Received: 7 February 2019 | Revised: 27 April 2019 | Accepted: 28 April 2019

DOI: 10.1002/ppp3.38

OPINION

Plants People Planet PPP Open Access

Intersecting urban forestry and botanical gardens to address big challenges for healthier trees, people, and cities

Nicole Cavender | Gerard Donnelly

The Morton Arboretum, Lisle, Illinois, USA

Correspondence
Nicole Cavender, The Morton Arboretum, 4100 Illinois Route 53, Lisle, Illinois 60532, USA.
Email: ncavender@mortonarb.org

Societal Impact Statement

The need for urban greening increases with global urbanization. Trees are major assets to livable urban areas, providing valuable environmental services to combat challenges such as pollution, urban heat, and flooding, as well as to improve social cohesion, human health, and well-being. Investments in tree planting and arboriculture yield valuable returns, but trees face many challenges in the unnatural and stressful urban environment and in a rapidly changing climate. Botanical gardens have expertise in growing plants in designed landscapes. We urge their increased involvement with urban forestry to improve sustainability of cities and human lives.

Summary

Improving urban forests is one of the solutions to achieving several of the United Nations Sustainable Development Goals and making cities healthier and more livable for people. Priority should be given to protecting mature trees and promoting long-lived trees in the future. Achievement of this goal requires recognition of the myriad stresses trees face in built landscapes as well as the challenges related to climate change. Because all people living in communities are affected by the urban forest, developing solutions and forestry action plans should be a social endeavor and include diverse partnerships. Botanical gardens and arboreta can provide key resources in support of these efforts. They have a significant public reach, maintain a strong professional network, and can make important contributions to address key priorities including (a) protecting existing trees; (b) improving tree selection, diversity, and age structure; and (c) improving planning, standards, training, and management. A focus on below-ground aspects, such as root development and soil composition, is a critical component for success. Horticultural and scientific knowledge combined with extensive public reach make botanical gardens and arboreta important potential partners in achieving urban forest objectives, but a greater call to action is needed.

KEYWORDS

arboreta, botanical gardens, cities, climate change, environmental services, global urbanization, human health, human well-being, trees, urban forestry, urban greening

1 | URBANIZATION AND THE URBAN FOREST

Future world population growth in, and migration to, urban areas will redistribute the Earth's population in a way that will affect the natural systems of the Earth and the interactions between urban environments and populations (Torrey, (2004). Urban people alter their environment through their consumption of food, energy, water, and land. And in turn, the polluted urban environment affects the health and quality of life of the urban population. Urgent action and new partnerships are needed to work toward solutions for sustainability and the well-being of people and the environment in urban areas. Urban greening with a focus on improving the longevity and health of trees in urban forests can enhance ecosystem services and living conditions of metropolitan areas (Endreny, 2018).

The world population increased more than 400 percent over the 20th century (Roser, 2017). In 2018, more than 50 percent of the world's population lived in urban areas and this segment is predicted to rise to 68 percent by 2050 (UN DESA, 2018). Rapid urbanization is often accompanied by environmental degradation (e.g., air pollution, heat island effects, soil erosion, habitat and wildlife loss, carbon emissions, noise levels, etc.) impacting human health, quality of life, and well-being (Gurjar, Butler, Lawrence, & Lelieveld, 2008; Roy, Byrne, & Pickering, 2012). These effects can be exacerbated by global climate change, requiring an urgent response. Efforts to improve human life are the focus of the United Nations Sustainable Development Goals, which include action steps for additional tree cover in cities to help ameliorate environmental, economic, and social conditions for urban people and communities (FAO, 2016).

The urban forest includes the sum of all trees growing in highly altered community environments where humans are the main drivers of influence and disturbance (Escobedo, Kroger, & Wagner, 2011). The urban forest encompasses trees on both public and private property, including individual trees along streets and in backyards, as well as stands of remnant forests (Nowak, Noble, Sisinni, & Dwyer, 2001). Furthermore, urban forestry is “the art, science, and technology of managing trees, forests, and natural systems in and around cities, suburbs, and towns for the health and well-being of all people” (Helms, 1998).

