The benefits of trees for livable and sustainable communities

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Societal Impact Statement
Trees play a critical role for people and the planet. Numerous studies have demonstrated that the presence of trees and urban nature can improve people's mental and physical health, children's attention and test scores, the property values in a neighborhood, and beyond. Trees cool our urban centers. Trees are essential for healthy communities and people. The benefits that trees provide can help cities and countries meet 15 of the 17 internationally supported United Nations Sustainable Development Goals. This critical review provides a comprehensive argument that trees should be considered an important part of the equation by project managers and civic leaders as we collectively work toward reaching these sustainability goals.

Summary
We live in an era influenced by humans to the point that the Earth's systems are now altered. In addition, a majority of the world's population live in cities. To meet the needs of people in a changing world, The United Nations General Assembly created the United Nations Sustainable Development Goals (UN SDG) to improve the quality of life for people. These broad goals outline the greatest challenges of our time. An effective strategy to assist in meeting these goals is to plant and protect trees, especially in cities where the majority of people live. This paper serves as a critical review of the benefits of trees. Trees promote health and social well-being by removing air pollution, reducing stress, encouraging physical activity, and promoting social ties and community. Children with views of trees are more likely to succeed in school. Trees promote a strong economy and can provide numerous resources to the people that need them. While cities are getting hotter, trees can reduce urban temperatures. They provide habitat and food for animals. Finally, trees are valuable green infrastructure to manage stormwater. Money spent on urban forestry has a high return on investment. As we navigate this human-dominated era, we need skilled people who understand the nuances of the built environment and trees as we strategically plan the cities of the future. The overwhelming evidence from the scientific literature suggests that investing in trees is an investment in meeting the UN SDG, and ultimately an investment for a better world.

KEYWORDS
benefits of trees, cities, climate change, ecosystem services, human health, sustainability, United Nations Sustainable Development Goals, urban forest
1 | INTRODUCTION

This current era, the Anthropocene, is driven by human influence and it has ushered in a growing number of direct and indirect challenges that can greatly impact the health and prosperity of people and the planet (Ellis, 2015). Climate change is driving an unprecedented number of extreme climatic events and causing ocean levels to rise (Goudie, 2019). The human population continues to increase (UN, 2015a) and metropolitan regions are growing and expanding. By 2050, most of the world’s population (70%) will live in cities (FAO, 2016). These concentrated populations have a wide variety of challenges, ranging from people not having access to clean water to pollution-related health issues (UN, 2015b).

People and cities need efficient and effective solutions to address the challenges of this current era. In 2015, the United Nations (UN) outlined 17 goals for sustainable development. The UN Sustainable Development Goals (UN SDG), while ambitious, have the promise to improve the quality of life for the billions of people on this planet and serve as a strong example of what the global society prioritizes (UN, 2015b).

Environmental and nature-based solutions can help address a majority of these outlined goals. Previous work has aligned environmental topics, such as plant conservation (Sharrock & Jackson, 2017), soil and soil science (Keestra et al., 2016), and the prevention of land degradation (Vlek, Khamzina, & Lulseged, 2017) as solutions to meet the UN SDG. One additional way to address the challenges that the urban population faces is to provide people with green spaces and to plant, maintain, and protect trees (FAO, 2016; Endreny et al., 2017; Endreny, 2018; World Resources Institute, 2018). The direct and indirect benefits of trees and nature are vast (Blackmore, 2009; Brack, 2002; Hirons & Thomas, 2018; Kuo, 2015; Tyrväinen, Pauleit, Seeland, & De Vries, 2005), and much research has focused on the benefits of trees to urban residents (Jennings & Johnson Gaither, 2015).

This paper provides a critical and succinct review on how the benefits of trees can increase the well-being of a majority of the world’s population. The authors classify the benefits of trees into five categories: (a) health and social well-being; (b) cognitive development and education; (c) economy and resources; (d) climate change mitigation and habitat; and (e) green infrastructure (Table 1). In addition to the benefits in these categories, the presence of trees and green space can help a city to meet Goal 11, sustainable cities (UN, 2015b). There is a link between trees, green spaces, and mortality, and it is documented in the literature (James, Hart, Banay, & Laden, 2016; Nowak et al., 2018; Villeneuve et al., 2012). In particular, the authors associated the increase in cardiovascular and respiratory deaths with the infestation and death of ash trees (genus Fraxinus) in counties within the United States (Donovan et al., 2013). Having more trees, especially the right mature species planted in the right locations, can reduce particulate matter and other forms of air pollution, which could reduce mortality and morbidity in our urban centers.

Beyond pollution removal, the presence of trees provides additional direct and indirect benefits to human health and wellness (Donovan, 2017). Regardless of why trees provide so many benefits (see Biophilia hypothesis [Wilson, 1984; Kellert & Wilson, 1995] and Attention Restoration Theory [(Kaplan & Kaplan, 1989; Kaplan, 1995]), the presence of trees and green space promotes well-being. Trees and greener environments are strongly linked to reduced negative thoughts, reduced symptoms of depression, better reported moods, and increased life satisfaction (Berman et al., 2012; Bratman, Hamilton, Hahn, Daily, & Gross, 2015; Li, Deal, Zhou, Slavenas, & Sullivan, 2018; Lohr & Pearson-Mims, 2006; Mayer, Frantz, Bruehlman-Senecal, & Dolliver, 2009; Taylor, Wheeler, White, Economou, & Osborne, 2015; White, Alcock, Wheeler, & Deplege, 2013). A view of trees can help patients recover in a hospital (Ulrich, 1984) and reduce diastolic blood pressure and stress in research participants (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Jiang, Larsen, Deal, & Sullivan, 2015). Residents of tree-lined communities feel healthier and have fewer cardio-metabolic conditions than their counterparts (Kardan et al., 2015). The presence of trees can even improve the condition of people with a neurodegenerative disease (Mooney & Nicell, 1992).

2 | THE SCIENTIFIC BENEFIT OF TREES

2.1 | Health and social well-being

One of the most important benefits for human health that urban forests can provide is the interception and reduction of air pollution (McDonald et al., 2007, 2016; Nowak, Crane, & Stevens, 2006; Nowak, Hirabayashi, Bodine, & Greenfield, 2014; Nowak, Hirabayashi, Doyle, McGovern, & Pashe, 2018). Air pollution (e.g. particulate matter (PM), ozone, carbon monoxide, polycyclic aromatic hydrocarbons, nitrogen dioxide, sulfur dioxide, etc.) is linked to bronchitic symptoms, intraocular pressure (leads to glaucoma), myocardial infarction (i.e. heart attacks), changes in autonomic and micro-vascular function, autism, blood pressure, cognitive development problems in children (slower processing speeds, behavioral problems, attention deficit/hyperactivity disorder symptoms), blood mitochondrial abundance, heart failure, and mortality in humans (Berhane et al., 2016; Di et al., 2017; Hoek et al., 2013; Mustafić et al., 2012; Nwanaji-Enwerem et al., 2019; Peterson et al., 2015; Shah et al., 2013; Volk, Lurmann, Penfold, Hertz-Picciotto, & McConnell, 2013; Weichenthal, Hatzopoulou, & Goldberg, 2014; Zhong et al., 2016). Trees remove a tremendous amount of air pollution. It is estimated that from the contiguous United States, urban trees remove 711,000 metric tons of air pollution each year (Nowak et al., 2006). Previous research demonstrated that out of 35 woody species studied, all accumulated PM (Mo et al., 2015). Further, Chen, Liu, Zhang, Zou, and Zhang (2017) suggested that PM$_{2.5}$ accumulation capacity increases as a tree matures, and a diverse planting of species augments the trapping of PM$_{2.5}$.

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In addition, as people value trees and natural environments, they like being around them and viewing them (Dwyer, Schroeder, & Gobster, 1991; Kaplan, Kaplan, & Wendt, 1972; Lohr, Pearson-Mims, Tarnai, & Dillman, 2004). The presence of trees and green spaces may encourage physical activity (Bell, Wilson, & Liu, 2008; Ellaway, MacIntyre, & Bonnefoy, 2005), which is related to physical and mental health. Given the multi-faceted health benefits of the ecosystem service ecotherapy (Summers & Vivian, 2018), the very act of planting and caring for trees may promote mental and physical health. Trees not only make people happier and healthier, but they make communities more livable.

