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University of Kentucky
College of Agriculture,
Food and Environment
Cooperative Extension Service

Ecosystem Services of Landscape Plants

A GUIDE FOR GREEN INDUSTRY PROFESSIONALS

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Introduction

This publication is meant to assist green industry professionals in marketing and customer education efforts as they explore marketing their products and services to improve green infrastructure. Consumers are placing increasing value on and acknowledging the critical role that landscape plants play in the urban environment, from reducing urban heat islands to improving the aesthetic experience (i.e. curb appeal) we derive from the landscape of an individual home. Further, there is a growing body of scientific literature evaluating the critical role of trees in landscaping within urban and suburban environments such as residential neighborhoods, commercial/industrial areas, and associated green infrastructure such as park systems and green belts.

An **ecosystem** is a community of living organisms in combination with the nonliving components (air, water, mineral soil) interacting as a system. One useful tool for articulating the functions landscape plants do for us is the concept of **ecosystem services**. "Ecosystem services are the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill human life." (Daily 1997).

As green industry professionals, we know that landscape plants do a lot for us. Though this is easily stated, it may not be easy to precisely describe or quantify the contributions of landscape plants to ecosystem services. There is no definitive list of ecosystem services nor a single definition for the concept, but for the sake of this publication we will be using the working definition of the Millennium Ecosystem Assessment, an inter-governmental report involving the work of over 1,360 experts worldwide to assess the consequences of ecosystem change for human well-being: "Ecosystem services are all benefits to humankind provided by ecosystems."

The focus of this publication is to describe the contributions of woody landscape plants to urban ecosystems with the goal of aiding green industry professionals in their work with customers who may have ecologically minded demands. Customers may include private businesses capitalizing on sustainability initiatives, community associations promoting open spaces, public firms engaged in climate change mitigation, and private homeowners hoping to increase the value of their property.

The resource list at the end of this document provides readers more detailed information. The free, peer-reviewed software suite i-Tree from the U.S. Forest Service is particularly valuable to individuals, firms, and communities who want to quantify the environmental services provided by existing and potential trees in their communities. The software was particularly valuable in compiling a list for comparing site suitability and ecosystem service benefit potential among a list of landscape trees. For this list, see the Species Reference Table located in the Appendix.

Types of Ecosystem Services

Woody landscape plants provide us with numerous valuable ecosystem services, including improvement of air quality, increased cultural and aesthetic value, biodiversity potential, carbon sequestration, energy conservation and microclimate regulation, improvement of human health, noise attenuation/reduction, and stormwater management. Green industry professionals must express to their customers the ability of landscape plants to improve green infrastructure.

Air Quality

Back in the 1800s, parks, habitats for trees and other landscape plants, were referred to as the "lungs of cities" by Frederick Law Olmsted, considered the "Father of American Parks." Air pollution is a significant risk factor for a number of health conditions, including respiratory infections, heart disease, stroke, and lung cancer. The human health effects of poor air quality are far reaching. The most common sources of air pollutants include particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. Indoor air pollution and urban air quality are

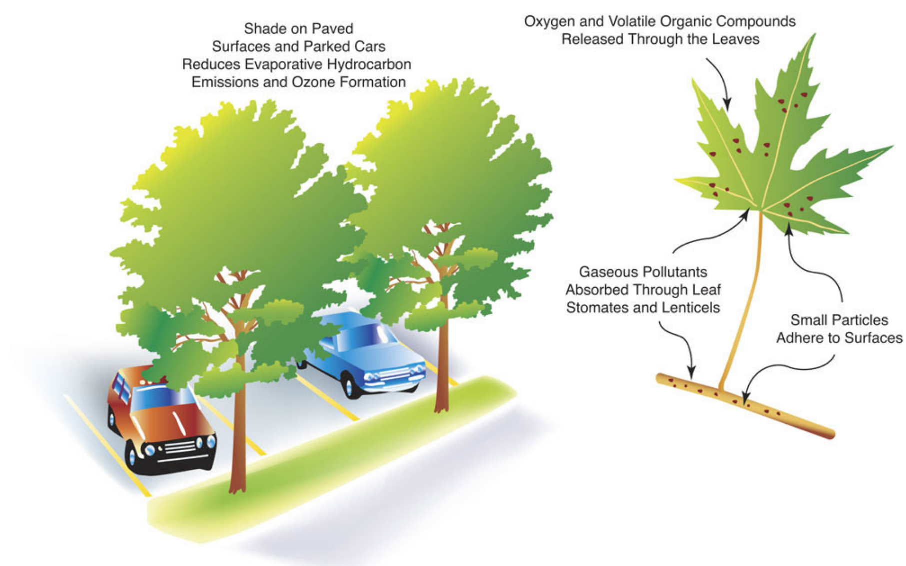


Figure 1. The interaction between trees and air pollutants. Mike Thomas, International Society of Arboriculture.

Table 1. Landscape plants with high tolerance to and potential for removal of carbon monoxide.

Latin name	Common Name	Latin name	Common Name
Aesculus hippocastanum	Horse chesnut	*Fagus grandifolia*	American beech
Betula alleghaniesis	Yellow birch	*Liriodendron tulipifera*	Tulip tree
Carpinus betulus	European hornbeam	*Prunus serotine*	Black cherry
Carya glabra	Pignut hickory	*Sassafras albidum*	Sassafras
Catalpa speciosa	Northern Catalpa	*Thuja plicata*	Western red cedar
Celtis occidentalis	Common hackberry	*Tilia americana*	American basswood
Chamaecyparis thyoides	Atlantic white cedar	*Ulmus americana*	American elm

Table 2. Landscape plants with high tolerance to and potential for removal of ground level ozone.

Latin name	Common Name	Latin name	Common Name
Acer rubrum	Red maple	*Juglans nigra*	Black walnut
Aesculus hippocastanum	Horse chesnut	*Liriodendron tulipifera*	Tulip tree
Betula alleghaniesis	Yellow birch	*Magnolia acuminate*	Cucumber tree
Carpinus betulus	European hornbeam	*Metasequoia glyptostroboides*	Dawn redwood
Carya laciniosa	Shellbark hickory	*Sassafras albidum*	Sassafras
Carya ovata	Shagback hickory	*Sequoia sempervirens*	Coast redwood
Celtis occidentalis	Common hackberry	*Prunus serotine*	Black cherry
Corylus colurna	Turkish hazelnut	*Tilia americana*	American basswood
Fagus grandifolia	American beech	*Ulmus americana*	American elm
Fraxinus americana	White ash	*Zelkova serrata*	Japanese zelkova

Table 3. Landscape plants with high tolerance to and potential for removal of sulfur and nitrogen.

Latin name	Common Name	Latin name	Common Name
Acer rubrum	Red Maple	*Liriodendron tulipifera*	Tulip tree
Aesculus hippocastanum	Horse Chesnut	*Magnolia acuminate*	Cucumber tree
Betula alleghaniesis	Yellow birch	*Picea abies*	Norway spruce
Cedrus deodara	Deodar Cedar	*Pinus strobus*	eastern white pine
Celtis occidentalis	Common hackberry	*Platanus hybrid*	London planetree
Fagus grandifolia	American beech	*Populus deltoids*	Eastern cottonwood
Fraxinus americana	White ash	*Tilia americana*	American basswood
Ginkgo biloba	Ginkgo	*Ulmus americana*	American elm
Gymnocladus dioicus	Kentucky coffeetree	*Zelkova serrata*	Japanese Zelkova
Juglans negra	Black walnut		

Table 4. Landscape plants with high tolerance to and potential for removal of particulate matter.