2 | THE BENEFITS OF TREES

Trees improve the environment, save money, and improve people's lives. Urban forests are critical components of green infrastructure and cities, and they are important in providing ecosystem services to a large global population. A growing body of literature recognizes the important contributions of trees in urban forests (see Turner-Skoff & Cavender, 2019). Urban trees reduce air pollution, removing one-quarter of harmful particulate matter and offsetting carbon emissions through carbon storage (Alliance for Community Trees, 2011; McDonald et al., 2016; Schwab, 2009). They mitigate water pollution by reducing storm water runoff (McPherson, Simpson, Peper, Maco, & Xiao, 2005; Schwab, 2009). Urban trees lower energy costs of buildings through shading and evaporative cooling, reducing building energy consumption by up to 40 percent (Cameron & Blanuša, 2016; Huang, Akbari, & Taha, 1990; Livesley, McPherson, & Calfapietra, 2016; Norton et al., 2015). They also provide many health benefits to people (Donovan, 2017; Schwab, 2009). Views of trees are correlated with less pronounced ADHD (Attention Deficit Hyperactivity Disorder) in children, reduced violence in public housing communities (25 percent fewer incidents), and 23 percent fewer employee sick days for those with views of trees (Bengston & Dockry, 2014; Kuo & Sullivan, 2001; Roy et al., 2012).

3 | LARGE TREES OF THE URBAN FOREST DELIVER THE MOST BENEFITS

Within the urban forest, the larger and more mature trees, with their fuller crowns and leaf surface areas, provide more carbon storage, economic benefits, and other ecosystem services than do smaller trees (Díaz-Porras, Gaston, & Evans, 2014; Lindenmayer & Laurance, 2017; Stephenson et al., 2014; Wolf, 2005). Mature trees provide more shade for people and more habitat and food for animal species (Remm & Löhmus, 2011; Stagoll, Lindenmayer, Knight, Fischer, & Manning, 2012). Mature trees often provide symbolic, religious, and historic value, and they provide iconic landscape elements in urban parks and centerpieces in public common spaces. People generally prefer views of large trees and favor large trees along streets and in neighborhoods (Blicharska & Mikusiński, 2014). Large, mature trees provide key infrastructure for the green cities and deliver the most benefits. Large trees, however, face the most threats and are in global decline (Lindenmayer, Laurance, & Franklin, 2012).

4 | THE PROBLEM: TREES FACE ACUTE/CHRONIC STRESS IN URBANIZED ENVIRONMENTS

Trees confront difficult and often extreme conditions in built environments that limit their ability to reach maturity, compromising benefits delivered to the environment and people. Simply planting trees does not equate to an increase in tree cover in the long-term (Roman, Battles, & McBride, 2014). A 50 percent loss of trees within 5 years of planting is not uncommon, and the average median lifespan of urban street trees is between 13 and 19 years (Watson & Himelick, 2013). Trees are faced with a complex array of stressors that often prevent them from realizing their biological potential in terms of tree form, health, and life span (Jim, 2005). Much of this stress originates below ground in the soil and in the root system. Roots are often constrained by the alien physical, chemical, and biological properties of urban soils (Watson, Hewitt, Custic, & Lo, 2014). Trees growing in built environments must contend with limited sunlight in the shade of buildings, increased air pollution from vehicles, and limited room for crown

