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REVIEW

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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 (Keesstra 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 and communities, of the UN SDG through providing universal access to green and public spaces. This paper expands on the work of the FAO (2016) and highlights additional goals of the UN SDG that can be met through a healthy urban forest.

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, & Pasher, 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 $PM_{2.5}$.

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 one particular study, 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, & Depledge, 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).

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 Increase physical activity Decrease aggression and violence Reduce crime
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

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;

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'Neil-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 Disorder (ADD) and Attention Deficit Hyperactivity Disorder (ADHD) 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 ADD and ADHD (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 fiscally 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 forgeable 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 SDG 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.

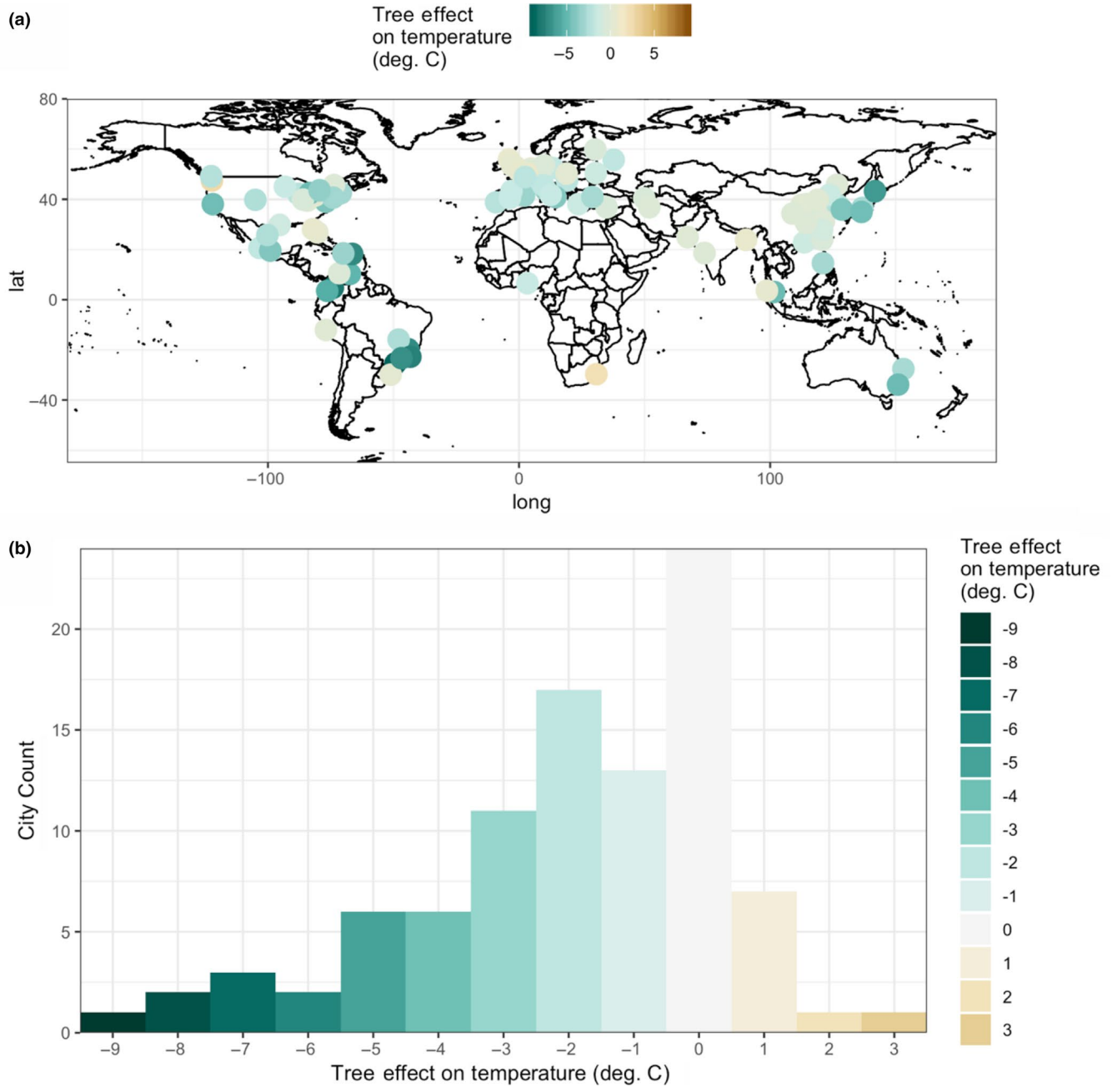

FIGURE 1 (a) Trees greatly contribute to urban cooling. Cities included in this evaluation have an estimated population in the metropolitan area greater than 2 million in the year 2000, a metropolitan area greater than 1,000 km^2, and an urban heat island effect greater than 1°C (Center for International Earth Science Information Network - CIESIN - Columbia University, 2016). The effect of trees on urban cooling was calculated by subtracting the temperature in areas without trees from the observed temperatures; (b) while the standard deviation is large, it is not normally distributed. The impact of trees on cooling the urban environment is ecologically and statistically significant. Figures are created by Dr Christy Rollinson, Forest Ecologist at The Morton Arboretum

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 inequality 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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