree cover in cities is the natural characteristics of the surrounding region. In forested areas of the United States, urban tree cover averages 34%. Cities within grassland areas average 18% tree cover, while cities in desert regions average only 9% tree cover (Nowak *et al.*, 2001). Cities in areas conducive to tree growth naturally tend to have more tree cover as non-managed spaces tend to naturally regenerate with trees. In forested areas, tree cover is often specifically excluded by design or management activities (e.g. impervious surfaces, mowing).

Table 5.1 Mean percent tree cover and standard error (SE) for US cities within different potential natural vegetation types (forest, grassland, desert) by land use (from Nowak *et al.*, 1996).

Land use	Forest		Grassland		Desert	
	Mean	SE	Mean	SE	Mean	SE
Park	47.6	5.9	27.4	2.1	11.3	3.5
Vacant/wildland	44.5	7.4	11.0	2.5	0.8	1.9
Residential	31.4	2.4	18.7	1.5	17.2	3.5
Institutional	19.9	1.9	9.1	1.2	6.7	2.0
Other ¹	7.7	1.2	7.1	1.9	3.0	1.3
Commercial/industrial	7.2	1.0	4.8	0.6	7.6	1.8

¹Includes agriculture, orchards, transportation (e.g., freeways, airports, shipyards) and miscellaneous.

Within a city, factors such as land use, population density, management intensity and human preferences affect the amount of tree cover and biodiversity. These factors are often interrelated and create a mosaic of tree cover and species across the city landscape. Land use is a dominant factor affecting tree cover (Table 5.1). However, land use can also affect species composition as non-managed lands (e.g. vacant) tend to be dominated by native species or invasive exotic species. Within managed land uses, the species composition tends to be dictated by a combination of human preferences for certain species (tree planting, perceptions of weediness) and how much land is allowed to naturally regenerate. In some areas of the urban environment (e.g. street trees), tree species composition is often totally dictated by humans – within climatic constraints.

Tree species diversity in cities

Tree diversity, represented by the common biodiversity metrics of species richness (number of species) and the Shannon-Wiener diversity index (Barbour *et al.*, 1980), varies among and within cities and through time. Based on field sampling of randomly located 0.04 ha plots located throughout various cities in North America (Nowak *et al.*, 2008), species richness varied from 37 species in Calgary, Alberta, Canada, to 109 species in Oakville, Ontario, Canada

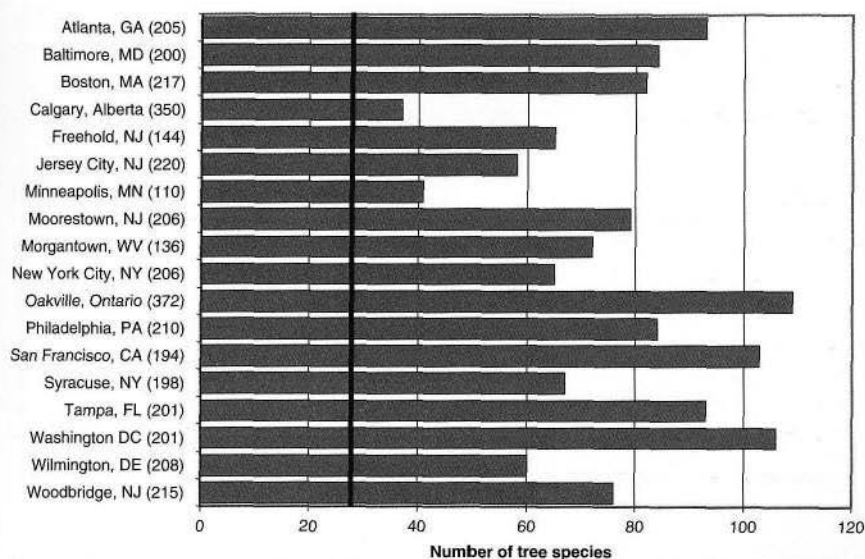


Figure 5.1 Species richness values for tree populations in various cities. Numbers in parentheses are sample size based on 0.04 ha plots. Dark line indicates average species richness in eastern US forest by county (26.3) (Iverson & Prasad, 2001).