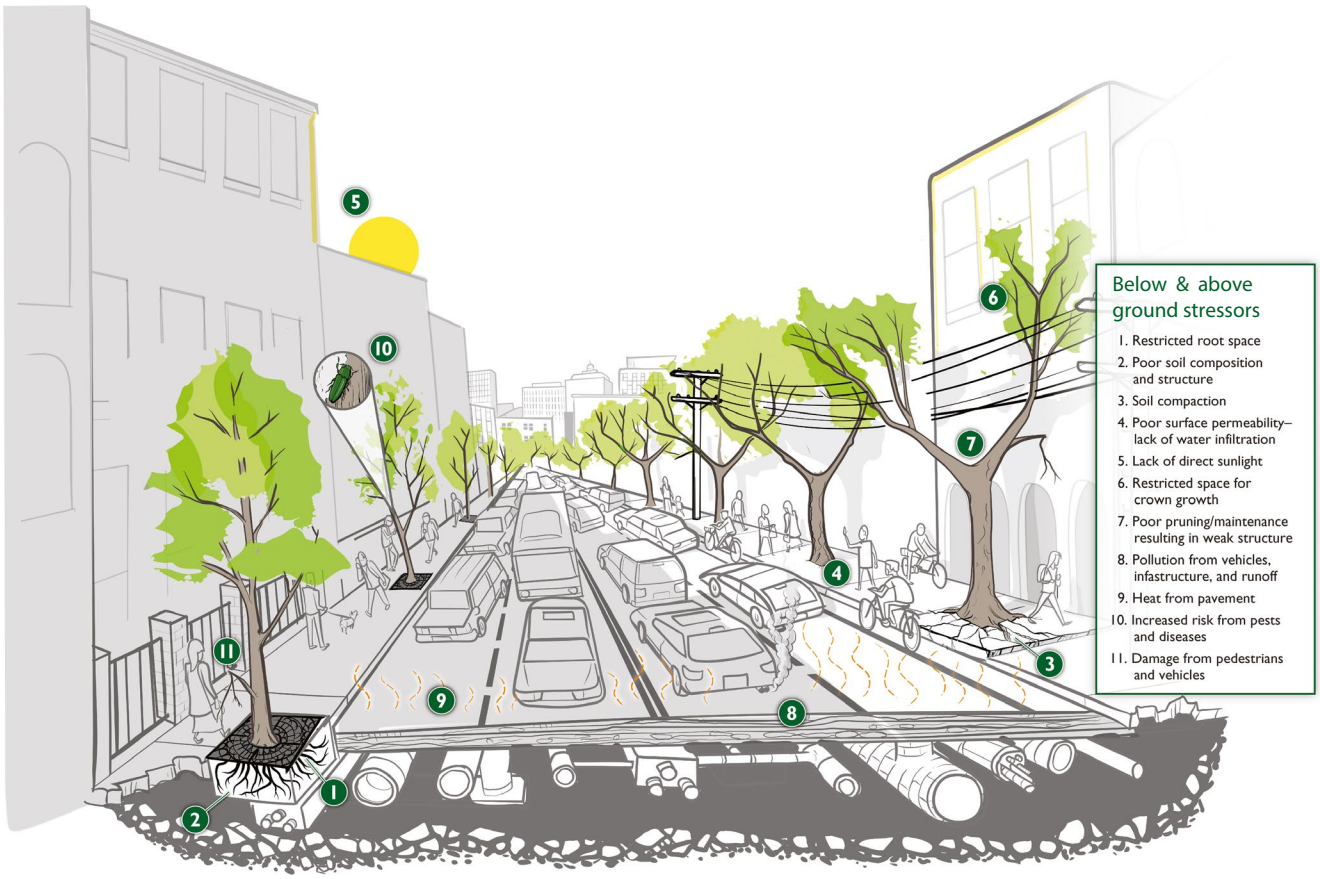

FIGURE 1 The major below ground and above ground stressors trees face in urban and built environments that limit their ability to survive and reach maturity

growth due to the presence of buildings and utilities (See Figure 1). Furthermore, as average global temperatures climb and climate patterns shift, trees face increased pressures from pests, diseases, and invasive plants (Mainka & Howard, 2010).

To realize the full benefits of urban forests, ameliorate the effects of a growing urban population, and plan for a better future, people must intervene on behalf of trees and take strategic action. We must actively protect, plant, and properly care for trees throughout their lives. A global movement is needed to recognize the importance of trees and rally to protect and strategically plant more of them. People have much to gain from investing resources in trees, but more attention and resources are needed. Trees are long-lived and need time to mature, so we must not wait to act (McDonald et al., 2016).

5 | THE SOLUTIONS: PRIORITIES FOR INTERVENTION

5.1 | Protect existing trees

The first priority should be to protect existing trees, since they are delivering the most immediate benefits. Policies and protection regulations at local, regional, and national levels are needed to regulate and promote the protection of existing trees, especially those that are large or of historical value. The economic, environmental, social, and cultural loss is tremendous each time a mature tree is removed. More civic engagement, advocacy, and legal protection is needed. The most successful government tree protection policies are based on a solid community forest management plan that includes a forest inventory, a clear strategic direction, and the support of International Society of Arboriculture (ISA) Certified Arborists, or similar professional arboricultural accreditation, on staff. Permits should be required for significant tree removals and incentives offered to private property owners who proactively plant trees on their property. Procedures and guidelines on planting, tree care, tree protection, legacy tree preservation, tree removal, tree replacement, and invasive species control are of essential value. Creating community "Tree Boards" of experts and interested citizens is recommended to provide assistance, direction, and expertise to government entities regarding the preservation, planting, management, and protection of trees. Tools are also available to help involve citizens in monitoring and protection of trees and forests (Crocker et al., 2019).

5.2 | Improve tree selection, diversity, and age structure

There is a lack of diversity and age structure in urban forests, especially the street tree component. Often, only three to five genera dominate urban areas (50 to 70 percent of all street trees) (Pauleit

et al., 2002). Because age diversity is also limited, trees that are providing benefits for a large area may fail or need to be removed around the same time and benefits cannot be recovered for decades. Pests and diseases are threats to urban trees, especially under a changing climate, and it will be increasingly important that a more diverse palette of trees be used to mitigate concentrated risk and to improve resiliency.

Many plantings fail because the wrong trees are chosen. Trees need to be matched with the location and local growing conditions. A greater application of horticultural knowledge is needed for improved selection criteria of species, especially in a changing climate. More evaluation and monitoring is needed for regional species selections. An understanding of the urban forest composition (i.e., audit or inventory) is required first to be able to develop sound strategies for improving species diversity and age structure. Botanical gardens can be excellent resources for improved plant selections (Hirons & Sjöman, 2019; Chicagoland Grows®; www.chicagolandgrows.org) and for tools, such as the Northern Illinois Tree Selector (2019), which can help people select the appropriate tree for the appropriate site.