Well-maintained trees are associated with improving the social capital and ecology of a community (Coley, Sullivan, & Kuo, 1997; Elmendorf, 2008; Holtan, Dieterlen, & Sullivan, 2015; Kuo, 2003; Lohr et al., 2004). The presence of trees and green spaces may encourage physical activity (Bell et al., 2008; Ellaway et al., 2005), which is related to physical and mental health. Given the multi-faceted health benefits of the ecosystem service ecotherapy (Summers & Vivian, 2018), the very act of planting and caring for trees may promote mental and physical health. Trees not only make people happier and healthier, but they make communities more livable.

### TABLE 1

A high-level overview of the benefits that urban trees provide, and how the direct and indirect benefits relate to the corresponding United Nations Sustainable Development Goals. Further, the presence of trees and green space can help a city meet Goal 11, or sustainable cities and communities, through providing universal access to green and public spaces.

| Benefit of urban trees category | Corresponding United Nations Sustainable Development Goals | Scientific benefits of trees highlights |
|--------------------------------|----------------------------------------------------------|---------------------------------------|
| **Health and social well-being** | | |
| Trees promote physical and mental health for urban residents. They support community ties and reduced crime rates. | Goal 3: Good health and well-being  
Goal 11: Sustainable cities and communities  
Goal 16: Peace, justice, and strong institutions | Reduce pollution  
Improve physical and mental health  
Strengthen community ties |
| **Cognitive development and education** | | |
| Trees increase a student’s ability to succeed in school. | Goal 4: Quality education | Improve student performance  
Reduce stress  
Increase in concentration  
Reduce symptoms of ADD/ADHD  
Increase in attention  
Increase in self-discipline |
| **Economy and resources** | | |
| Trees are good for the economy and they reduce energy bills. They provide many resources, such as food, to a community. | Goal 1: No poverty  
Goal 2: Zero hunger  
Goal 7: Affordable and clean energy  
Goal 8: Decent work and economic growth  
Goal 10: Reduced inequalities  
Goal 12: Responsible consumption and production | High return-on-investment  
Support tourism  
Increase home prices and rental rates  
Reduce energy use and bills  
Promote food sustainability  
Provide resources and firewood |
| **Climate change mitigation and habitat** | | |
| Trees mitigate the Urban Heat Island Effect and store and sequester carbon. They are important for habitat. | Goal 3: Good health and well-being  
Goal 13: Climate action  
Goal 15: Life on land | Reduce Urban Heat Island Effect  
Store and sequester carbon  
Provide critical habitat |
| **Green infrastructure** | | |
| Trees are important forms of infrastructure, especially for storm water management | Goal 3: Good health and well-being  
Goal 6: Clean water and sanitation  
Goal 9: Industry, innovation and infrastructure  
Goal 11: Sustainable cities and communities  
Goal 12: Responsible consumption and production  
Goal 14: Life below water  
Goal 15: Life on land | Manage storm water  
Reduce pollution  
Protect life below water and on land |
Kuo, Sullivan, Coley, & Brunson, 1998), reducing violence and aggression in households (Kuo & Sullivan, 2001a), and limiting criminal activity in neighborhoods (Donovan & Prestemon, 2012; Kuo & Sullivan, 2001b; Troy, Morgan Grove, & O’Neill-Dunne, 2012; Troy, Nunery, & Grove, 2016). In one study, Kondo, Han, Donovan, and MacDonald (2017) demonstrated that the loss of ash trees due to the emerald ash borer in Cincinnati, Ohio, USA, was positively associated with increases in crime. This could be an example of “cues to care,” which is the idea that a well-tended landscape is valued and viewed (Troy et al., 2016). While there is a perception that the presence of trees can increase crime, it is likely related to unmanaged and smaller trees that provide greater protection to a criminal (Donovan & Prestemon, 2012). Regardless of this perception, evidence indicates that trees make residents feel safer (Kuo, Bacaicoa, & Sullivan, 1998).

Based on literature cited, trees can help meet our societal goals as outlined in the UN SDG, especially Goal 3: Ensure healthy lives and promote well-being for all at all ages; Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable; and Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels. These benefits from trees, if distributed throughout communities, can help make cities more sustainable and livable (Table 1).

### 2.2 | Cognitive development and education

To increase literacy and numeracy, children need to have access to nature, and at the very least, green and natural views of trees (Berman, Jonides, & Kaplan, 2008; Faber Taylor, Kuo, & Sullivan, 2002; Lin, Tsai, Sullivan, Chang, & Chang, 2014; Tennessen & Cimprich, 1995). As reviewed in Kuo, Browning, Sachdeva, Lee, and Westphal (2018), stress levels, concentration, and intrinsic motivation are likely strong factors in a child’s success as a student. Students who are focused, attentive, and engaged are more likely to succeed in school and receive a quality education. Attention Deficit Hyperactivity Disorder (ADHD) and Attention Deficit Disorder (ADD) can impact a student’s success in school (Rief, 2012). Green environments, such as open spaces with big trees, are related to reduced symptoms of ADHD and ADD (Faber Taylor & Kuo, 2009; Faber Taylor, Kuo, & Sullivan, 2001).

Tree cover is strongly linked to student academic performance (Kuo, Browning, Sachdeva, et al., 2018; Kweon, Ellis, Lee, & Jacobs, 2017; Matsuoka, 2010). In one study, views of trees and shrubs at schools, as opposed to grass, were strongly related to future education plans and graduation rates (Matsuoka, 2010). Li and Sullivan (2016) found that students who had views of trees and green environment from their classrooms, as compared to being in a room without windows or a room with a view of a brick wall, scored substantially higher on tests measuring attention, and they had a faster recovery from a stressful event. Students who learn in the presence of trees and nature have improved classroom engagement (Kuo, Browning, & Penner, 2018). Trees can promote a quality education, which has innumerable advantages for society. Access to trees supports a quality education and can help countries meet the UN SDG, especially Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (Table 1).

### 2.3 | Economy and resources

Trees provide many ecosystem services that can benefit a city environment, ranging from reducing energy use and removing pollution (Nowak & Greenfield, 2018) to increasing property values, developing the local economy, and supporting tourism (Nesbitt, Hotte, Barron, Cowan, & Sheppard, 2017). In the United States alone, it is estimated that trees provide $18.3 billion in annual value due to air pollution removal, reduced building energy use, carbon sequestration, and avoided pollutant emissions (Nowak & Greenfield, 2018). Allocating resources in tree planting and maintenance can be a financially sound decision based on the benefits and ecosystem services that trees provide (McPherson, Simpson, Peper, Maco, & Xiao, 2005). This high return on investment can be multiples of invested capital over time (McPherson, van Doorn, & de Goede, 2016). Many benefits are not fully captured in this return on investment. In addition, the presence of shade trees can reduce the rate of ageing of road and pavement surfaces (McPherson & Muchnick, 2005), influence shoppers to visit a shopping area (Wolf, 2005), and increase the selling price of a home (Anderson & Cordell, 1988; Donovan & Butry, 2010; Sander, Polasky, & Haight, 2010). As long as trees do not block the view of an office building, quality landscaping with properly maintained trees can increase rental rates (Laverne & Winson-Geideman, 2003). A properly planted tree can also reduce energy use (Akbari, 2002; Donovan & Butry, 2009; Pandit & Laband, 2010; Simpson, 1998), which can reduce the cost of energy bills.