Latin name	Common Name	Latin name	Common Name
Abies concolor	White fir	*Pinus strobus*	Eastern white pine
Calocedrus decurrens	Incense cedar	*Pinus taeda*	Loblolly pine
Cedrus libani stenocoma	Hardy Cedar of Lebanon	*Taxus cuspidate*	Japanese yew
Chamaecyparis thyoides	Atlantic white cedar	*Thuja plicata*	Western redcedar
Cryptomeria japonica	Japanese red cedar	*Tilia americana*	American basswood
Magnolia grandiflora	Southern magnolia	*Ulmus americana*	American elm
Picea abies	Norway spruce	*Zelkova serrata*	Japanese zelkova
Picea pungens	Blue spruce		

listed as two of the world's worst toxic pollution problems in the 2008 Blacksmith Institute World's Worst Polluted Places report. Leaves contribute to the removal of pollutants from the air, and it is important to develop landscapes with leaf growth at multiple layers using shrubs, herbaceous perennials, and dwarf and standard trees.

A few ways that plants reduce air pollution:

- Absorption of gaseous pollutants (e.g. ozone, nitrogen oxides, and sulfur dioxide) through their leaves
- Reduction of ozone concentrations at ground level by reducing temperatures via evapotranspiration and shading
- Fuzzy leaves are much more effective in capturing particulate matter than smooth/hairless leaves
- Collection of dust, ash, pollen, and other particulate matter on their leaves, reducing its presence in the air breathed

In 2006 the city of Los Angeles started an initiative to plant one million new trees. A comprehensive study of this initiative estimates that, depending on the rate of tree mortality, these trees will save the citizens of Los Angeles between 53 and 78 million dollars in healthcare costs alone over the next 35 years.

A research series in 2010 by the Virginia-based National Recreation and Park Association published a list of trees associated with improving air quality based on their tolerance for specific air pollutants and their potential for removal of those air pollutants. Plants from that list with a high tolerance of pollutants and the potential for removal of various air pollutants are provided in Tables 1, 2, 3 and 4.

Carbon monoxide is a colorless, odorless, and tasteless gas. It is toxic to humans above concentrations of 35 ppm. A product of exhaust from internal combustion engines, it is common in urban areas.

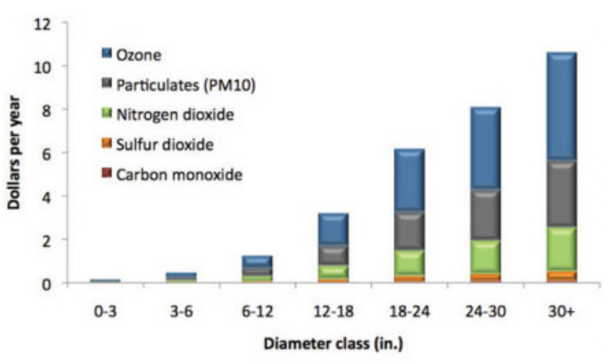
Though not emitted directly by car engines or industrial operations, **ozone** is formed by the reaction of sunlight on air containing the products of fuel combustion. Ground-level ozone has the following health effects at concentrations common in urban air: reduced lung function, aggravation of asthma, increased susceptibility to respiratory infections, and damage to lung lining. A study in 2004 estimated that decreasing urban ozone concentrations by 33 percent would save roughly 4,000 lives per year in the U.S. (Bell et al. 2004).

Particulate matter is the term for solid or liquid particles suspended in the air. Some are large enough to be seen, such as soot or smoke. Others can only be detected with an electron microscope. Particulate matter can be emitted directly from combustion or formed in the atmosphere when sulfur and nitrogen oxides react to form fine particles. The PM-10 government standard set by the EPA for inhalable particles with diameters generally includes particles with a diameter of 10 micrometers and smaller. Major concerns from exposure include effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death.

Both **sulfur** and **nitrogen oxides** are products of fossil fuel combustion. Sulfur is linked to power plants and industrial facilities, while nitrogen oxides are more commonly a product of transportation and off-road equipment. Within 50 meters of a roadway, concentrations have been measured to be approximately 30 to 100 percent higher than concentrations away from roadways. As with other air pollutants, the primary health impact is reduced respiratory function with risk for asthma in children and the elderly (EPA).

A more complex relationship exists between trees and ground-level ozone air pollution. Some tree species emit biogenic volatile organic compounds (BVOCs), which are precursors to ground-level ozone. BVOCs (and other VOCs) react with nitrogen oxides in the presence of sunlight to form ground-level ozone. The formation of BVOCs by trees is temperature dependent, with higher emission rates at higher temperatures, though the amount they produce is minuscule compared to the quantities of VOCs and other pollutants they absorb. In 2004, a model simulation of a 20 percent loss of forest around Atlanta led to a 14 percent increase in ground level ozone concentrations for a modeled day (Cardelino and Chameides 1990). Analysis of the model indicates "although there were fewer trees to emit VOCs, an increase in Atlanta's air temperatures due to the urban heat island [due to simulated tree loss] increased VOC emissions" from remaining trees and human sources, an increase in ground-level ozone concentrations. Similar modeling of the New York City metropolitan area revealed that increasing tree cover by 10 percent in urban areas reduced maximum ozone levels by about 4 parts per billion (Luley and Bond 2002).

Figure 2. Comparative economic value of pollutant removal. Nowak and Heisler, National Recreation and Park Association



Source: NRPA.org - Air Quality Effects of Urban Trees and Parks (2010)

Cultural and Aesthetic Value

Adding plants to a landscape increases property values. Good tree cover can raise the total sale price by 6 to 9 percent (Morales, Boyce and Favretti 1976), and the mere presence of trees may add a 3 to 5 percent premium to the sale price of a property (Anderson and Cordell 1985). Hedges or landscaped walls raises the sales price 4 percent (Des Rosiers et al. 2002). In 2003 interviews with realtor associations advised that "spending 5% of the value of your home on the installation of a quality, low-maintenance landscape increased resale values by 15%, which translates into a 150% return on the landscape investment" (Taylor 2003). A low-maintenance landscape is an uncrowded, simple landscape design that is not labor intensive. General characteristics include fewer grassy areas, often offset by hardscaping, mulched beds, and locally adapted, hardy perennial plant material. A recent study in Toronto found that "having 10 more trees in a city block, on average, improves health perception in ways comparable to an increase in personal income of $10,000 or being 7 years younger" (Kardan 2015).

Biodiversity Potential

Biodiversity is the variety of life on earth. Biodiversity allows ecosystems to adjust to disturbances. Ecosystems that can withstand disturbance are said to be resilient. Genetic diversity prevents and/or limits the impact of diseases and helps species adjust to changes in their environment. Most medical discoveries to cure diseases and lengthen life spans have been made because of research into plant biology, animal biology, and genetics. Healthy, native landscape plants when used intentionally to develop ecosystems will protect the biodiversity of local communities and provide habitat for local wildlife.