Even if the need for greater diversity in urban forests is recognized, where is this diversity going to come from? The supply chain of quality trees is limited across the world (Nyoka et al., 2015; Whittet, Cottrell, Cavers, Pecurul, & Ennos, 2016). More investment is needed to develop a diverse supply of trees so that appropriate and adaptable trees are available at the local level across the globe.

5.3 | Improve planning, standards, training, and management

Improving the urban forest is very much a social endeavor, because it requires people to take action. A strong case for trees needs to be made with community decision makers so that trees are placed on the agenda for public consideration. As the public and community decision makers become more aware that investing in urban forestry can be a solution for many pressing urban environmental problems, trees will be considered a higher priority. Multiple stakeholders need to come together to develop a vision and goals that serve the entire community and recognize that urban forestry is a long-term proposition. Plans should include an understanding of current conditions, an awareness of risks to the urban forest ecosystem, a strategy to involve public and private partnerships, an acknowledgment of the economic value that the urban forest is delivering, and a financial strategy for realistic investment over time (Darling, Custic, Scott, & Smith, 2017; Schwab, 2009). City planning should incorporate tree preservation laws, development regulations, design and planting standards, and long-term maintenance provisions. It is not enough to make short-term commitments to planting more trees, because success will be determined by survivorship and sustainability, which require improved site conditions, good planting and care standards, a trained workforce, and ongoing maintenance. Improving planting standards and horticultural practices will increase the longevity of trees so that longer term benefits can be derived.

Humans are responsible in a large part for creating the conditions under which trees will thrive, survive, or fail. A particular area that needs improved attention is the landscape below ground. Considerably more is now known about soils and root growth, and what is required below ground for successful growth of trees (Watson, Costello, Scharenbroch, & Gilman, 2009; Watson, Gilman, Miesbauer, Morgenroth, & Scharenbroch, 2019), but this knowledge must now be put into practice.

6 | PARTNERING WITH BOTANICAL GARDENS

Urban forests can span entire regions across diverse demographics. Sustaining and improving them is increasingly reliant on different interest groups sharing a common ambition and working together in partnership. Botanical gardens and arboreta have an important role to play in meeting the great modern need for urban greening. Their direct involvement in sustaining healthy forests is needed now more than ever to amplify best practices and to engage local citizens in a community-based process. Gardens can provide key resources for planners, architects, consultants, and government bodies and add major value and influence to urban forestry planning and implementation. They can provide meaningful contributions in a variety of ways, and many public gardens have already developed successful models and approaches.

Botanic Gardens Conservation International (BGCI) defines botanical gardens as "institutions holding documented collections of plants for purposes of scientific research, conservation, display and education." An arboretum is a type of botanical garden that specializes in trees. The role of botanical gardens has changed and expanded through time. Botanical gardens are in the forefront of organizations committed to promoting the conservation of plants and their habitats, developing sustainable environmental management practices, and providing green spaces where people can reconnect with the natural world (Rakow & Lee, 2011). Many botanical gardens are expanding their reach, and new ones are under development across the globe. BGCI supports a network of more than 500 member gardens in 99 countries (www.bgci.org).

In many cases, botanical gardens and arboreta are already playing a role in sustaining urban forests by functioning as public green space—maintaining part of the urban forest—and delivering environmental, aesthetic, and social benefits (Ward, Parker, & Shackleton, 2010). Where botanical gardens have excelled most is in their botanical and horticultural knowledge and expertise. "Botanical gardens have unrivalled skills and knowledge of growing plants built up from many years of practical experience" (Heywood, 2017). Their horticultural and arboricultural knowledge, which has been amassed over decades or centuries, is needed now more than ever for greening and growing trees where people need them most: where they live, work, and play. With the growing need for urban greening, botanical gardens are positioned to respond to the conservation and sustainability needs of their local communities.