While urban trees can provide economic benefits, they can also provide resources, such as food, to a community. The idea that trees can provide food security and promote well-being is not new. In fact, agroforestry was previously recognized as a way to meet the United Nations Millennium Development Goals (Garrity, 2004). Hundreds of tree species are used for agroforestry to promote food sustainability and nutritional security (Dawson et al., 2013; Orwa, Mutua, Kindt, Jamnadass, & Simons, 2009). Urban orchards, or urban food forestry, can be an efficient way to consistently provide free or low-cost nutrient-dense food to the people that need it (Clark & Nicholas, 2013). Urban street trees can provide many resources to the inhabitants of cities. In New York City, 88% of tree species present are forgivable for medicine, food, etc., including nine out of ten of the most common tree species (Hurley & Emery, 2018). The “Incredible Edible” movement is an example of how underutilized plots in urban environments can be used to grow food, as a means to reduce food deserts and build community (Morley, Farrier, & Dooris, 2017). Planting urban orchards in available spaces could prove an important tool to reduce hunger and increase social ties. Urban foraging may not be practiced in areas of higher opportunity (Larondelle & Strohbach, 2016), and so it may not receive the attention it deserves as a solution for food security.
Forests also provide the habitat for non-timber forest products (NTFP) that can provide valuable resources to a local community (Turner, 2015). Some examples of NTFP include American ginseng (Panax quinquefolius L.), maple syrup (derived from Acer spp.) and nuts (from trees like the European Chestnut, Castanea sativa Mill.; Poe, McLain, Emery, & Hurley, 2013; Turner, 2015). Traditionally NTFP are associated with a rural environment, yet urban NTFP can provide additional financial, food, and medicinal security to people living in cities (Kaoma & Shackleton, 2015; McLain, Hurley, Emery, & Poe, 2013; McLain, Poe, Hurley, Lecompte-Mastenbrook, & Emery, 2012; Poe et al., 2013).

Finally, wood is an important source of material and energy for much of the world. Trees that are cut down in cities or communities can be used for timber (Sherrill, 2003). This could be used for fuel or for producing goods. Innovative programs can promote sustainability and creative usage of urban wood. An example of this is the "Working for Water" program which trains people in South Africa to remove woody invasive species, and then the cleared wood can be used for a variety of secondary industries (Binns, Illgner, & Nel, 2001). While this program works with invasive species, it serves as an example of creative solutions involving the community with urban issues involving trees. Urban forests can also help supply affordable energy to people that need it (FAO, 2016). It is important to note, however, that burning wood is a large contributor to air pollution in urban environments (Favez, Cachier, Sciare, Sarda-Estève, & Martinon, 2009). Therefore, if wood is used for fuel, it should be burned in such a way that the benefits outweigh the harm to human health. Trees are a valuable resource, even after they are cut down.

Trees can help countries meet the UN SDGs by providing food, resources and economic advantages to countries. These goals include: Goal 1: End poverty in all its forms everywhere; Goal 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture; Goal 7: Ensure access to affordable, reliable, sustainable, and modern energy for all; Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; Goal 10: Reduce inequality within and among countries; and Goal 12: Ensure sustainable consumption and production patterns.

2.4 Climate change mitigation and habitat

Climate change directly impacts where people live. One of the most pressing risks for human health associated with a changing climate are the increases in heat-related deaths, diseases, and infectious diseases (Patz, Campbell-Lendrum, Holloway, & Foley, 2005). The increase in heat and heat-related health problems is especially prevalent in cities, where the Urban Heat Island Effect increases the impact of heat waves (Ward, Lauf, Kleinschmit, & Endlicher, 2016). Properly placed trees can mitigate temperatures in built environments. Not only do trees provide shade through intercepting and absorbing light, but through evapotranspiration trees actively cool the air of cities (EPA, 2008; Hirons & Thomas, 2018; Schwab, 2009).

An analysis of 94 urban areas around the world indicates that trees have a significant impact on the temperature, and are responsible for, on average, 1.9°C (SD 2.3) of cooling in a city (Figure 1a). Trees incorporated into the built environment can reduce a city’s temperature by 9°C (Figure 1b). This reduction of temperature in major cities (Akbari, Pomerantz, & Taha, 2001; Loughner et al., 2012; McDonald et al., 2016) can ultimately help ameliorate the impact of climate change on human health.

One of the key ways to limit the impacts of climate change is to reduce the amount of carbon released into the atmosphere. Trees are beneficial to storing carbon, which is a major contributor to climate change (Nowak, 1993). Nowak and Crane (2002) determined that not only do urban trees in the coterminous United States sequester 22.8 million tons of carbon each year, but the urban forest in this area stores 700 million tons of carbon. The more mature a tree is, the more carbon it stores in its woody biomass (Schwab, 2009). Although trees are not the single answer, healthy and mature trees have the potential to make significant carbon mitigation returns.

Finally, trees, specifically mature ones, perform a keystone role in terrestrial ecosystems (Manning, Fischer, & Lindenmayer, 2006). Trees are critically important, especially in urban areas, as they provide food and habitat for birds, invertebrates, mammals, and plants (Fahey, Darling, & Anderson, 2015; Schwab, 2009; Tyrväinen et al., 2005). Improving and maintaining biodiversity is necessary for a sustainable city.

Therefore, planting and protecting trees can help a country meet the following UN SDG: Goal 3: Ensure healthy lives and promote well-being for all at all ages; Goal 13: Take urgent action to combat climate change and its impacts; and Goal 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

2.5 Green infrastructure

Trees are considered “decentralized green infrastructure” and can be important tools for managing water, especially in an urban ecosystem (Berland et al., 2017). Water runoff is a serious issue in the city environment, as runoff can increase the exposure to pollution and cause property damage (Braden & Johnston, 2004). Trees can help reduce and intercept stormwater and improve the quality of runoff water (Berland et al., 2017; Bolund & Hunhammar, 1999; Brack, 2002; Livesley, McPherson, & Calfapietra, 2016; Scharenbroch, Morgenroth, & Maule, 2016). With less contact on impervious surfaces, stormwater is cooler and has fewer pollutants when it enters local waterways and water-related ecosystems (Schwab, 2009). Trees can also be valuable in phytoremediation, where they can remove heavy metals and other contaminants from the environment (French, Dickinson, & Putwain, 2006). While gray infrastructure depreciates over time, trees appreciate in value as they mature (Hauer & Johnson, 2003). Therefore, an investment in trees can make economic sense and align with the UN SDG.
Green infrastructure protects life below water and life on land, while promoting sustainability. The ability of trees to reduce the pollution in the waterways is beneficial to human health and well-being. Therefore, by promoting trees as green infrastructure, the following UN SDG can be met: Goal 3: Ensure healthy lives and promote well-being for all at all ages; Goal 6: Ensure availability and sustainable management of water and sanitation for all; Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable; Goal 12: Ensure sustainable consumption and production patterns; Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development; and Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss (Table 1).
3 | IMPORTANT CONSIDERATIONS

While the above outlines how the benefits of trees can help build sustainable cities in the future and reach the collective agenda of the UN SDG, there are important considerations associated with this review. First, while there is strong evidence that nature benefits humans, much of the research conducted has been correlative. Future studies should address methodological limitations and minimize potential errors or bias in research (such as self-reporting moods, sampling bias, lack of control group, and short-time frames of research; Keniger, Gaston, Irvine, & Fuller, 2013). Despite these concerns, the vast number of studies illustrating the breadth of benefits related to trees is compelling.

Many of these papers describe the importance of urban green space. Green space can be defined as herbaceous or woody vegetated areas such as parks, forests, or gardens (Jennings & Johnson Gaither, 2015). It is unlikely that the papers that asked questions about green space focused on grassy fields that lacked trees. In addition, research shows that green spaces without trees or dense vegetation can have negligible or negative impacts on people (Kuo, Browning, Sachdeva, et al., 2018; Kweon et al., 2017; Matsuoka, 2010; Reid, Clougherty, Shmool, & Kubzansky, 2017).

While this review stresses the importance of trees, this is not to say that other forms of nature will not provide similar benefits. However, in the space-limited city, trees are practical. They provide a strong return on investment given their vertical orientation and size.

