Rationale for the increased use of conifers as functional green infrastructure

A literature review and synthesis by J. Casey Clapp

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Abstract

Trees in the urban landscape are key components of green infrastructure. Green infrastructure is the aggregate of plants and green spaces in the urban landscape. This infrastructure serves many functions within the urban area and provides a multitude of benefits that are becoming increasingly valuable as municipalities strive for urban sustainability. The value of the urban forest is an integral part of securing funding and support for urban forestry initiatives: the higher the value the more support is gained, and the more benefits accrued. According to available street tree inventories, most species that make up street trees in urban forests in the United States and Canada are broadleaf deciduous species. Many of the benefits that urban trees provide are attributed to their canopies (i.e. rainwater interceptions, pollution absorption, wildlife cover, etc.). When these trees drop their leaves, the canopy-dependent benefits of their canopies affectively drop to negligent levels. Especially in regions where rainfall events occur mostly during this leaf-off season, the additional canopy cover afforded by evergreen tree species, in concert with the canopy architecture and density of evergreen conifers specifically, helps maintain the canopy-dependent benefits that a city depends on. This paper investigates the role that conifers play in increasing the canopy-dependent ecosystem services of an urban forest and the unique role they play in increasing the stability of the urban forest through diversification.

Keywords: Conifers, Diversity, Ecosystem Benefits, Green Infrastructure, Urban Forestry

Introduction

Urban forests are an integral part of urban ecosystems. As one of the major non-point sources of air and water pollution, our urban areas are ecosystems that are out of balance, contributing to the problem of pollution while depending on the surrounding natural systems to clean it up (NOAA, 2007; Douglas, 1983). Indirectly, as well, these urban areas contribute to environmental issues such as global climate change and deforestation by using enormous amounts of resources for energy (Rees and Wackernagel, 1996). By harboring 83.7% of the US population (Mackun and Wilson, US Census, 2011), our urban areas demand the greatest use of natural capital and produce the greatest amount of depleted capital (i.e. waste) (Rees and Wackernagel, 1996). Due to such resource demands, they also require the greatest remediation efforts (Rees and Wackernagel, 1996). Urban forests play an extremely important role in helping to mitigate the environmental impacts of urban areas, and they play an equally important role in the social health of the citizens.

The benefits of urban trees include the filtering of pollutants from the air like ozone (Nowak *et al*., 2000; Taha, 1996), carbon monoxide, carbon dioxide, particulate matter (microscopic dust) and sulfur dioxide (Nowak *et al*., 2006; Geiger, 2005); intercepting and storing rainwater (Xiao and McPherson, 2002; Xiao *et al*., 1998; Hirabayashi, 2013; Xiao *et al*., 2000); mitigating the urban heat island effect (Peters and McFadden, 2010; Konopacki and Akbari, 2001; Peters *et al*. 2010); psychologically benefiting urban residents by reducing stress and increasing happiness (Kaplan and Kaplan, 1989; Kuo, 2003; White *et al*., 2013), as well as playing a role in the healthy development of children (Sebba, 1991; Donovan *et al*., 2011). Urban trees indirectly affect carbon emissions by shading buildings, thereby reducing the amount of energy needed relative to summer cooling (Heisler, 1986[1]; Akbari, 2002). Urban trees are also increasingly being researched for their potential as traffic control mechanisms (Wolf and Bratton, 2006; Grey and Deneke, 1986). They have also long been examined as functional landscape features that offer visual and auditory benefits that may act as wind barriers, as movement control mechanisms, and as buffers (Niemiera, 2009; Grey and Deneke, 1986; Robinette, 1972).

The aggregate of these benefits, called ecosystem services (Costanza *et al*., 1997), can be given an economic value (McPherson *et al*., 2005[1]; Nowak *et al*., 2002) which provides a monetary incentive for improving and maintaining an urban forest. This value is extremely important because it serves as the impetus for investment in the urban forest. The higher the value of the urban forest, the more likely local and regional agencies may be willing to invest in it, which in turn adds value to the urban forest via new plantings, hazard mitigation, and educational outreach. By comparing the amount of money that is invested into the urban forest to the amount returned in the form of ecosystem services, many municipalities see a positive return on investment. For example, in 2007 every $1.00 spent on urban forest management (e.g. planting, maintenance, employing staff, etc.) in New York City returned $5.60 in ecosystem services (Peper *et al.*, 2007). This is true for several cities across the US (table 1).