This wildlife can include butterflies and songbirds. Native insects attracted to native plants support the dietary requirement of native song birds. Butterflies are attracted to species of flowering plants based on the seasonality of flowering, while songbirds are attracted to trees based on height and other growth characteristics, emphasizing the importance of plant variety when creating ecosystems. A study in 2009 across several pairs of suburban properties in southeast Pennsylvania showed that bird species of regional conservation concern were eight times more abundant and significantly more diverse on properties with native landscaping in the built environment (Burghardt 2009).

Urbanization can contribute to loss of biodiversity through habitat destruction and the homogenization of ecosystems (Alvey 2006). Landscaping with a diversity of plant material helps offset the negative impacts of urbanization on biodiversity by providing for habitat for many species that would otherwise be displaced (Dearborn 2010).

Carbon Sequestration

Increased concentrations of atmospheric carbon dioxide contribute to the increase in average global temperature and disruption of climates around the world (Working Group I and Richard Alley 2007). Carbon dioxide concentrations in the atmosphere have been increasing rapidly since the industrial revolution, primarily from the use of fossil fuels but also from changing land uses. Each person, product, and activity emits carbon dioxide and other greenhouse gases such as methane and nitrous oxide, into the atmosphere. The potential impact of those emissions on global warming is called the carbon footprint of that product or activity. We each have a carbon footprint that has a negative impact on the atmosphere. Such human activity can be offset by carbon sequestration by woody plants and soil carbon storage.

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide. In the context of woody landscape plants, carbon sequestration is a function of photosynthesis: the plant builds itself by taking the carbon from carbon dioxide in the atmosphere. At maturity, approximately 50 percent of an individual tree or shrub's dry biomass is carbon, depending upon the density of the wood. When a landscape plant dies and is replaced, burial of the old tree represents the easiest method to ensure long-term storage in soil of most carbon captured by the tree. Green spaces are planned and large trees are planted in public rights of way, parks, and other open spaces to increase the availability of "carbon sinks," which are resources that serve to reduce the amount of carbon dioxide in the atmosphere (McPherson 2005).

The Intergovernmental Panel on Climate Change, an international body for assessing science related to climate change, established a 100-year assessment period as a standard for determining the carbon footprint of products and processes. We can express carbon sequestration by a woody plant in terms of the amount of carbon held from the atmosphere each year of the 100-year assessment period. When weighted for a portion of a 100-year assessment period, it has been estimated that a deciduous shade tree (*Acer rubrum)* in the suburban landscape can reduce the potential global warming impact from carbon dioxide by 670 kg CO_2, after accounting for emissions during production and take-down at the end of life. Published impact data on atmospheric carbon weighted annually for their functional life estimated that red maple, flowering deciduous tree (redbud), evergreen tree (blue spruce), evergreen shrub (*Taxus*), and deciduous shrub (*Viburnum*) in the lower Midwest reduce CO_2 in the atmosphere by an estimated 666, 430, 63, 9, and 11 kg CO_2 over their lifetime, respectively (Table 5). These estimations do not consider the long-term carbon storage in plant roots, which has not been quantified at this time but could be substantial for some plants.

Table 5. Global warming impact of aboveground plant growth weighted by life expectancy after accounting for emissions during production and take-down at end of life.

Landscape Plant	Years	kg CO_2
Red maple tree – *Acer rubrum*	60	-666
Evergreen tree – *Picea pungens*	50	-430
Flowering deciduous tree – *Cercis canadensis*	40	-63
Deciduous shrub – *Viburnum x juddi*	50	-11
Evergreen shrub – *Taxus x media 'Densiformus'*	50	-9

After woody plants are taken out of the landscape, their utilization has an effect on projected carbon sequestration. Smaller plants and many trees are typically chipped for use as mulch or soil conditioner. The carbon in this mulch will be released into the atmosphere over a one- to three-year period. Chipping is the most common end of life for an urban tree in the eastern U.S., and this end was assumed when calculating the values in the Table 5.

Denser and more valuable species may be used as firewood or as lumber in small construction. The utilization of urban trees for wood and paper products is still in its infancy, but the idea is drawing "increasing attention from researchers, community officials, arborists, tree care firms, and wood-using industries including bio-energy producers" (Bratkovich 2008). A 1994 national inventory of urban tree residues included a survey of tree care firms, municipal/county park and recreation departments, municipal tree care divisions, county tree care divisions, electric utility power line maintenance, landscape maintenance/landscaper/nursery firms, and excavator/land clearance firms. The U.S. nationally produced an estimated 38 million green tons (25 million tons on a dry basis) of urban tree residues. Only 25 percent of this residue was reported as recycled or sold/used for a product, and 70 percent of the residue was given away, landfilled, or left on site. A 2003 report from the USDA Forest Service's Forest Products Laboratory estimated that in 2002 urban wood residues in the municipal solid waste stream alone totaled 16.2 million tons of chips, logs, stumps, tree tops, and brush; 9.3 million tons recovered for compost and mulch, 1.9 million tons were sent to combustion facilities, 1.7 million tons were considered unusable, and more than 3.5 million tons were used as "good wood" for further processing into products.

Use of urban trees for bio-energy in a residential wood stove or for large scale energy production is ultimately preferable to the use of fossil fuel sources for similar purposes, as the carbon sequestered is "young" and therefore closer to being a neutral impact on climate change when compared to fossil carbon stores, the impact of which can exceed 650 million years. Already cities are taking advantage of the synergy between bio-energy's benefits, its demands in urban areas, and the availability of urban trees. In downtown St. Paul, Minnesota, less than a mile from the State Capital building, District Energy St. Paul operates a combined heat and power plant serving the commercial, industrial, and residential downtown area. A steam-powered turbine generates 25 megawatts of electricity for the grid, and waste energy—heat energy not converted to electricity by the turbine—created in the process is used to heat the downtown area. The multi-fuel plant is capable of burning coal, natural gas, or biomass in the form of wood chips. It consumes 300,000 tons of wood chips per year, which provide 60 percent of its fuel. Considering the estimated volume of urban tree removals nationwide—17 million tons annually—the magnitude of bio-energy potential from urban tree removals to generate renewable energy should not be overlooked.

Energy Conservation and Microclimate Regulation

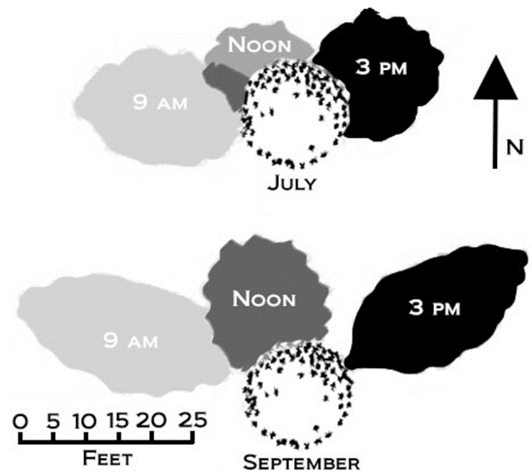
A microclimate is the climate of a small area that is different from the area around it. Microclimates can be very small, as in a protected courtyard near a building. Small areas may be warmer or colder, wetter or drier, or more or less prone to frosts. Landscape plants influence significant factors such as sun exposure and air movement in the formation of microclimates. In addition, trees evaporate substantial amounts of water through their leaves, which can significantly reduce nearby air temperatures.

Shading by plants can greatly increase human comfort in a given area. Effects of shade from a plant in a microclimate varies because the angle of the sun changes throughout the day as well as throughout the season (Figure 3). Seasonality may also influence the direction and speed of prevailing winds. For example, winds in the lower Midwest come predominately from the southwest during hot summer months and from the northwest during cold winter months.