Trees do not only provide positive benefits, however, as there can be negative associations surrounding trees. These disservices to people can range from financial strains associated with tree maintenance and care, to property damage, to safety issues associated with limited visibility and security, and the inconvenience of messiness (Escobedo, Kroeger, & Wagner, 2011; Lohr et al., 2004; Lyytimäki & Sipilä, 2009; Roy, Byrne, & Pickering, 2012; Staudhammer, Escobedo, Luley, & Bond, 2009; Wyman, Escobedo, Stein, Orfanedes, & Northrop, 2012).

One of the most commonly cited disservices associated with trees is the production of biogenic Volatile Organic Compounds (bVOCs) which react with nitrogen oxides, to increase air pollution in the form of ozone (Hirons & Thomas, 2018; Salmond et al., 2016). This negative impact on air quality can be exasperated during heat waves (Churkina et al., 2017) or in street canyons (Salmond et al., 2016). As it is situational, measuring the impact of bVOCs is complicated. Species, number of trees, and location planted makes a difference in the type and amount of air pollution produced or accumulated by trees (Calfapietra et al., 2013; Donovan, Stewart, Owen, MacKenzie, & Hewitt, 2005; Janhäll, 2015). Complicating the issue of disservices/benefits, the amount of ozone that a tree intercepts and uptakes may be greater than any ozone produced through bVOCs (Calfapietra et al., 2013; Salmond et al., 2016). Further, trees are more effective at absorbing and accumulating gas and particulate pollutants than other city surfaces (as reviewed in Salmond et al., 2016).

Since trees can produce disservices, trees should be valued for what they holistically contribute to a community, rather than being valued for singular benefits. For example, while trees in a street canyon may result in more localized pollution, they may provide secondary benefits such as reducing the movement of pollutants to other locations or masking noise pollution (Salmond et al., 2016). In fact, the benefits of trees are often so valued that any disservices that can be associated with them are outweighed (Lohr et al., 2004; Wyman et al., 2012). When planting trees, people can reduce possible disservices through careful species selection, and selecting species with low potential for invasion. Resources exist, like the Northern Illinois Tree Selector (2019), which can help people select the appropriate tree for the appropriate site, all the while considering disservices, services, and if a tree species has invasive traits.

The benefits of trees are relative to seasonal and temperate zone differences. Another important consideration is that not all trees are equal. Some benefits may be more pronounced in specific species (Chen et al., 2017; Grote et al., 2016; Xiao & McPherson, 2016). Benefits differ within a species as well. A small street tree does not provide the same benefits as a large, 100-year-old tree. Mature and old trees are increasingly rare, and yet they can provide the greatest benefits (Lindenmayer, 2017; Lindenmayer & Laurance, 2017; Lindenmayer, Laurance, & Franklin, 2012). Given that they are single organisms, large old trees provide a disproportionate impact on biodiversity and ecological processes, from providing habitat for other animals and plants to facilitating important ecological cycles (Le Roux, Ikin, Lindenmayer, Manning, & Gibbons, 2015; Lindenmayer, 2017; Lutz et al., 2018; Stagoll, Lindenmayer, Knight, Fischer, & Manning, 2012). A larger tree can provide substantially greater benefits than a smaller tree can (Stephenson et al., 2014). There is also cultural value associated with large and mature trees (Blicharska & Mikusiński, 2014). Cities and urban centers should manage their forests to conserve large-diameter trees to maximize the ecosystem services the trees can provide (see Cavender & Donnelly, 2019).

Few trees reach maturity in an urban environment (Watson & Himelick, 2013). While many cities participate in tree plantings, the lack of follow-up care can impact survival rates, thus result in a waste of resources (Widney, Fischer, & Vogt, 2016). However great the number of benefits a mature tree can provide, it takes time for the benefits of trees to exceed the costs associated with the planting and maintenance (Vogt, Hauer, & Fischer, 2015). One way to increase survival rates of planted trees—and thus, ensure a wise investment—is to garner community support with tree plantings. This can reduce vandalism and create a sense of ownership (Black, 1978). For example, Sklar and Ames (1985) found that trees planted with community participation had significantly higher survival rates (~60%–70%) as compared to trees that were planted without community participation (~1%). Involving the local community in tree planting may also increase neighborhood ties (Watkins et al., 2018). This may lead to a positive social effect.

A major issue that extends beyond the scope of this paper is that often low-income countries have the greatest need for improved urban conditions, and therefore, they may have the greatest need for...
trees. However, many of these countries may not have the climate to support trees; they may be xeric or in areas that are susceptible to droughts (McDonald et al., 2016). The variance in climates emphasizes the importance of proper selection of trees, identifying trees that are adapted to local climates or have high plasticity and can survive in unfavorable conditions. Green infrastructure that collects and integrates stormwater drainage where trees are planted may offer a solution to tree survival in xeric environments. Regardless, water availability must be considered before planting (McDonald et al., 2016).

Moving forward, emphasis should be placed on reducing the inequity of tree distribution in the urban forest within and among cities. Trees and green spaces are often unequally distributed among communities with varying demographics such as income and race (Jennings, Johnson Gaither, & Gragg, 2012; Landry & Chakraborty, 2009; Pincetl, 2010). Schwarz et al. (2015) found that when analyzing seven major cities, the authors found a strong relationship between urban tree cover and income: the lower the income, the fewer the trees. Decision-makers may underestimate the importance of trees and plants in humanitarian work due to bias of plant blindness (Balding & Williams, 2016), but this paper illustrates the benefits.

Future research is needed to understand all of the benefits and disservices that trees provide to people. First, moving beyond correlation, more experimental studies should be conducted that evaluate the benefit of trees to people. Jennings and Johnson Gaither (2015) outlined how future research should focus efforts on understanding how health and green space are related in low-income populations and rural minorities. Historically, research has been geographically biased with many of the studies occurring in North America and Europe (Keniger et al., 2013). There are many opportunities to expand this research to the southern hemisphere. Given the short-time frame of most social and psychological studies (Keniger et al., 2013), longitudinal studies will help determine longer-term impacts of trees and nature on people. As discussed in Salmond et al. (2016), researchers should work to understand the scale of benefits or disservices. This includes a more localized approach to research, such as understanding the local impacts of street trees in regulating air quality, rather than at regional scale. In addition, rather than focusing on individual pollutants, research is needed that investigates the interaction of air pollution, pollen, and temperature at a local scale (Salmond et al., 2016). Understanding the benefits of nature, beyond trees, is important for strategic urban planning in xeric environments. Finally, while there are trade-offs between disservices and services, future-focused urban planning and research is needed so the right species are planted in the right environment to minimize the negative impacts of any disservices and maximize the benefits.

4 | CONCLUSION

Investing in trees will result in sustainable cities with happier and healthier people. We reviewed the substantial evidence to better understand the tangible and real benefits that trees provide. While there are considerations, planting and protecting trees is a real solution to many of society’s challenges, offering high potential with relatively small input and energy. The results can be profound in the long term. In particular, the five categories of benefits outlined in this article (health and social well-being, cognitive development and education, economy and resources, climate change mitigation and habitat, and green infrastructure) are of particular importance, especially as there is a great global migration into cities. While previous work illustrated that trees can help meet several of the UNSDG, this review demonstrates that planting and protecting of trees can directly and indirectly contribute to 15 of the 17 goals. This is more than previously described. Beyond the UN SDG, the planting and protecting of trees supports the United Nation’s New Urban Agenda (NUA). The NUA, which was created to promote the development of sustainable cities, stresses the importance of green and quality public spaces, as well as green infrastructure (United Nations, 2017). For people to receive their benefits, the urban forest needs to be healthy and diverse to create the most sustainable and livable communities possible.

We have entered a new era in which humans are the dominant species and the main influencer of the planet. The built environment as it currently exists is not conducive to most trees (Watson & Himelick, 2013). In order to receive the benefits that trees provide, we need people who have the skills required to care for trees. Horticulture experts and plant scientists are of vital importance to the world, and they need to be future-focused in their work, actively seeking positive outcomes for society’s challenges (Blackmore & Paterson, 2006; Raven, 2019; Smith, 2019). This new era of the Anthropocene requires a new era of horticulture. Experts need to understand how to address society’s needs and the realities of the urban environment, while taking trees and adapting them to where people live. This requires skills in arboriculture, sourcing, cultivation, production, and care in a way that is calculated and encompasses urban planning. We also need broad engagement across all sectors (Cavender & Donnelly, 2019) to strategically plan and manage the urban forest to gain the most benefits (Miller, Hauer, & Werner, 2015).