Table 1: The ratios for returns on investment in several cities across the United States. The ratio corresponds to the dollar amount returned to the municipality through ecosystem services per one US dollar invested.

City	Investment return ratio (investment:return)	Citation
New York, NY	1:5.60	Peper *et al*. 2007
Berkeley, CA	1:1.37	Maco *et al*. 2005
Fort Collins, CO	1:2.18	McPherson *et al*. 2005(1)
Glendale, AZ	1:2.41	McPherson *et al*. 2005(1)
Cheyenne, WY	1:2.09	McPherson *et al*. 2005(1)
Bismarck, ND	1:3.09	McPherson *et al*. 2005(1)
Charlotte, NC	1:3.25	McPherson *et al*. 2005(2)
Minneapolis, MN	1:1.59	McPherson *et al*. 2005(3)

In order to make this return as large as possible, specific design choices must be made when selecting trees to ensure that the maximum future benefit value is gained, and that the minimum number of infrastructure conflicts are created. To do this, an urban forester or landscape architect must take several different components of the specific site into consideration, including soil conditions, water availability, temperatures, potential infrastructure conflicts (above and below-ground), the presence of contaminants like road salt, and light availability. In addition, an urban forester or landscape architect must take landscape or city-wide components into consideration such as species diversity, insect and disease pests, climate conditions, and invasive species potential. Finally, the specific benefits that are desired for the site must be considered (i.e. shade for buildings, sound barriers, rain water interception, seasonal color, etc.).

Different species of trees provide both differing amounts and types of benefits that may be both intrinsic (i.e. the inherent differences between trees, such as mature size) and temporally (i.e. how they differ over time, such as evergreen trees in comparison to deciduous trees) in nature. By not considering these criteria in planting choices, along with the site and landscape-wide criteria, cities may be limiting the amount of benefits that could be garnered if a different tree was planted in the same spot.

One example may include a recently built roundabout in an urban setting that is scheduled to be planted with large-growing trees. If the urban forester has the flexibility to choose a broadleaf, deciduous planting (i.e. red maple, *Acer rubrum*) or an evergreen, coniferous species (i.e. Port Orford-cedar, *Chamaecyparis lawsoniana*), the total benefits of each tree may differ greatly. As an evergreen tree, the Port Orford-cedar can continually intercept and store a significant amount of rainwater and pollutants throughout the year, whereas the red maple will drop its leaves during winter, thereby largely losing its capacity to intercept rainwater (Xaio *et al*., 2000; Xaio *et al*., 1998), as well its ability to remove pollutants from the air (Nowak *et al*., 2006). By selecting and establishing an evergreen conifer instead of a deciduous broadleaf tree, the urban forester has increased the annual potential for rainwater interception and pollution removal at this site. Indeed, by increasing the use of evergreen conifers across the urban landscape where deemed appropriate, the annual net benefit of the urban forest at large can be increased.

In addition to these direct ecological benefits, more indirect benefits may be derived from diversifying the urban forest with both evergreen and deciduous conifers. From a functional infrastructure perspective, ecosystem benefits are important properties of the urban forest, and it is these benefits that urban forest managers strive to increase and maintain. When urban trees are lost or severely damaged due to disease and insect pest outbreaks or severe weather, the amount of ecosystem benefits associated with the affected areas can be significantly reduced. Preliminary findings relative to canopy loss and ambient temperature increases in areas severely damaged by a tornado in Springfield, Massachusetts in 2011 show that increases in temperature can be as much as 2-degrees Celsius (3.6-degrees Fahrenheit) (Brooks and Bloniarz, 2011). Estimates of potential canopy loss due to Asian longhorned beetle (*Anoplophora glabripennis)* show that urban forest damage and benefit loss in the United States could range from $81 million in San

Francisco, CA to $2.25 billion in New York City, NY (Nowak *et al*. 2001). In order to lessen the impact of these types of catastrophes, urban foresters must diversify the species composition of their urban forests. Indeed, by diversifying using coniferous tree species, the urban forest has the potential to become more stable through changing climactic conditions as well as during outbreaks of disease or insect pests.