TABLE 1 Suggested contributions of botanical gardens to improve urban forests

Contribution	Description	Outcomes
Tree collection performance records	Keep ongoing and long-term records that track tree provenance, phenology, disease threats, and overall performance	Improved understanding of tree adaptability to local conditions, the urban environment, and climate change.
Tree selection and planting guides	Develop planting guides that identify trees appropriate for the region with information on tree traits, recommended planting sites, growth information, tolerances, and performance limitations	Improved strategies for increasing diversity and the life span of trees in urban forests
Tree breeding and evaluation	Utilize tree collection germplasm to develop, test, and introduce resilient trees for built environments	Increased tree diversity; new introductions of trees to the market with increased disease and pest resistance as well as overall adaptability
Tree inventories and mapping	Assist and provide guidance to cities and communities with urban forest inventories, including: species composition, locations, age distribution, canopy cover, health condition, ecosystem service valuation, and threats	Improved understanding of the status, assets, benefits, and distribution of the urban forest so that better management strategies can be developed and implemented
Urban forest management plans	Assist in developing regionally specific plans that identify goals, needs, and prioritized activities to improve and care for the urban forest	Improved decisions that favor a future with a robust, healthy, and long-lived urban forest for the region
Community tree planting and stewardship	Organize and participate in tree planting and care activities in communities, schools, public spaces, and private lands	Improved and longer lived regional canopy; engaged constituency of tree advocates
Restoration activities	Assist with activities that enhance the overall functioning of forest ecosystems within the urban forest, such as removing invasive species, improving natural regeneration, prescribed fire management, and reducing harmful animal browsing	Enhanced functioning and ecosystem benefits of urban forests
Tree ordinance and protection policies	Advocate and assist in developing local policies that regulate and provide incentives for the preservation of existing trees and their proper care	Improved legal protection of green infrastructure that delivers essential environmental, economic, and social benefits to citizens
Tree research	Develop and participate in research that advances understanding of trees in built environments, the benefits they deliver, and methods of improving tree production, planting, and care	Improved knowledge, methods, standards, and best practices
Best management practices for homeowners	Provide guides, tools, and services for visitors and the public that help them choose, source, plant, care for, identify pests/diseases, improve awareness of invasive species, and maintain trees in their yard and community	Better selection of trees, improved care, and longer lived trees in the landscape
Arboriculture and urban forestry consulting	Provide consulting services such as tree inventories, risk assessments, development of tree management plans, tree pruning and care treatments, ordinance writing, inspection, and tree valuation	Improved capacity and skilled workforce available for the community to support the urban forest
Arboricultural training	Offer training that advances education for students, volunteers, arborists, tree managers, and other professionals working with urban tree establishment and management. Below-ground aspects are of particular importance for arboriculture training and practice.	Increased, trained workforce to support a healthier and longer lived urban forest
Planning new park/arboretum spaces	Assist and provide consultation for planning new park and arboretum spaces in brownfields or other available lands	Expanded urban forest
Tree sales	Propagate and source diverse and locally appropriate trees for purchase	Distribution of locally appropriate species to support a more diverse urban forest

(Continues)

TABLE 1 (Continued)

Contribution	Description	Outcomes
Onsite exhibits and education programs	Provide learning opportunities, engagement experiences, conferences, and displays about trees and needs for planting and sustaining the urban forest	Greater awareness, engagement, and skills dedicated to urban forestry
Public relations	Build awareness about the importance of trees and the urban forest and develop communication pieces for distribution in multiple media channels	Broader audience understanding of the importance of the urban forest and engagement in issues that need to be addressed
Networking and collaboration	Convene, coordinate, and provide tools for the community to develop informed and shared goals	Increased engagement and ownership for the urban forest
Funding proposals	Develop and submit funding proposals for supporting tree planting, training, and outreach	Increased resources to grow and support the urban forest
Urban forestry awards	Recognize outstanding citizens and organizations that have positively influenced the health and longevity of the urban forest	Improved awareness and recognition of forest and tree champions
Offsite training and education outreach	Develop school curricula (elementary-university) that incorporate scientific principles and benefits delivered by urban forests	Increased interest and knowledge about trees, urban forest ecosystems, and their needs
Participation in private and public boards	Participate in councils and boards that help drive decisions around urban and community forests (e.g., forestry agency advisory, International Society of Arboriculture, professional associations, environmental committees, IUCN)	Greater influence to improve critical decisions pertaining to urban forestry and greening

Botanical gardens also have a fast-growing public audience with more than 500 million visitors globally each year (Smith, 2019; personal communication). They provide a valuable role in reaching the public through garden visits and interpretive displays, as well as education, outreach, and training programs. This interaction with the public brings greater awareness to present needs and challenges for future sustainability, builds support, and spurs needed action within communities. Botanical gardens are often highly regarded by the public as a reputable source of expertise, bringing a voice of credibility to endeavors for the greater good.

Given their strength in botanical and horticultural knowledge, combined with their ability to reach broad audiences, botanical gardens are primed to intersect and provide instrumental contributions to urban forestry. Several examples of these contributions are outlined in Table 1. These contributions are based on the experience of The Morton Arboretum in fostering urban forest improvement in the metropolitan region of Chicago, Illinois, USA. The Morton Arboretum joined with regional partners to launch The Chicago Region Trees Initiative (CRTI) to coordinate action to plant and care for a healthier, more diverse, regional forest (www.chicagorti.org). It is one of the largest such initiatives in the United States with over 200 organizations and agencies from across the Chicago metropolitan region working together, guided by four overarching goals: (a) Inspire people to value trees; (b) increase the Chicago region's tree canopy; (c) reduce threats to trees; and (d) enhance indigenous oak ecosystems. These goals aspire to improve tree health, improve urban forest policy, increase funding for urban forestry, and integrate science. The CRTI Master Plan, its partners, and examples of programs and resources for urban forestry can be found on the public website.