(Figure 5.1). Species diversity varied from 1.6 in Calgary to 3.8 in Washington, DC (Figure 5.2). The species richness in all cities is greater than the average species richness in eastern US forests by county (26.3) (Iverson & Prasad, 2001). Species diversity in these urban areas is also typically greater than found in eastern U.S. forests (Barbour *et al.*, 1980). The study areas (Figure 5.1) typically analysed the entire urban political boundary of the city, with the exceptions of Oakville, Ontario, Canada, which focused on more developed parts of the city, and Tampa, FL; and Wilmington, DE; which focused on the city and the surrounding metropolitan area.

The species richness and diversity numbers are not directly comparable as each city had a different sample size, but most cities had around 200 plots. Calgary, which had the lowest species richness and diversity, also had one of the largest sample sizes (350 plots). Though a larger sample size will tend to increase a richness estimate, relatively few tree species were encountered in this grassland city, whose tree population was dominated by Quaking Aspen (*Populus tremuloides*) (67%). The estimates of species richness and diversity

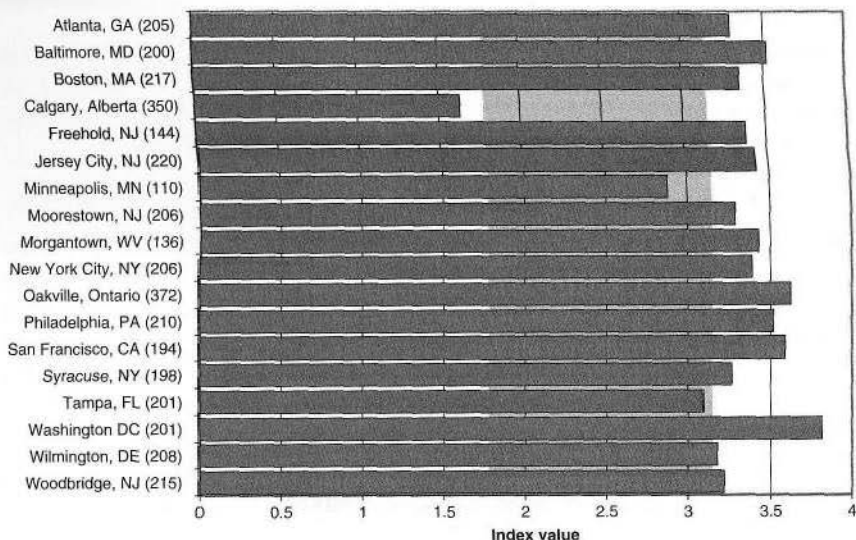


Figure 5.2 Shannon-Wiener Diversity Index values for tree populations in various cities. Numbers in parentheses are sample size based on 0.04 ha plots. Shaded area indicates typical range of diversity values for forest in the eastern United States (1.7–3.1) (Barbour *et al.*, 1980).

are also likely to be conservative in all cities as some tree species were only identified to genera (e.g., *Crataegus* spp., *Malus* spp.). Tree species were not identified to cultivars, and included hybrid species.

In addition to tree species richness and diversity tending to increase in urban areas relative to their surrounding habitat, the global geographic range of species also tends to increase for urban trees with exotic species introduced from around the world. For cities in North America (Figure 5.3), most tree species are native to North America. However, on average, about 20% of the tree population is native to Europe or Asia. In Freehold and Jersey City, NJ, greater than one-third of the tree population is native to Europe or Asia. In the Mediterranean-type climate of San Francisco, CA, where many plant species can survive, only 25% of the tree population is native to North America. Most trees are native to Europe or Asia (33%) or Australia (29%).