Finally, urban trees themselves are pieces of infrastructure. Specifically, they are a part of the "green infrastructure" of a city (Firehock, 2010). The term green infrastructure refers to the parts of the urban landscape that are growing (or "green") and, importantly, support the function and the health of the community (Benedict and McMahon, 2006). Conversely, gray infrastructure refers to the built portions of the landscape that support the function and health of the community, such as roads, storm drains, street lights, and waste water management systems (Brown, 2006). What these two terms have in common is the functions that they serve.

Infrastructure intrinsically has a purpose, and little infrastructure is built without a specific purpose in mind or a problem to solve. When building rainwater catchment systems, for example, engineers design the system to work as efficiently as possible, taking into account things such as maximum flow capacity, the lifetime of the system, and where to locate specific components to gain the maximum benefit possible for the system as a whole, with the least amount of maintenance. Being that urban trees are pieces of infrastructure within a city, their planting and use should be as deliberately planned and designed as any other piece of urban infrastructure. In the above rainwater catchment example, this translates as using the proper size of piping, the proper style of drain, and the proper flow design for the desired function. In urban forestry, this translates as using the proper tree for the proper site, the tree that best accomplishes the desired functions, and the proper design to allow for those functions to realize their maximum potential.

Evergreen conifers can provide specific design functions and ecological values that broadleaf deciduous trees cannot offer during specific times of the year. By first describing the goals and objectives of a site and entire urban area, as well as the limitations that might exist due to pre-existing structures or other goals, urban foresters can employ evergreen and deciduous conifers as specific infrastructure components that accomplish unique goals and provide benefits throughout the entire year, rather than only during the growing (i.e.

leaf-on) season. In short, it is prudent for urban foresters and landscape architects to select coniferous trees when they may be better suited to a given site as components of urban infrastructure.

Findings

Rainwater

Rainwater management is a growing concern for municipalities. Due to regulations at local, state, and federal levels, water runoff from urban areas must meet certain standards to be released back into natural water systems (Clean Water Act, 1972). Much of the time, this requires urban runoff to be treated in water quality facilities which are constructed and operated at great costs to the local municipality. Thus, municipalities are constantly looking at ways to manage rainwater in a more cost-effective manner. One method of accomplishing this is to reduce the amount of water that requires treatment. This may be obtained by allowing relatively clean rainwater to infiltrate directly into the ground, or by intercepting, storing, and allowing the rainwater to evaporate. Urban trees offer the latter benefit by intercepting rainwater with their leaves, branches, and trunks and allowing it to evaporate before it falls to the ground, and by absorbing it through their roots for use in photosynthesis and other tree functions (Hirabayashi, 2013; Xiao *et al*., 2000).

Current methods of calculating how an urban tree intercepts water, reaches its maximum holding capacity, and begins to release excess water via dripping, as well as how much water potentially evaporates (which varies depending on weather processes and conditions) are detailed by Hirabayashi (2013) and Xiao *et al*. (2000). The equations used are heavily dependent on the leaf area index (LAI) of the individual tree, and that of the combined canopies where several trees are grown in close proximity and achieve crown closure.

Leaf area index is a measure of how dense a canopy is. It is found by identifying the amount of foliage that covers a given unit of ground area. The higher the LAI, the denser the tree canopy is, and the more effective it is at intercepting and holding rain water. Xiao *et al*. (2000) showed that when a tree loses its leaves, its LAI drops to a negligible amount, thus all the benefits associated with the canopy are lost, as well. They found that an open-grown, evergreen oak tree (*Quercus suber*) intercepted an average of 27% of gross rainfall, compared with only 15% for the open-grown, deciduous pear tree (*Pyrus calleryana*) over one year. The main difference in these findings can be attributed to the temporal changes of each tree. In short, the evergreen tree continued to offer the benefit of rainwater interception throughout the leaf-off season while the deciduous tree offered a negligible amount associated with its branches and trunk. According to Xiao *et al*. (1998), similar results were obtained when modeling urban forest interception in Sacramento, California, USA. They concluded that urban forests in rural and urban areas had a lower storage capacity as a whole in the winter time due to a lower average LAI because the deciduous trees were in their leaf-off period. This led to a 14% reduction in interception benefits in the rural area and a 26% reduction in the city area.