If we want to have the benefits of urban trees in the future, we must think of our urban forests as an investment. Like any investment, if trees are not cared for, they depreciate in value and can become a liability. Through planting and care, however, urban forests can have compounding benefits, trickling through every layer of society, leading to a better world. As the proverb says, “The best time to plant a tree is twenty years ago, the second best time is now.” We must act now for a better world.

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**REFERENCES**

Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution*, 116, S119–S126. https://doi.org/10.1016/S0269-7491(01)00264-0

Akbari, H., Pomerantz, M., & Taha, H. (2001). Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices. *Landscape and Urban Planning*, 51(1–2), 153–164. https://doi.org/10.1016/S0169-2046(01)00232-0

Anderson, L. M., & Cordell, H. K. (1988). Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices. *Landscape and Urban Planning*, 51(1–2), 153–164. https://doi.org/10.1016/S0169-2046(01)00232-0

Balding, M., & Williams, K. J. H. (2016). Plant blindness and the implications for plant conservation. *Conservation Biology*, 30(6), 1192–1199. https://doi.org/10.1111/cobi.12738

Bell, J. F., Wilson, J. S., & Liu, G. C. (2008). Neighborhood greenness and 2-year changes in body mass index of children and youth. *American Journal of Preventive Medicine*, 35(6), 547–553. https://doi.org/10.1016/j.amepre.2008.07.006

Berhane, K., Chang, C. C., McConnell, R., Gauderman, W. J., Avol, E., Rapaport, E., ... Gilliland, F. (2016). Association of changes in air quality with bronchitic symptoms in children in California, 1993–2012. *JAMA*, 315(14), 1491–1501. https://doi.org/10.1001/jama.2016.3444

Berland, A., Shiflett, S. A., Shuster, W. D., Gar mestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning*, 162, 167–177. https://doi.org/10.1016/j.landurbplan.2017.02.017

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, 19(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., ... Jonides, J. (2012). Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders*, 140(3), 300–305. https://doi.org/10.1016/j.jad.2012.03.012

Binns, J. A., Illgner, P. M., & Nel, E. L. (2001). Water shortage, deforestation and development: South Africa’s working for water programme. *Land Degradation & Development*, 12(4), 341–355. https://doi.org/10.1002/ldr.455

Black, M. E. (1978). Tree vandalism: Some solutions. *Journal of Arboriculture*, 4(1), 114–116.

Blackmore, S., & Paterson, D. (2006). Gardening the earth: The contribution of botanic gardens to plant conservation and habitat restoration. In E. Leadlay, & S. Jury (Eds.), *Taxonomy and plant conservation: The cornerstone of the conservation and the sustainable use of plants* (pp. 266–273). Cambridge: Cambridge University Press.

Blicharska, M., & Mikusinska, 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

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, 29(2), 293–301. https://doi.org/10.1016/S0921-8009(99)00123-0

Brack, C. L. (2002). Pollution mitigation and carbon sequestration by an urban forest. *Environmental Pollution*, 116, S195–S200. https://doi.org/10.1016/S0269-7491(01)00251-2

Braden, J. B., & Johnston, D. M. (2004). Downstream economic benefits from storm-water management. *Journal of Water Resources Planning and Management*, 130(6), 498–505. https://doi.org/10.1061/(ASCE)0733-9496(2004)130:6(498)

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., & Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proceedings of the National Academy of Sciences*, 112(28), 8567–8572. https://doi.org/10.1073/pnas.1510459112

Califpiatrica, C., Fares, S., Manes, F., Morani, A., Sgrigna, G., & Loreto, F. (2013). Role of Biogenic Volatile Organic Compounds (BVOC) emitted by urban trees on ozone concentration in cities: A review. *Environmental Pollution*, 183, 71–80. https://doi.org/10.1016/j.envpol.2013.03.012

Cavender, N., & Donnelly, G. (2019). Intersecting urban forestry and botanical gardens to address big challenges for healthier trees, people, and cities. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.38

Center for International Earth Science Information Network - CIESIN - Columbia University. (2016). *Global Urban Heat Island (UHI) Data Set*. 2013. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4H70CRF

Chen, L., Liu, C., Zhang, L., Zou, R., & Zhang, Z. (2017). Variation in tree species ability to capture and retain airborne fine particulate matter (PM2.5). *Scientific Reports*, 7(1), 3206. https://doi.org/10.1038/s41598-017-03360-1

Churkina, G., Kuik, F., Bonn, B., Lauer, A., Grote, R., Tomiak, K., & Butler, T. M. (2017). Effect of VOC emissions from vegetation on air quality in Berlin during a heatwave. *Environmental Science & Technology*, 51(11), 6120–6130. https://doi.org/10.1021/acs.est.6b06514

Clark, K. H., & Nicholas, K. A. (2013). Introducing urban food forestry: A multifunctional approach to increase food security and provide ecosystem services. *Landscape Ecology*, 28(9), 1649–1669. https://doi.org/10.1007/s10980-013-9903-z

Coley, R. L., Sullivan, W. C., & Kuo, F. E. (1997). Where does community grow?: The social context created by nature in urban public housing. *Environment and Behavior*, 29(4), 468–494. https://doi.org/10.1177/00138741965702900402

Dawson, I. K., Place, F., Torquebiau, E., Malézieux, E., Iiyama, M., Sileshi, G. W., ...Jamnadass, R. (2013). Agroforestry, food and nutritional security. In United Nations Food and Agriculture Organization.

Di, Q., Dai, L., Wang, Y., Zanobetti, A., Choirat, C., Schwartz, J. D., & Dominici, F. (2017). Association of short-term exposure to air pollution with mortality in older adults. *The Journal of the American Medical Association*, 318(24), 2446–2456. https://doi.org/10.1001/jama.2017.17923

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

Donovan, G. H., & Butry, D. T. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings*, 41(6), 662–668. https://doi.org/10.1016/j.enbuild.2009.01.002

Donovan, G. H., & Butry, D. T. (2010). Trees in the city: Valuing street trees in Portland, Oregon. *Landscape and Urban Planning*, 94(2), 77–83. https://doi.org/10.1016/j.landurbplan.2009.07.019

Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatzios, D., & Mao, M. Y. (2013). The relationship between trees and human health: Evidence from the spread of the emerald ash borer. *American Journal of Preventive Medicine*, 44(2), 139–145. https://doi.org/10.1016/j.amepre.2012.09.066
Donovan, G. H., & Prestemon, J. P. (2012). The effect of trees on crime in Portland, Oregon. Environment and Behavior, 44(1), 3–30. https://doi.org/10.1177/0014482510383328

Donovan, R. G., Stewart, H. E., Owen, S. M., MacKenzie, A. R., & Hewitt, C. N. (2005). Development and application of an urban tree air quality score for photochemical pollution episodes using the Birmingham, United Kingdom, area as a case study. Environmental Science & Technology, 39(17), 6730–6738. https://doi.org/10.1021/es05081y

Dwyer, J. F., Schroeder, H. W., & Gobster, P. H. (1991). The significance of urban trees and forests: Towards a deeper understanding of values. Journal of Arboriculture, 17(10), 276–284.

Ellaway, A., Macintyre, S., & Bonnefoy, X. (2005). Graffiti, greenery, and obesity in adults: Secondary analysis of European cross sectional survey, Bmj, 331(7517), 611–612. https://doi.org/10.1136/bmj.38575.664549.F7

Ellis, E. C. (2015). Ecology in an anthropogenic biosphere. Ecological Monographs, 85(3), 287–331. https://doi.org/10.1890/14-2274.1

Elmendorf, W. (2008). The importance of trees and nature in community: A review of the relative literature. Arboriculture and Urban Forestry, 34(3), 152–156.