Tree species diversity and richness in urban and urbanizing areas can change significantly through time as landscapes become developed. As an example, presettlement Oakland, CA, was dominated by grassland, marsh and

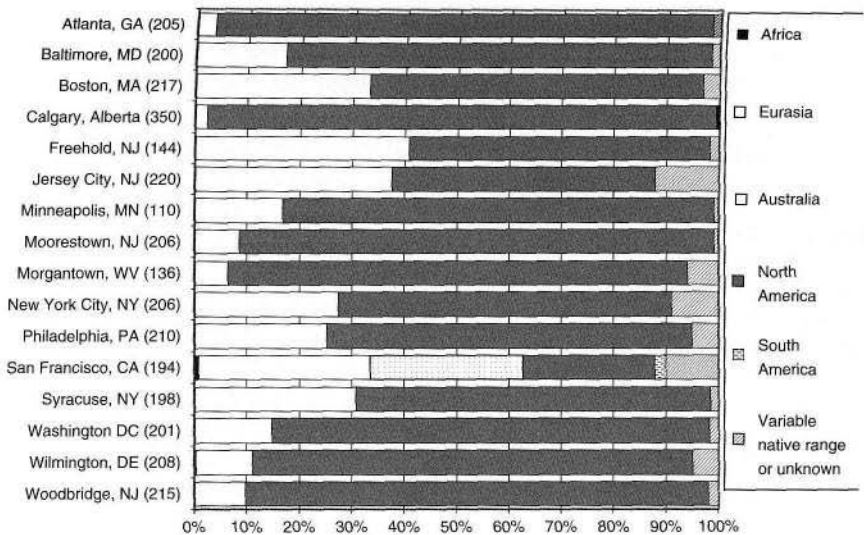


Figure 5.3 Percent tree population distribution by region of origin in various North American cities. Numbers in parentheses are sample size based on 0.04 ha plots.

shrubs, with only approximately 2.3% tree cover in 1852 (Nowak, 1993a). Species richness at that time is estimated at 10 species, dominated by Coast live Oak (*Quercus agrifolia*), California Bay (*Umbellularia californica*) and Coast Redwood (*Sequoia sempervirens*), with an estimated Shannon-Wiener diversity index value of 1.9 (Nowak, 1993a). By the early 1990s, Oakland's tree cover had increased to 19% with over 350 tree species and Shannon-Wiener diversity index value of approximately 5.1. Tree species composition is currently dominated by trees from Australia and New Zealand (38%), with only 31% of the trees native to Oakland. The most common tree species now are Blue Gum (*Eucalyptus globulus*) (23%), Coast live Oak (12%), California Bay (9%) and Monterey Pine (*Pinus radiata*) (7%).

Tree species diversity and richness is enhanced in urban areas compared with surrounding landscapes and/or typical forest stands as native species richness is supplemented with species introduced by urban inhabitants or processes. People often plant trees in urban areas to improve aesthetics and/or the physical or social environment. Some non-native species can invade via transportation corridors or escape from cultivation (e.g. Muehlenbach, 1969;

Haigh, 1980). The ecosystem services or benefits ascribed to urban trees include improvements in air and water quality, building energy conservation, cooler air temperatures, reductions in ultraviolet radiation, and many other environmental and social benefits (e.g. Dwyer *et al.*, 1992). One of the most significant means by which trees can help improve the urban environment is by affecting the local microclimate.

Urban climate and trees

The urban climate is dominated by regional climatic variables, but at the local scale, urban surfaces and activities (e.g. buildings, vegetation, emissions) can and do influence local meteorological variables such as air temperature, precipitation and wind speeds. Thus management decisions regarding urban design with trees can affect local microclimates.

Urban effects on local climate

Urban areas often create what is known as the 'urban heat island', where urban surface and air temperatures are higher than the surrounding rural areas. These urban heat islands can vary in intensity, size and location based on many factors and can lead to increased temperatures in the range of 1–6 °C (US EPA, 2008). Heat island intensity is often largest during calm, clear evenings following sunny days as rural areas cool off faster at night than cities, which retain much of the heat stored in roads, buildings and other structures. Heat island intensity also generally decreases with increasing wind speed and/or increasing cloud cover, is best developed in the warm portion of the year, and tends to increase with increasing city size and/or population (Arnfield, 2003). Factors that contribute to urban heat islands include enhanced heat storage and absorption by urban surfaces, loss of evaporative cooling and anthropogenic heat sources. These increases in urban air temperatures can lead to increased energy demand in the summer (e.g. to cool buildings), increased air pollution, and heat-related illness.