In addition to providing shade, deciduous trees and shrubs provide a unique tool in microclimate regulation: by losing their leaves in winter—though the remaining trunk and branches block 30 to 40 percent of sunlight—sunlight will penetrate and warm the air and ground beneath (Figure 4). In the summer months, their leaves provide shade and reduce the temperature of objects and the air below the canopy (Figure 5). In contrast, evergreens will consistently provide shade (blocking 80–90% of sunlight) and function as windbreaks throughout the year, and small evergreen shrubs placed a few feet from the home provide a gap of insulating air, protecting the home from heat loss due to wind.

Because landscape plants impact the air temperature and flow around them, the placement of landscape plants in relation to climate controlled buildings can have a profound impact on energy savings. Evergreens used for winter windbreaks reduce infiltration of cold air into buildings by up to 50 percent (Sparling 2007). A study in 2003 showed that over a summer, suburbs with trees were, on average, 4 to 6 degrees cooler than suburbs without trees and that tree groves were 9 degrees cooler than open terrain, on average. (McPherson 2011).

Figure 3. Shade patterns of a 20-foot tree during July and September. Joshua Knight, Horticulture, University of Kentucky



Schoolyards, typical built environments, are hot places. They are often covered by the three hottest materials found in the urban environment: asphalt pavement, steel or tar and chip roofs, and mowed turf. They tend to retain heat and act as heat islands. A case study in Waterloo, Ontario, revealed that the surface temperature of schoolyards was reduced by more than 40 degrees and air temperature was reduced by almost 20 degrees when properly placed trees shaded the surfaces and cooled the space through evapotranspiration (Moogk-Soulis 2011). A single, properly watered tree can evaporate-transpire 40 gallons of water in a day, offsetting the heat equivalent to that produced by one hundred 100-watt lamps burning eight hours a day (Rosenfeld 1997).

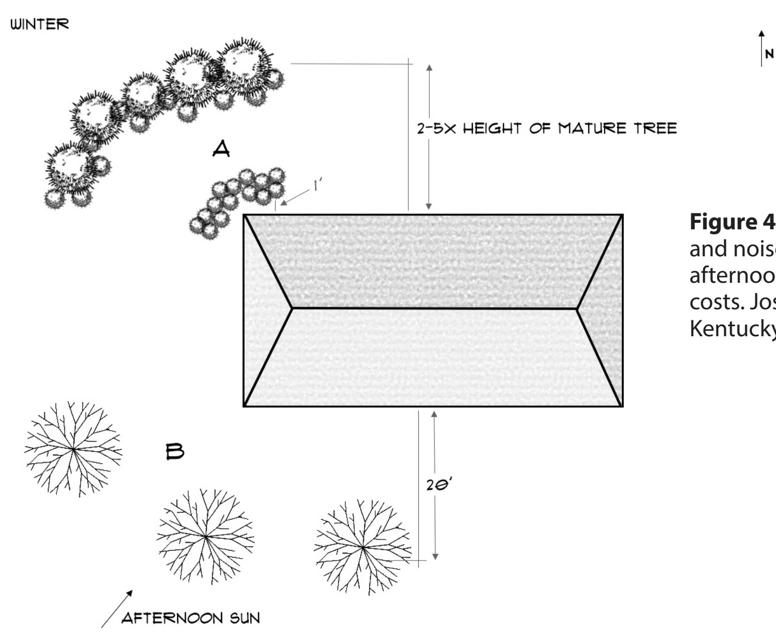


Figure 4. In winter, evergreen trees provide wind and noise reduction; bare deciduous trees allow afternoon sun to warm house, reducing heating costs. Joshua Knight, Horticulture, University of Kentucky

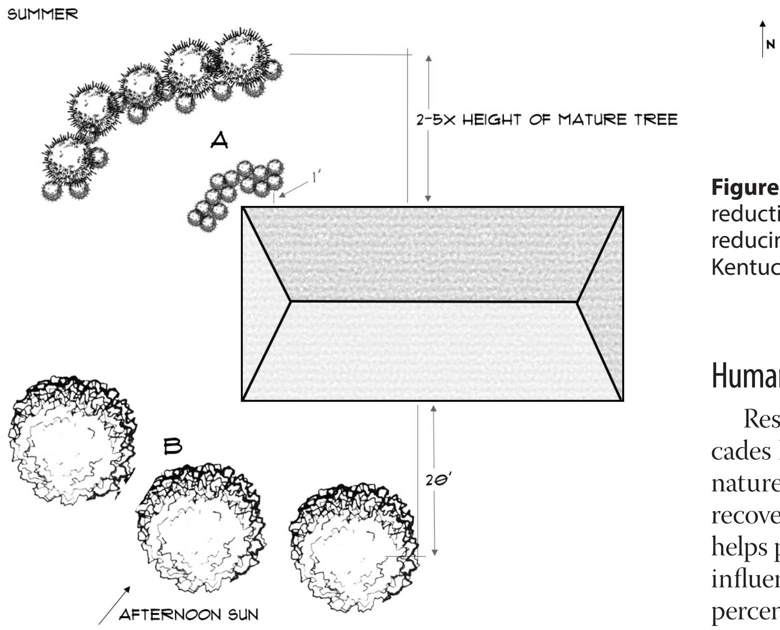


Figure 5. In summer, evergreen trees provide wind and noise reduction; deciduous trees provide shade from afternoon sun, reducing cooling costs. Joshua Knight, Horticulture, University of Kentucky

More than making the outdoor environment comfortable, regulating the microclimate around buildings can result in energy savings from climate control within those buildings (Figure 6). The Los Angeles Million Trees Initiative is expected to save more than $117 million in electricity costs over 35 years (McPherson 2011). In 2002, it was calculated that 57.8 cents was saved per square meter of tree canopy cover in urban environments per year (Brack 2002).

Human Health

Research in health and social sciences over the last few decades has investigated the many connections between urban nature and human health. The presence of plants in hospital recovery rooms and/or views of aesthetically pleasing gardens helps patients to heal faster. Going outside or being under the influence of plants can increase memory retention up to 20 percent, a University of Michigan study showed in 2008 (Berman, Jonides, and Kaplan 2008). Repeated studies have shown that people who spent more time around plants are much more likely to help others and often have more advanced social relationships. Children who spend time around plants absorb and retain information better.

While these individual studies result in an ever increasing pool of facts, the repeated analysis of these facts has yielded a more comprehensive understanding of how plants—as components of green infrastructure—contribute to human health and well-being. Evidence suggests three principal ways green infrastructure can contribute to people's health and quality of life: through support for physical activity such as walking, through support for mental health by offering restorative experiences and engagement with the natural environment, and through opportunities for positive social interaction (de Vries 2010). These three areas of support—physical, psychological, and social—encompass the range of ecosystem services (Figure 7).