Endreny, T. A. (2018). Strategically growing the urban forest will improve our world. Nature Communications, 9(1), 1160. https://doi.org/10.1038/s41467-018-03622-0

Endreny, T., Santagata, R., Perna, A., De Stefano, C., Rallo, R. F., & Ugliati, S. (2017). Implementing and managing urban forests: A much needed conservation strategy to increase ecosystem services and urban well-being. Ecological Modelling, 360, 328–335. https://doi.org/10.1016/j.ecolmodel.2017.07.016

Environmental Protection Agency. (2008). Reducing urban heat islands: Compendium of strategies. Draft. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/heat-islands/heat-island-compendium of strategies.

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

Faber Taylor, A., & Kuo, F. E. (2009). Children with attention deficits concentrate better after walk in the park. Journal of Attention Disorders, 12(5), 402–409. https://doi.org/10.1177/1087073708322000

Faber Taylor, A., Kuo, F. E., & Sullivan, W. C. (2001). Coping with ADD: The surprising connection to green play settings. Environment and Behavior, 33(1), 54–77. https://doi.org/10.1177/0013916011972864

Faber Taylor, A., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: Evidence from inner city children. Journal of Environmental Psychology, 22(1–2), 49–63. https://doi.org/10.1006/jenv.2001.0241

Fahey, R. T., Darling, L., & Anderson, J. (2015). Oak ecosystem recovery plan: Sustaining oaks in the Chicago wilderness region. Chicago Wilderness Oak Ecosystem Recovery Working Group. Retrieved from https://www.dnr.illinois.gov/conservation/IWAP/Documents/Chicag o%20Wilderness%20Oak%20Ecosystem%20Recovery%20Plan. pdf

Favez, O., Cachier, H., Sciare, J., Sarda-Estève, R., & Martinon, L. (2009). Evidence for a significant contribution of wood burning aerosols to PM2.5 during the winter season in Paris, France. Atmospheric Environment, 43(22–23), 3640–3644. https://doi.org/10.1016/j.atmosenv.2009.04.035

Food and Agriculture Organization of the United Nations (FAO). (2016). Guidelines on urban and peri-urban forestry. F. Salbitano, S. Borelli, M. Conigliaro, & Y. Chen (Eds.), FAO Forestry Paper 178: Rome: Food and Agriculture Organization of the United Nations.

French, C. J., Dickinson, N. M., & Putwain, P. D. (2006). Woody biomass phytoremediation of contaminated brownfield land. Environmental Pollution, 141(3), 387–395. https://doi.org/10.1016/j.envpol.2005.08.065

Garrity, D. P. (2004). Agroforestry and the achievement of the Millennium Development Goals. Agroforestry Systems, 61(1–3), 5–17. https://doi.org/10.1023/B:AGFO.0000028986.37502.7c

Goudie, A. S. (2019). Human impact on the natural environment: Past, present and future. Chichester, West Sussex: John Wiley & Sons.

Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariañanos, P., Churkina, G., ... Calafapietra, C. (2016). Functional traits of urban trees: Air pollution mitigation potential. Frontiers in Ecology and the Environment, 14(10), 543–550. https://doi.org/10.1002/fee.1426

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. Journal of Environmental Psychology, 23(2), 109–123. https://doi.org/10.1016/S0272-4449(02)00109-3

Hauer, R. J., & Johnson, G. R. (2003). Tree risk management. In J. D. Pokorny (Ed.), Urban tree risk management: A community guide to program design and implementation (pp. 5–10). St. Paul, Minnesota: USDA Forest Service, Northeastern Area, State and Private Forestry.

Hiorns, A. D., & Thomas, P. A. (2018). Applied tree biology. Oxford, UK: John Wiley & Sons.

Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., & Kaufman, J. D. (2013). Long-term air pollution exposure and cardio-respiratory mortality: A review. Environmental Health, 12(1), 43. https://doi.org/10.1186/1476-069X-12-43

Holtan, M. T., Dieterlen, S. L., & Sullivan, W. C. (2015). Social life under cover: Tree canopy and social capital in Baltimore, Maryland. Environment and Behavior, 47(5), 502–525. https://doi.org/10.1177/0013916513180644

Hurley, P., & Emery, M. R. (2018). Locating provisioning ecosystem services in urban forests: Forageable woody species in New York City, USA. Landscape and Urban Planning, 170, 266–275. https://doi.org/10.1016/j.landurbplan.2017.09.025

James, P., Hart, J. E., Banay, R. F., & Laden, F. (2016). Exposure to greenness and mortality in a nationwide prospective cohort study of women. Environmental Health Perspective, 124(9), 1344–1352. https://doi.org/10.1289/ehp.1510363

Jahnell, S. (2015). Review on urban vegetation and particle air pollution–Deposition and dispersion. Atmospheric Environment, 105, 130–137. https://doi.org/10.1016/j.atmosenv.2015.01.052

Jennings, V., & Johnson Gaither, C. (2015). Approaching environmental health disparities and green spaces: An ecosystem services perspective. International Journal of Environmental Research and Public Health, 12(2), 1952–1968. https://doi.org/10.3390/ijerph120201952

Jennings, V., Johnson Gaither, C., & Gragg, R. S. (2012). Promoting environmental justice through urban green space access: A synopsis. Environmental Justice, 5(1), 1–7. https://doi.org/10.1089/env.2011.0007

Jiang, B., Larsen, L., Deal, B., & Sullivan, W. C. (2015). A dose-response curve describing the relationship between tree cover density and landscape preference. Landscape and Urban Planning, 139, 16–25. https://doi.org/10.1016/j.landurbplan.2015.02.018

Kaoma, H., & Shackleton, C. M. (2015). The direct-use value of urban tree non-timber forest products to household income in poorer suburbs in South African towns. Forest Policy and Economics, 61, 104–112. https://doi.org/10.1016/j.forpol.2015.08.005

Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective. New York, NY: Cambridge University Press.

Kaplan, S. (1995). The restorative benefits of nature: Towards an integrative framework. Journal of Environmental Psychology, 15(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kaplan, S., Kaplan, R., & Wendt, J. (1972). Rated preference and complexity for natural and urban visual material. Perception and Psychophysics, 12(4), 354–356. https://doi.org/10.3758/BF03207221

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T., & Berman, M. G. (2015). Neighborhood greenspace and health in a large urban center. Scientific Reports, 5, 11610. https://doi.org/10.1038/srep11610
Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, À.,..., Fresco, L. O. (2016). The significance of soils and soil science to rural development. *Soil Science Society of America Journal, 80*(3), 871–877. https://doi.org/10.2136/sssaj2015.05.0179

Kellert, S. R., & Wilson, E. O. (1996). *The biophilia hypothesis*. Washington, DC: Island Press.

Keniger, L. E., Gaston, K. J., Irvine, K. N., & Fuller, R. A. (2013). What are the benefits of interacting with nature? *International Journal of Environmental Research and Public Health, 10*(3), 913–935. https://doi.org/10.3390/ijerph10030913

Kondo, M. C., Han, S., Donovan, G. H., & MacDonald, J. M. (2017). The association between urban tree and crime: Evidence from the spread of the emerald ash borer in Cincinnati. *Landscape and Urban Planning, 157*, 193–199. https://doi.org/10.1016/j.landurbplan.2016.07.003

Kuo, F. E. (2003). Social aspects of urban forestry: The role of arboriculture in a healthy social ecology. *Journal of Arboriculture, 29*(3), 148–155.