Urban areas also affect local precipitation. In various city areas in the southeastern United States, there is an average increase of about 28% in monthly rainfall rates (average increase of about 0.8 mm/hr) within 30–60 km downwind of city areas, with a modest increase of 5.6% over the city area. The maximum downwind precipitation increase was 51% (Shepherd *et al.*, 2002).

During the monsoon season, the northeastern suburbs and exurbs (i.e., region beyond the suburbs) of Phoenix, AZ have experienced a 12–14% increase in mean precipitation from pre-urban to post-urban development (Shepherd, 2006). Similarly, the average warm-season rainfall in the Houston, TX area increased by 25% from pre- to post-urbanization (Burian & Shepherd, 2005). The increased precipitation patterns could be due to enhanced convergence associated with increased surface roughness, destabilization due to urban heat islands resulting in convective clouds, enhanced aerosols for cloud condensation nuclei, and/or bifurcating or diverting of precipitation systems by the urban canopy or related processes (Shepherd, 2005). Though many studies show an increase in precipitation due to urbanization, a study in the Pearl River Delta region of China suggests an urban precipitation deficit where urbanization reduces local precipitation during the dry season. This deficit may be caused by changes in surface hydrology that reduces the water supply to the local atmosphere (Kaufmann *et al.*, 2007).

Tree effects on local climate

As trees are part of the urban structure, they also affect local and regional temperature and precipitation. Trees can alter urban microclimates and cool the air through evaporation from tree transpiration, blocking winds, and shading various surfaces. Trees in urban areas can help mitigate heat island effects and reduce energy use and consequent power plant emissions. Local environmental influences on air temperature include amount of tree cover, amount of impervious surfaces in the area, time of day, thermal stability, antecedent moisture condition, and topography (Heisler *et al.*, 2007). Vegetated parks can cool the surroundings by several degrees Celsius, with higher tree and shrub cover leading to cooler air temperatures (Chang *et al.*, 2007). Trees can also have significant impacts on wind speeds, with measured reductions in wind speeds in high canopy residential areas (77% tree cover) in the order of 65–75% (Heisler, 1990).

Trees can also indirectly influence local climate by affecting global climate. Urban trees can potentially affect global climate change by altering carbon dioxide concentrations. Trees through their growth process can sequester significant amounts of carbon in their biomass (Nowak & Crane, 2002). In addition, trees near buildings can alter building energy use and potentially lower carbon emissions from power plants (Nowak, 1993b).

Urban plant biodiversity

The biodiversity in urban areas is affected by both natural and anthropogenic factors. Natural factors include climate, native species pools and soils. Anthropogenic factors include altered climate (local and global), pollution, physical disturbances, landscape design, and management activities related to species selection, plantings and removals. Thus to understand or sustain urban biodiversity in the future, three interacting factors need to be considered: (i) changing global climate that will alter future temperatures, precipitation, and growing season length; (ii) urban climate effects on local and regional temperatures and precipitation, whose effects are likely to increase due to increased extent and intensity of urbanization; and (iii) human activities in urban areas that affect pollution and carbon dioxide concentrations, disturbance patterns, and decisions related to vegetation design, selection, plantings and removals.

Just as management decisions made in previous decades are apparent today, the management decisions made today and in the future by multiple urban land owners will directly affect future urban vegetation structure and biodiversity. The survival and health of vegetation that is directly planted and managed will be affected by the altered urban and global climate. Vegetation in naturally regenerated areas will also be affected by a changing climate. Understanding how natural regeneration patterns of plants in cities will change, which species will thrive under future conditions, and how vegetation management can influence future biodiversity and potentially mitigate future climate change will be important for directing future urban biodiversity and local climate towards a desired state.

Species and diversity effects

The environmental conditions under which vegetation must endure have changed in cities relative to natural areas (e.g. increased carbon dioxide levels and temperature), and these conditions are likely to change further in the future due to climate change and increased urbanization. Thus, plant composition in urban areas has changed and will likely change in the future.