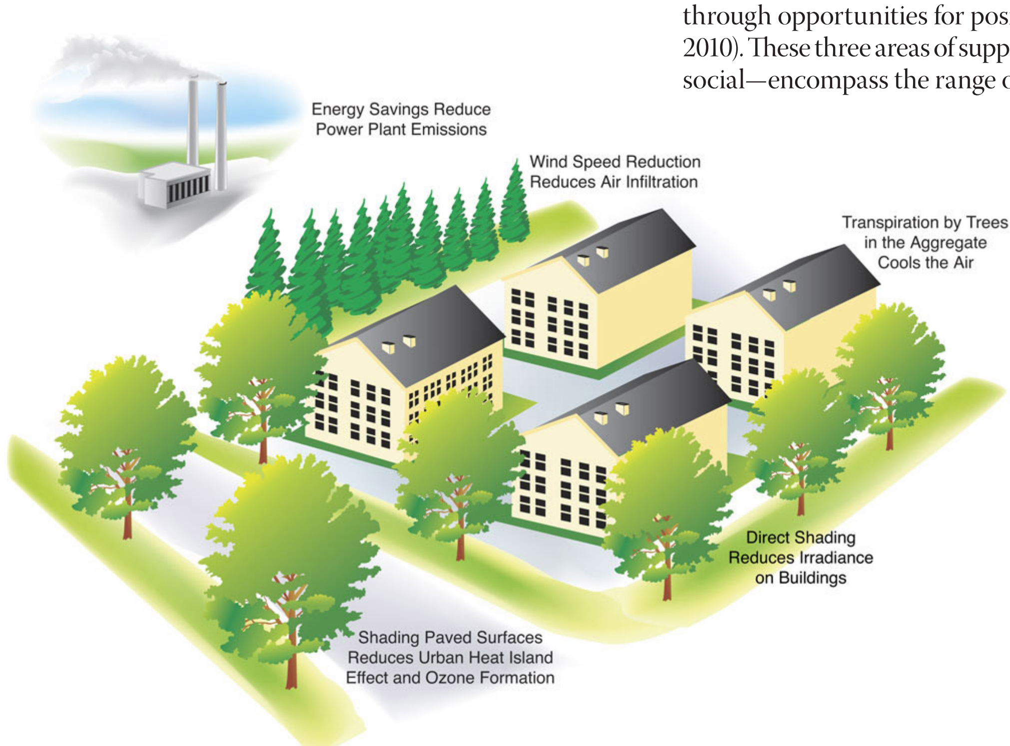


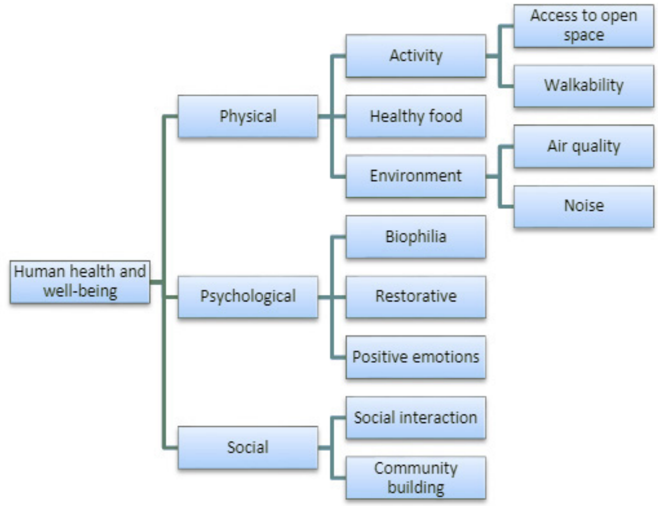
Figure 6. Urban vegetation saves energy in a variety of ways, many of which reduce power plant emissions. Mike Thomas, International Society of Arboriculture

Noise Attenuation/Reduction

Screens and hedges provide noise reduction, especially in urban areas where noise is easily reverberated from hard surfaces such as pavements or buildings. Plants are more effective at absorbing high-frequency sounds, which are bothersome to human ears, than they are at absorbing low-frequency sounds (Fare and Clatterbuck, 1998). Plants can also reflect noise and direct the sound waves much like objects in a stream of water will reflect or redirect the flow of water. The nature of sound wave absorption and reflection depends upon the density, size, leaf surface area, and overall architecture of the plant. More dense plants with larger leaves reflect and absorb more noise than plants with less dense foliage.

Combinations of a mounded area covered with low-growing plants, medium-sized plants, and larger plants located close to the source of the noise can provide the most noise abatement. Any one of these elements can reduce noise in the built environment but are most effective when used in combination (Figure 8).

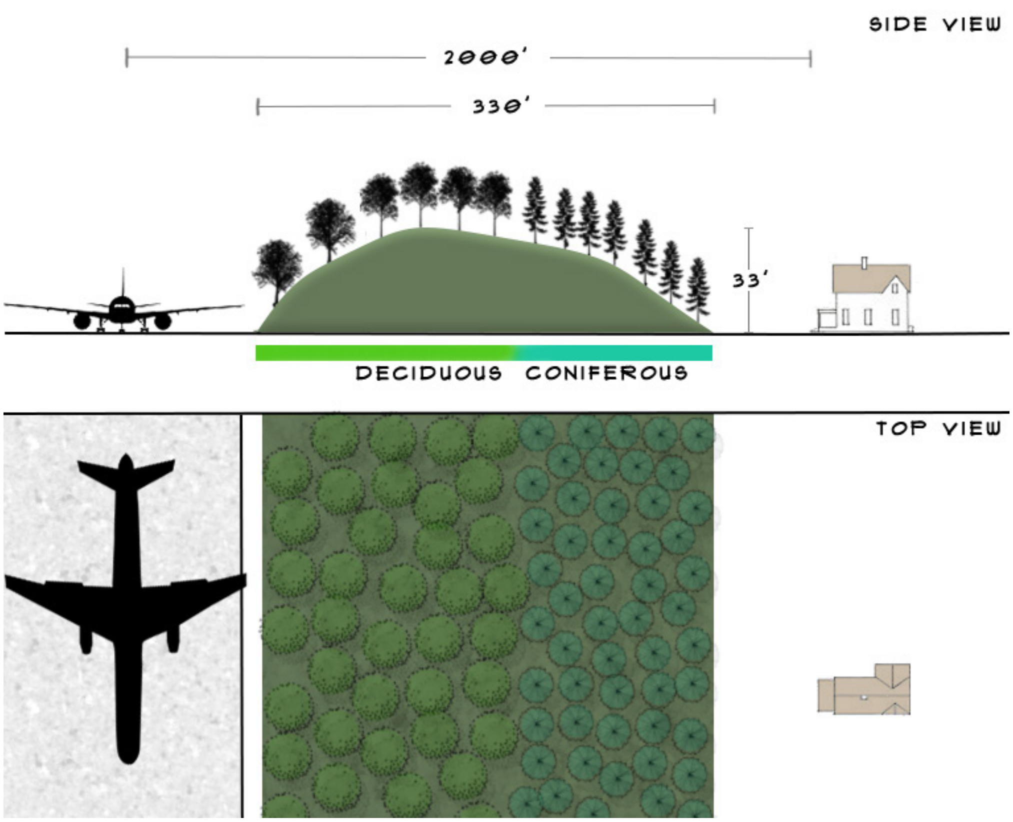
Figure 7. Benefits of green infrastructure on human health and well-being. Pitman, Daniels, and Ely 2014



Stormwater Management

A plant's leaves and branches create a crown. The crowns of many plants together make up an urban forest's canopy. Unless a storm is particularly intense or occurring in a location without significant canopy cover, most of the rain hits a leaf or branch surface and remains there, before evaporating or falling to the ground. Root systems provide channels for water infiltration into urban soils. As water moves through soil layers it is filtered for contaminants, putting less pressure on filtration systems and improving water quality downstream. This brief storage of rainwater by the plant is called rainfall interception, which is primarily dependent on the type and amount of leaves (Figure 9).