Kuo, F. E., Bacaicoa, M., & Sullivan, W. C. (1998). Transforming inner-city landscapes: Trees, sense of safety, and preference. *Environment and Behavior, 30*(1), 28–59. https://doi.org/10.1177/00139165983001002

Kuo, F. E., & Sullivan, W. C. (2001a). 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

Kuo, F. E., & Sullivan, W. C. (2001b). Environment and crime in the inner city: Does vegetation reduce crime? *Environment and Behavior, 33*(3), 343–367. https://doi.org/10.1177/0013916501333002

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. *American Journal of Community Psychology, 26*, 823–851. https://doi.org/10.1023/A:1022924028903

Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Frontiers in Psychology, 6*, 1093. https://doi.org/10.3389/fpsyg.2015.01093

Kuo, M., Browning, M. H. E., & Penner, M. L. (2018). Do lessons in nature boost subsequent classroom engagement? Refueling students in flight. *Frontiers in Psychology, 8*, 2253. https://doi.org/10.3389/fpsyg.2017.02253

Kuo, M., Browning, M. H. E. M., Sachdeva, S., Lee, K., & Westphal, L. (2018). Might school performance grow on trees? Examining the link between ‘greenness’ and academic achievement in urban, high-poverty schools. *Frontiers in Psychology, 25*, 1669. https://doi.org/10.3389/fpsyg.2018.01669

Kweon, B.-S., Ellis, C. D., Lee, J., & Jacobs, K. (1995). The biophilia hypothesis. Washington, DC: Island Press.

Lin, Y.-H., Tsai, C.-C., Sullivan, W. C., Chang, P.-J., & Chang, C.-Y. (2014). Does awareness effect the restorative function and perception of street trees? *Frontiers in Psychology, 5*, 906. https://doi.org/10.3389/fpsyg.2014.00906

Lindemayer, D. B. (2017). Conserving large old trees as small natural features. *Biological Conservation, 211*(B), 51–59. https://doi.org/10.1016/j.biocon.2016.11.012

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

Lindemayer, 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

 Livesey, 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 Environmental Quality, 45*(1), 119–124. https://doi.org/10.1111/jeq.12057

Lohr, V. L., & Pearson-Mims, C. H. (2006). Responses to scenes with spreading, rounded, and conical tree forms. *Environment and Behavior, 38*(5), 667–688. https://doi.org/10.1177/0013916506287355

Lohr, V. L., Pearson-Mims, C. H., Tarnai, J., & Dillman, D. A. (2004). How urban residents rate and rank the benefits and problems associated with trees in cities. *Journal of Arboriculture, 30*(1), 28–35.

Loughner, C. P., Allen, D. J., Zhang, D.-L., Pickering, K., Dickerson, R. R., & Landry, L. (2012). Roles of urban tree canopy and buildings in urban heat island effects: Parameterization and preliminary results. *Journal of Applied Meteorology and Climatology, 51*(10), 1775–1793. https://doi.org/10.1175/JAMC-D-11-0228.1

Lutz, J. A., Furniss, T. J., Johnson, D. J., Davies, S. J., Allen, D., Alonso, A., ... Zimmerman, J. K. (2018). Global importance of large-diameter trees. *Global Ecology and Biogeography, 27*(7), 849–864. https://doi.org/10.1111/geb.12747

Lyytimäki, J., & Sipilä, M. (2009). Hopping on one leg – The challenge of ecosystem disservices for urban green management. *Urban Forestry and Urban Greening, 8*(4), 309–315. https://doi.org/10.1016/j.ufug.2009.09.003

Manning, A. D., Fischer, J., & Lindemayer, D. B. (2006). Scattered trees are keystone structures – Implications for conservation. *Biological Conservation, 132*(3), 311–321. https://doi.org/10.1016/j.biocon.2006.04.023

Matsuoka, R. H. (2010). Student performance and high school landscapes: Examining the links. *Landscape and Urban Planning, 97*(4), 273–282. https://doi.org/10.1016/j.landurbplan.2010.06.011

Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E., & Dooliver, K. (2009). Why is nature beneficial? The role of connectedness to Nature. *Environment and Behavior, 41*(5), 607–643. https://doi.org/10.1177/0013916508319745

McDonald, A. G., Bealey, W. J., Fowler, D., Dragosits, U., Skiba, U., Smith, R. I., & Nemitz, E. (2007). Quantifying the effect of urban tree planting on concentrations and depositions of PM2.5 in two UK conurbations. *Atmospheric Environment, 41*(38), 8455–8467. https://doi.org/10.1016/j.atmosenv.2007.07.025

McDonald, R., Kroeger, T., Boucher, T., Longzhu, W., Salem, R., Adams, J., ... Garg, S. (2016). Planting healthy air: a global analysis of the role of trees. *The Nature Conservancy, 1*, 1–29.

McLain, R. J., Hurley, P. T., Emery, M. R., & Poe, M. R. (2013). Gathering ‘wild’ food in the city: Rethinking the role of foraging in urban...
ecosystem planning and management. Local Environment, 19(2), 220–240. https://doi.org/10.1080/13549839.2013.841659
McLain, R., Poe, M., Hurley, P. T., Lecompte-Mastenbrook, J., & Emery, M. R. (2012). Producing edible landscapes in Seattle's urban forest. *Urban Forestry and Urban Greening*, 11(2), 187–194. https://doi.org/10.1016/j.ufug.2011.12.002
McPherson, E. G., & Muchnick, J. (2005). Effects of street tree shade on asphalt concrete pavement performance. *Journal of Arboriculture*, 31(6), 303–310.
McPherson, E. G., van Doorn, N., & de Goede, J. (2016). Structure, function and value of street trees in California, USA. *Urban Forestry and Urban Greening*, 17(1), 104–115. https://doi.org/10.1016/j.ufug.2016.03.013
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.
Miller, R. W., Hauer, R. J., & Werner, L. P. (2015). *Urban forestry: Planning and managing urban greenspaces* (3rd ed.). Long Grove, Illinois: Waveland Press.
Mo, L., Ma, Z., Xu, Y., Sun, F., Lun, X., Liu, X., … Yu, X. (2015). Assessing the function and value of street trees in Beijing, China. *PLoS ONE*, 10(10), e0140664. https://doi.org/10.1371/journal.pone.0140664
Mooney, P., & Nicell, P. L. (1992). The importance of exterior environment for Alzheimer residents: Effective care and risk management. *Healthcare Management Forum*, 5(2), 23–29. https://doi.org/10.1016/S0840-4704(10)61202-1
Morley, A., Farrier, A., & Dooris, M. (2017). Propagating success? The Incredibl Edible Model Final Report. Manchester Metropolitan University and the University of Central Lancashire. Retrieved from https://www.incredibledible.org.uk/wp-content/uploads/2018/06/Propagating-success-the-incredibledible-model-Final-report.pdf
Mustafić, H., Jabre, P., Caussin, C., Murad, M. H., Escolano, S., Taflflet, M., … Jouven, X. (2012). Main air pollutants and myocardial infarction: A systematic review and meta-analysis. *JAMA*, 307(7), 713–721. https://doi.org/10.1001/jama.2012.126
Nesbitt, L., Hotte, N., Barron, S., Cowan, J., & Sheppard, S. R. J. (2017). The social and economic value of cultural ecosystem services provided by urban forests in North America: A review and suggestions for future research. *Urban Forestry and Urban Greening*, 25, 103–111. https://doi.org/10.1016/j.ufug.2017.05.005
Northern Illinois Tree Selector. (2019). The Morton Arboretum. Retrieved from https://www.mortonarb.org/trees-plants/tree-and-plant-advice/tree-species-list/filters
Nowak, D. J. (1993). Atmospheric carbon reduction by urban trees. *Journal of Environmental Management*, 37(3), 207–217. https://doi.org/10.1016/j.jema.1993.1017
Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees and shrubs in the United States. *Urban Forestry and Urban Greening*, 1, 104–115. https://doi.org/10.1016/S0267-7491(01)00024-7
Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees in Canada and its effect on air quality and human health in the United States. *Environmental Pollution*, 193, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028
Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, 193, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028
Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M., & Pasher, J. (2018). Air pollution removal by urban forests in Canada and its effect on air quality and human health. *Urban Forestry and Urban Greening*, 29, 40–48. https://doi.org/10.1016/j.ufug.2017.10.019
Nwanaji-Enwerem, J. C., Wang, W., Nwanaji-Enwerem, O., Vokonas, P., Baccarelli, A., Weisskopf, M., … Schwartz, J. (2019). Association of long-term ambient black carbon exposure and oxidative stress allelic variants with intraocular pressure in older men. *JAMA Ophthalmology*, 137(2), 129–137. https://doi.org/10.1001/jamaophthalmol.2018.5313
Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). The Agroforestry database: A tree reference and selection guide. Version 4.0. Retrieved from https://www.worldagroforestry.org/output/agroforestry-database
Pandit, R., & Laband, D. N. (2010). Energy savings from tree shade. *Economico logicals, 69(6), 1324–1329. https://doi.org/10.1016/j.econle n.2010.01.009
Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. *Nature*, 438(7066), 310–317. https://doi.org/10.1038/nature04188
Peterson, B. S., Rauh, V. A., Bansal, R., Hao, X., Toth, Z., Nati, G., … Perera, F. (2015). Effects of prenatal exposure to air pollutants (polycyclic aromatic hydrocarbons) on the development of brain white matter, cognition, and behavior in later childhood. *JAMA Psychiatry*, 72(6), 531–540. https://doi.org/10.1001/jamapsychiatry.2015.57
Pincett, S. (2010). Implementing municipal tree planting: Los Angeles million-tree initiative. *Environmental Management*, 45(2), 227–238. https://doi.org/10.1007/s00267-009-9412-7
Poe, M. R., McLain, R. J., Emery, M., & Hurley, P. T. (2013). Urban forest justice and the rights to wild foods, medicines, and materials in the city. *Human Ecology*, 41(3), 409–422. https://doi.org/10.1007/s10745-013-9572-1
Raven, P. H. (2019). Saving plants, saving ourselves. *Plants, People, Planet*, 1(1), 8–13. https://doi.org/10.1002/ppa3.3
Reid, C. E., Clougherty, J. E., Shmool, J. L. C., & Kubzansky, L. D. (2017). Is all urban green space the same? A comparison of the health benefits of trees and grass in New York City. *International Journal of Environmental Research and Public Health*, 14(11), 1411. https://doi.org/10.3390/ijerph14111411
Rief, S. F. (2012). *How to reach and teach children with ADD / ADHD: Practical techniques, strategies, and interventions*. San Francisco, CA: John Wiley & Sons.
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
Salmon, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., … Wheeler, B. W. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, 15(1), S36. https://doi.org/10.1186/s12940-016-0103-6
Sander, H., Polasky, S., & Haight, R. G. (2010). The value of urban tree cover: A hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. *Ecological Economics*, 69(8), 1646–1656. https://doi.org/10.1016/j.ecolecon.2010.03.011
Scharenbroch, B. C., Morgenroth, J., & Maule, B. (2016). Tree species suitability to bioswales and impact on the urban water budget. *Journal of Environmental Quality*, 45(1), 199–206. https://doi.org/10.2134/jeq2015.01.0060
Schwab, J. (2009). *Planning the urban forest: Ecology, economy, and community development*. Chicago, IL: American Planning Association.
Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., Mchale, M., Grove, J. M., … Cadenasso, M. L. (2015). Trees grow on money: Urban tree canopy cover and environmental justice. *PLoS ONE*, 10(4), e0122051. https://doi.org/10.1371/journal.pone.0122051
Shah, A. S. V., Langrish, J. P., Nair, H., McAllister, D. A., Hunter, A. L., Donaldson, K., … Mills, N. L. (2013). Global association of air pollution and heart failure: A systematic review and meta-analysis. *Lancet*, 382, 1039–1048. https://doi.org/10.1016/S0140-6736(13)60898-3
Sharrock, S., & Jackson, P. W. (2017). Plant conservation and the Sustainable Development Goals: A Policy paper prepared for the global partnership for plant Conservation. Annals of the Missouri Botanical Garden, 102(2), 290–302. https://doi.org/10.3417/D-16-0004A