Given projected climate change scenarios, natural tree species composition and ranges are projected to shift. Projections for 80 tree species in the United States show significant potential shifts in range and importance values for

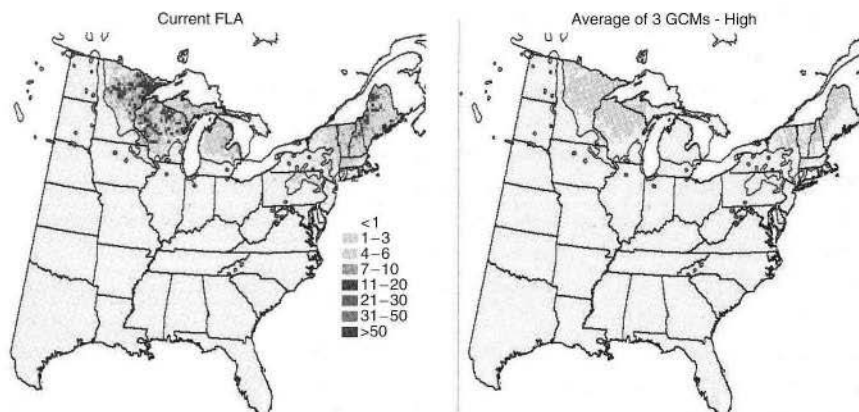


Figure 5.4 Geographic distribution of current importance values (Current Forest Inventory and Analysis (FIA)) for Paper Birch (*Betula papyrifera*) and predicted importance values based on future climate determined by average results of the three general circulation models (GCMs), assuming current emission trends continue into the future without modification (from Prasad *et al.*, 2007).

some species (Iverson *et al.*, 1999; Iverson & Prasad, 2001; Prasad *et al.*, 2007) (Figure 5.4). In addition to natural potential additions and losses of tree species, herbaceous species will also change. Increasing carbon dioxide levels have been found to stimulate Soya bean (*Glycine max*) growth, with weed growth stimulated to a greater extent during years with normal precipitation (Ziska & Goins, 2006). Not only can weed and crop growth be stimulated, but the plant chemistry can change. Increased carbon dioxide levels have been found to not only stimulate the growth of Poison Ivy (*Toxicodendron radicans*), but increase the production of urushiol, the oil in poison ivy that causes a rash in humans (Ziska *et al.*, 2007). Enhanced carbon dioxide levels can also increase growth and productivity of trees (Backlund *et al.*, 2008). These changes in tree and herbaceous plant populations will have impacts on urban biodiversity and urban vegetation management.

Changes in the urban distribution of ruderal herbaceous species, trees and shrubs due to increased temperatures have been noted in central European cities (Sukopp & Wurzel, 2003). Warmer city climates tend to lead to a longer growing season and a shift in phenological phases. Warmer cities or parts of cities have favoured the spread of the Tree of Heaven (*Ailanthus altissima*) in Central Europe. Reductions in low winter temperatures have facilitated

natural regeneration of English Laurel (*Prunus laurocerasus*) in Berlin. This species has been cultivated there since the 1600s, but the first seedlings were not observed until 1982. Phenological phases of plants have also been observed to start several days earlier in the city centres than at the city edge or in large parks. In West Berlin, Crimean Linden's (*Tilia euchlora*) first flowers are seen 8 days earlier in the inner city than at the city's edge (Zacharias, 1972; Sukopp & Wurzel, 2003). These shifts in species habitat and phenology are and will continue to affect future biodiversity in cities.

In natural sites where human activity and impacts are minimal, the existing vegetation structure would be that of the native vegetation types that existed in the recent past. However, the natural vegetation structure and biodiversity are likely to be altered as direct (e.g. development, agriculture) and indirect (e.g. climate change) anthropogenic influences are globally existent to varying degrees. To understand what types of species will be present on a particular urban site, three site attributes need to be considered in addition to regional species diversity: indirect anthropogenic effects (e.g. altered atmospheric chemistry, hydrology, light and temperatures), disturbance (e.g. trampling, fire, tilling) and direct vegetation management activities (e.g. plant introduction, planting, removals). The degree to which the natural species composition and patterns will be altered depends upon the degree of intensity and frequency of these three factors.