Botanical gardens have the opportunity and potential to make important contributions to urban forestry, but they are still underrepresented in such initiatives. An important barrier to consider is that although botanical gardens often have the knowledge and experience, they may not have the current capacity, and they would need additional support to be able to play a more influential role. Due to their mission-based business models, they generally have a high rate of return on investment and further support could be effectively leveraged. If botanical gardens can overcome the barrier of capacity, their involvement has promising potential to lead to greater success. We suggest a dual call for action: (a) botanical gardens need to exert themselves more in the process and not passively wait on the sidelines to be asked; and (b) city planners, landscape architects, consultants, politicians, and urban forest professionals need to reach out to their regional botanical gardens and arboreta to involve them in urban forestry efforts.

Resources exist to help identify arboretum and botanical garden partners for urban forestry initiatives. ArbNet (www.arbnet.org) is a network of the world's arboreta that facilitates professionalism and involvement of arboreta in urban forestry activities. ArbNet includes The Morton Registrar of Arboreta, a comprehensive list and database of named arboreta and other public gardens around the globe that have a substantial focus on woody plants. It also offers an Arboretum Accreditation Program. BGCI offers GardenSearch (https://www.bgci.org/garden_search.php), a global source of information on botanical gardens with a database that includes information on botanical institutions worldwide. Many countries also have professional associations of botanical gardens, such as The American Public Gardens Association, The European

Botanic Gardens Consortium, The Botanical Society of South Africa, and others. These networks and databases provide useful means for identifying botanical gardens as potential partners in the important work of urban greening and community forestry.

7 | CONCLUSIONS

There is a growing recognition that solutions are needed to ameliorate the environmental and social effects of an increasing urbanized world. Trees are critical components of green infrastructure and urban nature. Improving urban forests across metropolitan areas is a key solution that requires immediate and strategic action. To protect trees and ensure that people have the benefits trees provide, human intervention is needed. Priorities should focus on protecting existing trees, improving the selection and diversity of species, and improving planning, standards, and care for trees. Success in carrying out these priorities requires a more socially inclusive approach and is reliant on different interest groups. Botanical gardens and arboreta can greatly assist in these endeavors and many are already actively engaged. We encourage botanical gardens and arboreta to become more active and to take initiative to collaborate in urban forestry efforts, and we believe this will have growing relevance across the globe. Government officials, planners, and consultants should find and reach out to botanical gardens to collaborate at the local level. Botanical gardens have particular strengths in practical, horticultural knowledge and training, as well as public credibility and outreach. With their involvement, outcomes will likely be more successful. Protecting, planting, and caring for the world's urban forests will deliver great benefits environmentally, socially, and economically. Urban forest improvement is worth our attention and greater investment for a greener, healthier, and more beautiful world for people.

ACKNOWLEDGEMENTS

The authors thank Jessica Turner-Skoff, Claudia Wood, Alicia LaVire, and the three anonymous reviewers for their suggestions, as well as Caleb Phelps, Chai-Shian Kua, and Kris Bachtell for their contribution to the figure. We recognize Lydia Scott for her leadership of The Chicago Region Trees Initiative, from which we have learned much. We thank The Morton Arboretum supporters and our colleagues who work to understand, plant, and protect trees for a healthier and more beautiful world.

ORCID

Nicole Cavender https://orcid.org/0000-0001-5804-061X

REFERENCES

Alliance for Community Trees. (2011). *Benefits of trees and urban forests: A research list*. Retrieved from http://www.actrees.org/files/Research/benefits_of_trees.pdf. Accessed 19 January 2018.

Bengston, D., & Dockry, M. J. (2014). Can trees and humans survive together? *The Futurist*, July-August, 34–39.

Blicharska, M., & Mikusiński, G. (2014). Incorporating social and cultural significance of large old trees in conservation policy. *Conservation Biology*, *28*(6), 1558–1567. https://doi.org/10.1111/cobi.12341

Cameron, R. W. F., & Blanuša, T. (2016). Green infrastructure and ecosystem services: is the devil in the detail? *Annals of Botany*, *118*(3), 377–391. https://doi.org/10.1093/aob/mcw129

Crocker, E., Condon, B., Almsaeed, A., Jarret, B., Nelson, D., Aboot, A., … Staton, M. (2019). TreeSnap: A citizen science app connecting tree enthusiasts and forest scientists. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.41

Darling, L., Custic, M., Scott, L., & Smith, C. S. (2017). Increasing the benefits from urban trees while minimizing the costs: lessons learned from the Chicago Region Trees Initiative. *Illinois Municipal Policy Journal*, *2*(1), 119–134.