Figure 8. Cross-section and overhead image of a noise mitigation embankment used for airport design. Joshua Knight, Horticulture, University of Kentucky



Mature deciduous trees can intercept 500 to 700 gallons of water per year. Mature evergreen trees can intercept more than 4,000 gallons per year (Capiella, Schueler, and Wright 2005). Canopy cover over impervious surfaces (concrete, asphalt) has a profound effect on runoff, as most runoff is a product of impervious surfaces. Even tree cover over pervious surfaces such as soil and turf reduces total runoff by as much as 40 percent (Sanders 1986). Though some water eventually reaches the impermeable surfaces of the streets and runs into the stormwater infrastructure, slowing the water increases the capacity of existing infrastructure to handle water. The stormwater infrastructure is limited primarily by its capacity to handle water during peak precipitation events. Trees and green infrastructure have a leveling effect on these peaks, ultimately augmenting the overall capacity of stormwater handling.

The costs of upgrading conventional stormwater management infrastructure are often prohibitive for many municipalities and in some cases result in diminished returns, especially when compared to the cost and capacity for green infrastructure to manage stormwater. When analyzing the benefits provided by individual urban trees, drawing on data from i-Tree, stormwater management often represents the greatest economic return on investment. Expanding stormwater infrastructure in developed areas is expensive for municipalities, often requiring a bond and interest payments. Though these are costs that would be generally be covered by government funds (whether local, regional or federal), eventually the funds would be recovered by individual taxpayers.

Figure 9. Water movement of trees in a landscape. Mike Thomas, International Society of Arboriculture

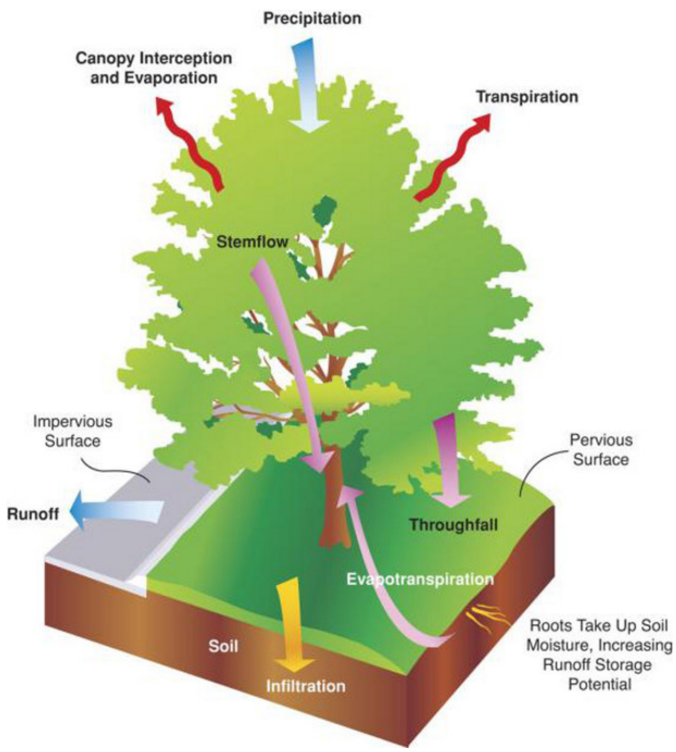


Figure 10. Before, during (below), and after (far right) construction of the Thoraton Creek water quality channel. SvR Design Company 2009

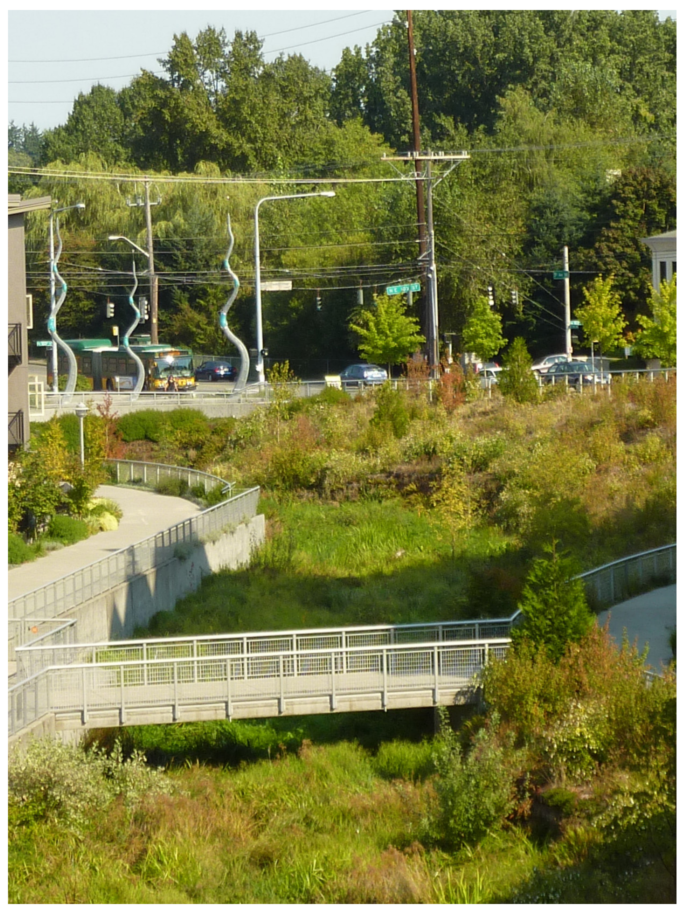
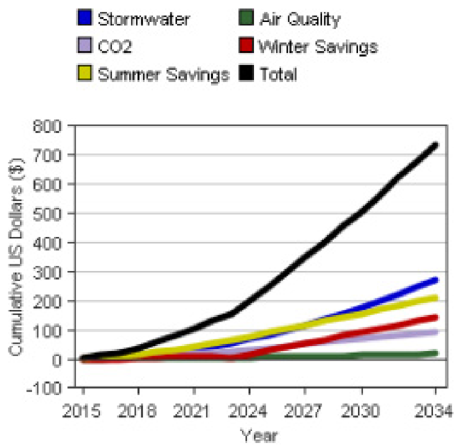


Figure 11. Cumulative tree benefit forecast for a properly sited red maple planted in 2015. i-Tree Design



Landscape plants used in combination with depressions in the landscape can improve the reduction in stormwater runoff by increasing water infiltration and evapotranspiration. Rain gardens, bioretention basins, or bioswales are increasingly constructed as part of green infrastructure in urban areas. In 2009, the city of Seattle developed the Thornton Creek water quality channel, a 2.5 acre facility of constructed landscape and native species plantings which slows and filters stormwater runoff from the largest watershed in the city (Figure 10).

The facility is a public, open space that is integrated into adjacent private development, which is also highly functional green infrastructure. The channel removes sediments and associated pollutants from 91 percent of the annual runoff from the 680-acre drainage area before it is released into Thornton Creek.

Summary

Landscape plants provide many critical services to people and our built environments, improving land value, health, comfort and overall quality of life. If planted in 2015, after 20 years of age, a single, healthy red maple placed 25 feet from the southwest corner of a climate-controlled structure will save $143 dollars in winter heating costs and reduce summer cooling costs by $210 in the state of Kentucky (Figure 11).