Indirect anthropogenic effects can alter species composition. For example, in a natural park in Tokyo, Japanese Red Pine (*Pinus densiflora*) were dying and being successional replaced with broad-leaved evergreen species (Numata, 1977). This shift in species composition has been attributed to sulphur dioxide air pollution with the broad-leaved species being more resistant to air pollution. Frequency of disturbance can also have a significant impact on species composition and diversity. Increased disturbance, up to a point, can lead to increased plant diversity within urban areas by temporarily reducing competition and allowing species to expand their realized niches (Peet *et al.*, 1983). However, at more highly disturbed sites in Europe, mature tree structures will likely not be sustained and these sites will tend to be colonized by stress-tolerant neophytic (species introduced after 1500) ruderals (Sukopp *et al.*, 1979). The degree of disturbance influences the amount and types of vegetation found at a site (e.g. Grime, 1977; Sukopp & Werner, 1982).

Overall, the most important factors affecting plant species diversity in urban areas are likely to be human values and actions. Regardless of natural plant patterns and regeneration, and influences of indirect anthropogenic

effects and disturbance, the direct human management of vegetation can override these forces and dictate a plant composition on a site through such factors as plantings, site modifications, herbicides and plant removal. Through management, humans can directly influence plant composition on a site. However, long-term survival, plant health and cost will be dependent upon species selections that are adapted to the site conditions, which include disturbance and anthropogenic indirect effects (e.g. pollution, climate change).

Outcomes and recommendations for urban biodiversity management

As humans are a main driver of the landscape of cities and vegetation management can significantly influence biodiversity in cities, the decisions and actions of urban dwellers are critical to sustaining biodiversity. Climate change is likely to alter plant composition and trends in cities. As cities are often already warmer and have higher carbon dioxide levels than the surrounding countryside, they offer an opportunity to study the potential impacts of climate change on plants and various ecosystem processes. Gradient studies from urban to rural areas can help reveal current and potential future vegetation responses to environmental changes (e.g. Carreiro & Tripler, 2005). Understanding the potential impacts of climate change on urban vegetation will be critical to sustaining tree population and diversity in urban areas in the future. Urban vegetation management can be used to sustain vegetation diversity and health in the future.

Managing for future conditions

As climates around urban areas are changing due to urban heat islands and global climate change, managers today need to understand the likely climate of the future for their area so they can begin planting trees that are adapted to both current site conditions and likely future conditions. This change may necessitate planting native species that are from warmer portions of their native habitat range or facilitating the movement of plants into new regions as climates change. However, the introduction of new plants should be done with caution to ensure adaptation and survival, and avoid invasiveness issues that can happen when plants are introduced into a new area. The concept of what is native to a region may not be appropriate in the future as native species

shift ranges under future climate conditions (e.g. Iverson *et al.*, 1999). Also, in the altered urban environment, many exotic species have been introduced, survive, or even outperform native species under certain urban conditions. Thus, the concept of native in highly altered, non-native urban environments is somewhat of an oxymoron.

Managers should look for species that will be adapted to current and future hardiness zones to ensure winter survival. Precipitation regimes are likely to be changed, but in varying fashions across the globe. Species planted should be able to thrive under the future drier or wetter conditions. Other considerations for species composition in a future urban climate include changes in plant pest populations and future storm intensities. Future plants will need to be able to thrive or survive in this potentially changed environment to help provide ongoing ecosystem services and minimize risk to the urban population.

Managing to reduce climate change effects

Besides providing for future tree and other plant populations that can be sustained in an altered urban environment, managers also need to consider species and designs that can help mitigate the potential future climate changes. Vegetation managers could focus on enhancing carbon storage by urban vegetation, minimizing the use of fossil fuel in vegetation management, and using vegetation designs to reduce air temperature and energy use.

The effects of urbanization and climate changes on urban plant biodiversity will vary across the globe, and are directly affected by human activities and their vegetation management principles. Managers need to understand these potential changes and how management can influence these changes to help sustain urban biodiversity, plant health, and, consequently, environmental quality and human health in a changing environment.

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