Díaz-Porras, D. F., Gaston, K. J., & Evans, K. L. (2014). 110 years of change in urban tree stocks and associated carbon storage. *Ecology and Evolution*, *4*(8), 1413–1422. https://doi.org/10.1002/ece3.1017

Donovan, G. H. (2017). Including public-health benefits of trees in urban-forestry decision making. *Urban Forestry and Urban Greening*, *22*, 120–123. https://doi.org/10.1016/j.ufug.2017.02.010

Endreny, T. A. (2018). Strategically growing the urban forest will improve our world. *Nature Communications*, *9*, 1160. https://doi.org/10.1038/s41467-018-03622-0

Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: analyzing ecosystem services and disservices. *Environmental Pollution*, *159*(8–9), 2078–2087. https://doi.org/10.1016/j.envpol.2011.01.010

Food and Agriculture Organization of the United Nations (FAO). (2016). Guidelines on urban and peri-urban forestry. In F. Salbitano, S. Borelli, M. Conigliaro, & Y. Chen (Eds.). *FAO Forestry Paper, No. 178*. Rome, Italy: FAO.

Gurjar, B. R., Butler, T. M., Lawrence, M. G., & Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmospheric Environment*, *42*(7), 1593–1606. https://doi.org/10.1016/j.atmosenv.2007.10.048

Helms, J. (1998). *The Dictionary of Forestry*. Western Heritage Co..

Heywood, V. H. (2017). The future of plant conservation and the role of botanic gardens. *Plant Diversity*, *39*, 309–313. https://doi.org/10.1016/j.pld.2017.12.002

Hirons, A. D., & Sjöman, H. (2019). Tree species selection for green infrastructure: A guide for specifiers, Issue 1.3. Trees & Design Action Group. Retrieved from http://www.tdag.org.uk/species-selection-for-green-infrastructure.html

Huang, J., Akbari, H., & Taha, H. (1990). *The Wind-shielding and shading effects of trees on residential heating and cooling requirements*. University of California, Berkeley, CA, USA: ASHRAE proceedings Applied Science Division, Lawrence Berkeley Laboratory.

Jim, C. Y. (2005). Outstanding remnants of nature in compact cities: patterns and preservation of heritage trees in Guangzhou city (China). *Geoforum*, *36*(3), 371–385. https://doi.org/10.1016/j.geoforum.2004.06.004

Kuo, F. E., & Sullivan, W. C. (2001). Aggression and violence in the inner city: Effects of environment via mental fatigue. *Environment and Behavior*, *33*(4), 543–571. https://doi.org/10.1177/00139160121973124

Lindenmayer, D. B., & Laurance, W. F. (2017). The ecology, distribution, conservation and management of large old trees. *Biological Reviews*, *92*(3), 1434–1458. https://doi.org/10.1111/brv.12290

Lindenmayer, D. B., Laurance, W. F., & Franklin, J. F. (2012). Global decline in large old trees. *Science*, *338*(6112), 1305–1306. https://doi.org/10.1126/science.1231070

Livesley, S. J., McPherson, G. M., & Calfapietra, C. (2016). The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environment Quality*, *45*(1), 119–124. https://doi.org/10.2134/jeq2015.11.0567

Mainka, S. A., & Howard, G. W. (2010). Climate change and invasive species: double jeopardy. *Integrated Zoology*, *5*(2), 102–111. https://doi.org/10.1111/j.1749-4877.2010.00193.x

McDonald, R., Kroeger, T., Boucher, T., Longzhu, W., Salem, R., Adams, J., … Garg, S. (2016). *Planting healthy air*. Arlington, VA, USA: The Nature Conservancy.

McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., & Xiao, Q. (2005). Municipal forest benefits and costs in five US cities. *Journal of Forestry*, *103*(8), 411–416. https://doi.org/10.1093/jof/103.8.411

Northern Illinois Tree Selector. (2019). The Morton Arboretum. Retrieved from https://www.mortonarb.org/trees- plants/tree-and-plant-advice/tree-species-list/filters. Accessed 26 April 2019.