This single tree would intercept 44,028 gallons of water and save the community $273 in stormwater reduction costs. Over the course of its life, it will actively remove NOx, CO, and particulate matter from the air, valued at $18 in savings to air quality, and reduce contributions of atmospheric carbon by 9,766 pounds through sequestration, decreased energy production needs, and emissions.

Through education efforts, advertising, and promotion, green industry professionals can help consumers understand the value of adding landscape plants to urban environments, thereby increasing the demand for green industry products and services.

Appendix: Species Reference Table

Species	Common Name	Approved Lexington street tree	Native to Kentucky	Maximum height (feet)	Relative growth rate	Resistance to insect pests	Resistance to disease problems	Resistance to storm damage	Will grow on poorly-drained soil	Will grow in hot, dry areas	Easy to transplant	Withstands city conditions	Storm water reduction	Air quality improvement	Wind reduction	Carbon sequestration
Large Trees																
Elm	**Elm**															
*Ulmus americana**	American elm*	A	Yes	120	●●●	○	○	●	●●	●	●●●	●●	●●●	●●●	●●●	●●●
Maple	**Maple**															
Acer rubrum	Red		Yes	90	●●●	●●	●●	●	●●●	●	●●	●	●●●	●●●	●●●	●●●
Acer saccharinum	Silver	NO	Yes	90	●●●	●●	●●	○	●●●	●	●●	●	●●	●●	●●	●●●
Acer saccharum	Sugar	A	Yes	90	●●	●	●	●●	●	●	●●	○	●●●	●●	●●	●●●
Oak	**Oak**															
Quercus alba	White	A	Yes	80	●	●●	●●●	●●●	●	●●●	○	●●	●	●●	●●	●●●
Quercus bicolor	Swamp white	A	Yes	60	●●	●●	●●	●●●	●●●	●●	●●	●●●	●	●●	●●	●●●
Quercus imbricaria	Shingle	A	Yes	60	●●	●●	●●	●●●	●●	●●	●	●●	●	●●●	●●	●●●
Quercus macrocarpa	Bur		Yes	80	●	●●	●●●	●●●	●	●●	●	●●●	●●	●●	●●	●●●
Quercus meuhlenbergii	Chinkapin		Yes	50	●●	●●	●●	●●	●●	●●	●	●●	●●	●	●●	●●●
Quercus palustris	Pin	NO	Yes	70	●●	●●	●●	●●●	●●	●	●●	●●	●	●	●●	●●●
Quercus phellos	Willow	A	Yes	75	●●●	●●	●●	●●	●●	●	●●●	●●●	●●	●●●	●●	●●●
Quercus robur	English		No	60	●●	●●	●●●	●●●	●	●●	●●	●●	●	●	●●	●●●
Quercus rubra	Red, Scarlet	A	Yes	70	●●●	●●	●	●●	●●●	●●●	●●	●●●	●	●●●	●●	●●●
Quercus shumardii	Shumard	A	Yes	80	●●●	●●	●●	●●	●●	●●	●●	●●	●●●	●●●	●●●	●●●
Fagus grandifolia	American beech	A	Yes	60	●	●●●	●●●	●●	●	●	●●	●●	●●●	●●●	●●	●●●
Ginkgo biloba	Ginkgo (male)			60	●	●●●	●●●	●●●	●	●●	●●	●●●	●●●	●●	●●	●●●
Gymnocladus dioicus	Kentucky Coffeetree	A	Yes	75	●	●●	●●	●●	●	●●	●●	●●	●●	●	●●●	●●●
Larix decidua	European larch	A	No	60	●●	●●●	●●●	●●	●	●●●	●●	●●	●●●	●●●	●●●	●●
Liquidambar styraciflua	Sweet gum	A	Yes	80	●●	●●	●	●●	●●●	●	●	●●	●●●	○	●●	●●
Liriodendron tulipifera	Tulip poplar	A	Yes	100	●●	●●	●●	●	●	○	●	●●	●●●	●●●	●●●	●●●
Platanus occidentalis	American Sycamore		Yes	100	●●●	●●	●	●●	●●●	●●	●●	●●	●●●	○	●●●	●●●
Taxodium distichum	Bald cypress	A	Yes	100	●●	●●●	●●●	●●	●●●	●●	○	●●	●●●	●●	●●	●●
Tilia americana	American basswood	A	Yes	80	●●	●●	●●	●●	●	●●	●●	●●●	●●●	●●●	●●●	●●●
Medium-sized trees																
Betula nigra	River birch		Yes	60	●●	●●	●●●	●●	●●●	●	●●	●●	●●	●●	●●	●●
Cladrastis kentukea	Yellowwood		Yes	40	●	●●●	●●●	●●	●	●●	●	●●	●●	●●	●●	●●●
Nyssa sylvatica	Black gum		Yes	30	●	●●●	●●●	●●	●●	●	○	●	●●	●●	●●	●●
Styphnolobium japonicum	Japanese pagoda tree		No	40	●●	●●●	●●	●●	●	●●	●●	●●●	●●	●●	●●	●●●
Small trees																
Acer buergerianum	Trident maple		No	30	●●	●●	●●	●●	●	●●●	●●●	●●	●●	●●	●●	●●
Koelreuteria paniculata	Golden-rain tree		No	20	●	●●●	●●	●	●	●●	●●●	●●	●●	●●	●●	●

*resistant cultivars only
○ poor
● fair
●● good
●●● excellent

Sources of information:
i-Tree Species, https://www.itreetools.org/utilities.php
Gilman, Edward F. Trees for urban and suburban landscapes. 1997. Cengage Learning.
Starbuck, Chris. Selecting Landscape Plants: Shade Trees. University of Missouri Extension, Department of Horticulture

Resources

Alvey, Alexis A. Promoting and preserving biodiversity in the urban forest. Urban Forestry and Urban Greening 5.4 (2006): 195-201.

Anderson, Linda M., and H. Ken Cordell. Residential property values improved by landscaping with trees. Southern Journal of Applied Forestry 9.3 (1985): 162-166.

Assessment, Millennium Ecosystem. Ecosystems and human well-being. Vol. 200. Washington, DC: Island Press, 2003.

Bell, M. L.; McDermott, A.; Zeger, S. L.; Samet, J. M.; Dominici, F. 2004. Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000. Journal of the American Medical Association 292(19): 2372. doi:10.1001/jama.292.19.2372.

Brack, Cris L. Pollution mitigation and carbon sequestration by an urban forest. Environmental pollution 116 (2002): S195-S200.

Burghardt, Karin T., Douglas W. Tallamy, and W. Gregory Shriver. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology 23.1 (2009): 219-224.

Cappiella, Karen, Tom Schueler, and Tiffany Wright. 2005. "Urban Watershed Forestry Manual Part 1: Methods for Increasing Forest Cover in a Watershed"

Daily, Gretchen. Nature's services: Societal dependence on natural ecosystems. Island Press, 1997.

De Vries, Sanne I., et al. Built environmental correlates of walking and cycling in Dutch urban children: Results from the SPACE study. International journal of environmental research and public health 7.5 (2010): 2309-2324.

Dearborn, Donald C., and Salit Kark. Motivations for conserving urban biodiversity. Conservation Biology 24.2 (2010): 432-440.

Deeproot. Green Infrastructure for Your Community. http://www.deeproot.com/blog/.