Sherrill, S. (2003). Harvesting urban timber: A guide to making better use of urban trees. Fresno, CA: Linden Publishing.

Simpson, J. R. (1998). Urban forest impacts on regional cooling and heating energy use: Sacramento county case study. Journal of Arboriculture, 24(2), 201–214.

Sklar, F., & Ames, R. G. (1985). Staying alive: Street tree survival in the inner-city. Journal of Urban Affairs, 7(1), 55–66. https://doi.org/10.1111/j.1467-9906.1985.tb00077.x

Smith, P. (2019). The challenge for botanic garden science. Plants, People, Planet, 1(1), 38–43. https://doi.org/10.1016/j/ppp3.10

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

Staudhammer, C. L., Escobedo, F., Luley, C., & Bond, J. (2009). Patterns of urban forest debris from the 2004 and 2005 Florida hurricane seasons. Southern Journal of Applied Forestry, 33(4), 193–196.

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckham, 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

Summers, J. K., & Vivian, D. N. (2018). Ecotourism: A forgotten ecosystem service: A review. Frontiers in Psychology, 9, 1389. https://doi.org/10.3389/fpsyg.2018.01389

Taylor, M. S., Wheeler, B. W., White, M. P., Economou, T., & Osborne, N. J. (2015). Research note: Urban street tree density and antidepressant prescription rates—A cross-sectional study in London, UK. Landscape and Urban Planning, 136, 174–179. https://doi.org/10.1016/j.landurbplan.2014.12.005

Tennessen, C. M., & Cimprich, B. (1995). Views to nature: Effects on attention. Journal of Environmental Psychology, 15(1), 77–85. https://doi.org/10.1016/0272-4944(95)90016-0

Troy, A., Morgan Grove, J., & O’Neil-Dunne, J. (2012). The relationship between tree canopy and crime rates across an urban-rural gradient in the greater Baltimore region. Landscape and Urban Planning, 106(3), 262–270. https://doi.org/10.1016/j.landurbplan.2012.03.010

Troy, A., Nunery, A., & Grove, J. M. (2016). The relationship between residential yard management and neighborhood crime: An analysis from Baltimore City and County. Landscape and Urban Planning, 147, 78–87. https://doi.org/10.1016/j.landurbplan.2015.11.004

Turner, J. B. (2015). The root of sustainability: Investigating the relationship between medicinal plant conservation and surface mining in Appalachia. PhD diss., West Virginia University, Morgantown, WV.

Tyrväinen, L., Pauleit, S., Seeland, K., & De Vries, S. (2005). Chapter 4: Urban forests and hurricanes in Florida. Southern Journal of Applied Forestry, 3(3), 152–158. https://doi.org/10.5849/sjaf.10-022

Xiao, Q., & McPherson, E. G. (2016). Surface water storage capacity of twenty tree species in Davis, California. Journal of Environmental Quality, 45(1), 188–198. https://doi.org/10.2134/jeq2015.02.0092

Zhong, J., Cayir, A., Trevisi, L., Sanchez-Guerra, M., Lin, X., Peng, C., … Baccarelli, A. A. (2016). Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry, 70(1), 71–77. https://doi.org/10.1001/jamapsychiatry.2013.266

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Vlek, P. L. G., Khamzina, A., & Lulsegged, T. (Eds.) (2017). Land degradation and the sustainable development goals: Threats and potential remedies. Nairobi, Kenya: International Center for Tropical Agriculture (CIAT).

Vogt, J., Hauer, R. J., & Fischer, B. C. (2015). The costs of maintaining and not maintaining the urban forest: A review of the urban forestry and arboriculture literature. Arboriculture & Urban Forestry, 41(6), 293–323.

Volk, H. E., Lurmann, F., Penfold, B., Hertz-Picciotto, I., & McConnell, R. (2013). Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry, 70(1), 71–77. https://doi.org/10.1001/jamapsychiatry.2013.266

Work Resources Institute. (2018). Cities4Forests. Retrieved from https://www.wri.org/our-work/project/cities4forests

Wyman, M., Escobedo, F., Stein, T., Orfanedes, M., & Northrop, R. (2012). Community leader perceptions and attitudes toward coastal urban forests and hurricanes in Florida. Southern Journal of Applied Forestry, 36(3), 152–158. https://doi.org/10.5849/sjaf.10-022