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

Nowak, D. J., Noble, M. H., Sisinni, S. M., & Dwyer, J. F. (2001). People and trees: Assessing the US urban forest resource. *Journal of Forestry*, *99*(3), 37–42. https://doi.org/10.1093/jof/99.3.37

Nyoka, B. I., Roshetko, J., Jamnadass, R., Muriuki, J., Kalinganire, A., Lillesø, J.-P., … Cornelius, J. (2015). Tree seed and seedling supply systems: A review of the Asia, Africa and Latin America models. *Small-scale Forestry*, *14*(2), 171–191. https://doi.org/10.1007/s11842-014-9280-8

Pauleit, S., Jones, N., Garcia-Martin, G., Garcia-Vadencantos, J. L., Riviére, L. M., Vidal-Beaudet, L., … Randrup, T. B. (2002). Tree establishment practice in towns and cities- Results from a European survey. *Urban Forests and Urban Greening*, *1*(2), 83–96. https://doi.org/10.1078/1618-8667-00009

Rakow, D. A., & Lee, S. A. (2011). *Public Garden Management. A Complete Guide to the Planning and Administration of Botanical Gardens and Arboreta*. Hoboken, NJ: John Wiley & Sons Inc.

Remm, J., & Löhmus, A. (2011). Tree cavities in forests—The broad distribution pattern of a keystone structure for biodiversity. *Forest Ecology and Management*, *262*(4), 579–585. https://doi.org/10.1016/j.foreco.2011.04.028

Roman, L. A., Battles, J. J., & McBride, J. R. (2014). The balance of planting and mortality in a street tree population. *Urban Ecosystems*, *17*(2), 387–404. https://doi.org/10.1007/s11252-013-0320-5

Roser, M. (2017). Our world in data: future world population growth. Institute for New Economic Thinking, The Oxford Martin School, University of Oxford. Retrieved from www.ourworldindata.org. Accessed 19 January 2019.

Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry and Urban Greening*, *11*(4), 351–363. https://doi.org/10.1016/j.ufug.2012.06.006

Schwab, J. (2009). *Planning the urban forest: Ecology, economy, and community development*. Chicago, IL, USA: American Planning Association.

Stagoll, K., Lindenmayer, D. B., Knight, E., Fischer, J., & Manning, A. D. (2012). Large trees are keystone structures in urban parks: Urban keystone structures. *Conservation Letters*, *5*(2), 115–122. https://doi.org/10.1111/j.1755-263X.2011.00216.x

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., … Zavala, M. A. (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature*, *507*(7490), 90–93. https://doi.org/10.1038/nature12914

Torrey, B. B. (2004). Urbanization: An environmental force to be reckoned with. Population Reference Bureau. Retrieved from https://www.prb.org/urbanization-an-environmental-force-to-be-reckoned-with/. Accessed 19 January 2018.

Turner-Skoff, J., & Cavender, N. (2019). The benefits of trees for livable and sustainable communities. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.39

United Nations, Department of Economic and Social Affairs, Population Division. (2018) *World Urbanization Prospects: The 2018 Revision, Methodology. Working Paper No. ESA/P/WP.252*. New York: United Nations.

Ward, C. D., Parker, C. M., & Shackleton, C. M. (2010). The use and appreciation of botanical gardens as urban green spaces in South Africa. *Urban Forestry and Urban Greening*, *9*(1), 49–55. https://doi.org/10.1016/j.ufug.2009.11.001

Watson, G. W., L. Costello, B. Scharenbroch, & E. Gilman (Eds.) (2009). In: *The Landscape below ground III: Proceedings of a third international workshop on tree root development in urban soils* (p. 403). Champaign, IL: International Society of Arboriculture.

Watson, G. W., E. Gilman, J. Miesbauer, J. Morgenroth, & B. Scharenbroch (Eds.) (2019). In: The Landscape Below Ground IV: Proceedings of the international workshop on tree root development in urban soils. Atlanta, GA: International Society of Arboriculture. In press.

Watson, G. W., Hewitt, A. M., Custic, M., & Lo, M. (2014). The management of tree root systems in urban and suburban settings II: a review of strategies to mitigate human impacts *Arboriculture and Urban Forestry*, *40*(5), 249–271.

Watson, G. W., & Himelick, E. B. (2013). In E. Hargrove (Ed.), *The practical science of planting trees*. Atlanta, GA, USA: International Society of Arboriculture.

Whittet, R., Cottrell, J., Cavers, S., Pecurul, M., & Ennos, R. (2016). Supplying trees in an era of environmental uncertainty: Identifying challenges faced by the forest nursery sector in Great Britain. *Land Use Policy*, *58*, 415–426. https://doi.org/10.1016/j.landusepol.2016.07.027

Wolf, K. L. (2005). Business district streetscape, trees and consumer response. *Journal of Forestry*, *103*(8), 396–400.

How to cite this article: Cavender N, Donnelly G. Intersecting urban forestry and botanical gardens to address big challenges for healthier trees, people, and cities. *Plants, People, Planet*, 2019;00:1–8. https://doi.org/10.1002/ppp3.38