Des Rosiers, François, et al. Landscaping and house values: An empirical investigation. The Journal of Real Estate Research 23.1/2 (2002): 139.

EPA.gov. https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects.

Fare, Donna C., and Wayne Kevin Clatterbuck. 1998. Evergreen Trees for Screens and Hedges in the Landscape. Agricultural Extension Service, University of Tennessee.

Gilman, E.F. 1997. Trees for urban and suburban landscapes: An Illustrated guide to Pruning. Albany, NY.

Ingram, D.L. Life cycle assessment of a field-grown red maple tree to estimate its carbon footprint components. The International Journal of Life Cycle Assessment 17(4). Published online: DOI: 10.1007/s11367-012-0398-7.

i-Tree Design. i-Tree Tools for Assessing and Managing Community Forests. http://www.itreetools.org/.

Kardan, Omid, et al. 2015. Neighborhood greenspace and health in a large urban center. Scientific Reports 5.

McKeever, David B., and Kenneth Skog. Urban tree and woody yard residues: Another wood resource, vol. 290. 2003. U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory.

McPherson, E. Gregory, et al. Million trees Los Angeles canopy cover and benefit assessment. Landscape and Urban Planning 99.1 (2011): 40-50.

McPherson, G., J.R. Simpson, P.J. Peper, S.E. Maco, and Q. Xiao. 2005. Municipal forest benefits and costs in five US cities. Journal of Forestry 103(8): 411-416.

Moogk-Soulis, C. Schoolyard heat islands: A case study in Waterloo, Ontario. Technical Aids Consulting Services. http://www.moogk-soulis.com/wp-content/uploads/2011/05/Moogk-Soulis.pdf.

Morales, D., B.N. Boyce, and R.J. Favretti. 1976. The contribution of trees to residential property value: Manchester, Connecticut. Valuation 23 (2): 27-43.

North Carolina State Cooperative Extension. Tree Facts. http://www.ncsu.edu/project/treesofstrength/treefact.htm.

Nowak, D. Species Selector (Beta) Utility. Tools for assessing and managing community forests. USDA Forest Service, Northern Research Station. https://www.itreetools.org/species/resources/SpeciesSelectorMethod.pdf.

Nowak, David J., and Gordon M. Heisler. 2010. Air quality effects of urban trees and parks. National Recreation and Park Association.

Pitman, Sheryn D., Christopher B. Daniels, and Martin E. Ely. Green infrastructure as life support: urban nature and climate change." Transactions of the Royal Society of South Australia 139.1: 97-112.

Rosenfeld, Arthur H., et al. Painting the town white and green. Technology Review 100.2 (1997): 52-59.

Sanders, Ralph A. Urban vegetation impacts on the hydrology of Dayton, Ohio. Urban Ecology 9.3 (1986): 361-376.

Sparling, Beth, Delia Bucknell, and Terrilyn Moore. 2007. Literature review of documented health and environmental benefits derived from ornamental horticulture products.

Tallamy, Douglas W. 2009. Bringing nature home: How you can sustain wildlife with native plants. Timber Press.

Taylor, Chris. Fertile Ground. Smart Money, March 2003.

The Nature Conservancy. Plant a Billion Trees. http://www.plantabillion.org/urban-trees/.

Treepeople.org. Top 22 Benefits of Trees. https://www.treepeople.org/resources/tree-benefits.

University of Nebraska-Lincoln. ReTree Nebraska. Reasons to Plant Trees. http://retreenebraska.unl.edu/reasons-plant-trees.

Whittier, Jack, Denise Rue, and Scott Haase. 1994. Urban tree residues: Results of the first national inventory. No. CONF-9410176. Western Regional Biomass Energy Program, Reno, NV (United States).

Working Group I and Richard Alley. 2007. Groupe d'experts intergouvernemental sur l'évolution du climat. Climate change 2007: the physical science basis: summary for policymakers. IPCC.

WorstPolluted.org. 2008. Reports. Blacksmith Institute. 14 Nov. 2016.

Kentucky Specific

Lexington-Fayette Urban County Government. 2007. Planting Manual, revised edition. http://www.lexingtonky.gov/Modules/ShowDocument.aspx?documentid=5307.

Lexington-Fayette Urban County Government. 2014. Urban Tree Canopy Report. http://www.lexingtonky.gov/index.aspx?page=3412.

Lexington-Fayette Urban County Government. Lexington Street Tree Guidelines. http://www.lexingtonky.gov/Modules/ShowDocument.aspx?documentid=23878.

End of Life

Bratkovich, S. 2008. Urban Tree Utilization and Why It Matters. US Forest Service. http://www.fs.fed.us/ucf/supporting_docs/DovetailUrban0108ig.pdf.

Municipal Tree Care and Management in the United States: A 2014 Community Forestry Census of Tree Activities. http://www.uwsp.edu/cnr/Pages/Forestry---MTCUS.aspx.

Air Quality

Cardelino, C.A., and W.L. Chameides. 1990. Natural hydrocarbons, urbanization and urban ozone. Journal of Geophysical Research 95(D9):13,971-13,979.

Environmental Protection Agency. National Ambient Air Quality Standards (NAAQS). http://www3.epa.gov/ttn/naaqs/.

Luley, C.J., and J. Bond. 2002. A Plan to Integrate Management of Urban Trees in Air Quality Planning. Report to Northeast State Foresters Association. Davey Resource Group, Kent, OH.

Nowak, D. 2004. The Effects of Urban Trees on Air Quality. USDA Forest Service. Syracuse, NY.

Energy

Energy.gov. Energy Saver 101: Everything You Need to Know about Landscaping. *http://www.energy.gov/articles/energy-saver-101-infographic-landscaping.*

Stormwater Management

Sanders, R.A. Urban vegetation impacts on urban hydrology of Dayton, Ohio. Urban Ecology 9:361-376.

State University of New York, College of Environmental Science and Forestry. Stormwater management rain garden and runoff calculator. *http://www.esf.edu/ere/endreny/GICalculator/RainGardenIntro.html.*

SvR Design Company. 2009. Thornton Creek Water Quality Channel–Final Report. http://www.seattle.gov/util/cs/groups/public/documents/webcontent/spu01_006146.pdf.

Xiao, Q., E.G. McPherson, S.L. Ustin, and M.E. Grismer. A new approach to modeling tree rainfall interception. Journal of Geographical Research Atmospheres 105:29,173-29,188.

Biodiversity and Wildlife

American Bird Conservancy. http://abcbirds.org/.

Invasive.org. Center for Invasive Species and Ecosystem Health. http://www.invasive.org/.

North American Bird Conservation Initiative–United States. Bird Conservation Regions. http://www.nabci-us.org/map.html.

US Forest Service. Invasive species maps. http://www.nrs.fs.fed.us/fia/maps/Invasive-maps/default.asp.

Noise Reduction

Georgia Forestry Commission. 2008. Green Buffers for Screening and Noise Reduction. http://www.gfc.state.ga.us/resources/publications/GreenBuffersforScreeningandNoiseReduction.pdf.

Joint Declaration on Green Airport Initiatives. Report on the East Asia Airports Alliance (EAAA). http://www.narita-airport.jp/en/eaaa/ecofesta2014.html.

Roman, L.A. How many trees are enough? Tree death and the urban canopy. Scenario Journal 4: Building the Urban Forest. Spring 2014. http://scenariojournal.com/article/how-many-trees-are-enough/.

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