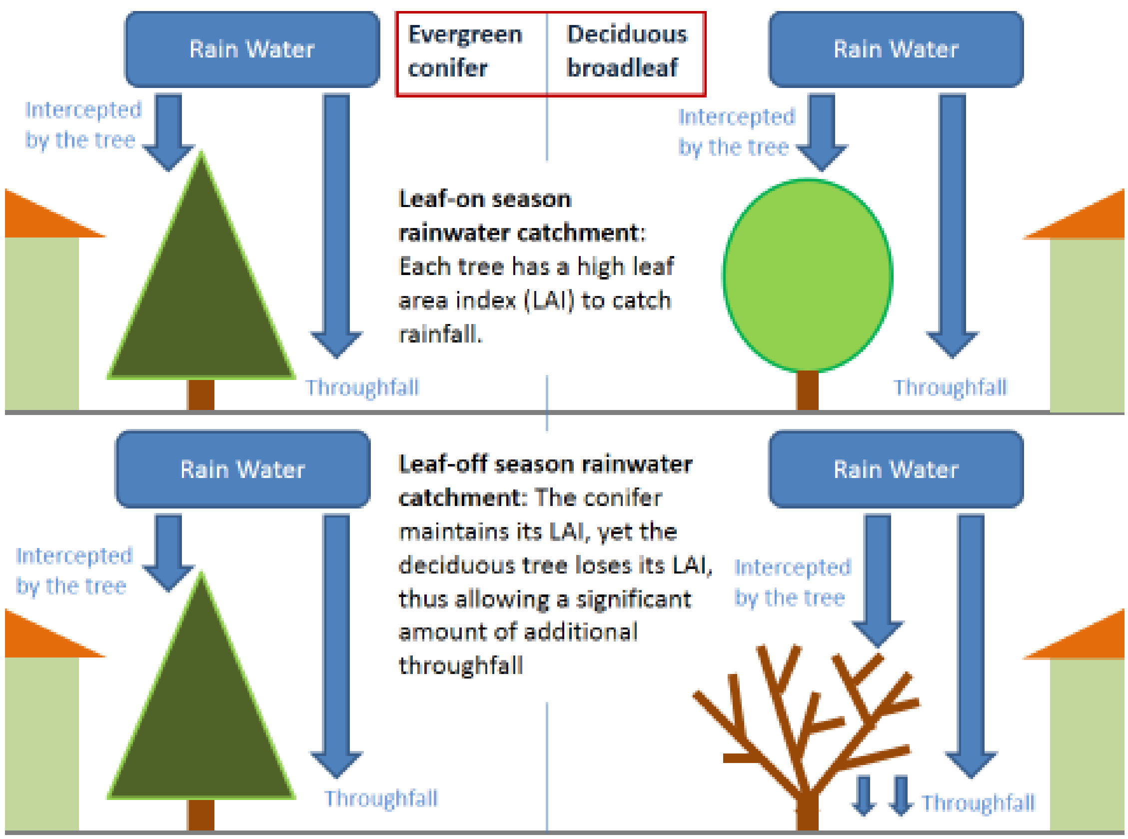


Figure 1: Illustration of year-round rainwater interception benefits of evergreen conifers as compared with deciduous broadleaf trees.

It can be readily observed that a forest dominated by deciduous species loses a significant amount of its rainwater interception benefits for nearly half the year. Thus, the percentage "missed" by the deciduous species can be substantial. A city with rainfall that occurs roughly uniformly throughout the year (such as Boston, Massachusetts, USA), and that has an urban forest dominated by deciduous tree species, would only intercept rainfall for roughly half the year, which would affectively be nearly half of the average annual rainfall (table 2). In a city with rainfall that occurs mostly in the winter time (such as Portland, Oregon, USA), an urban forest dominated by deciduous tree species would provide an even smaller amount of rainfall interception with regards to the total amount of average annual rainfall (table 2).

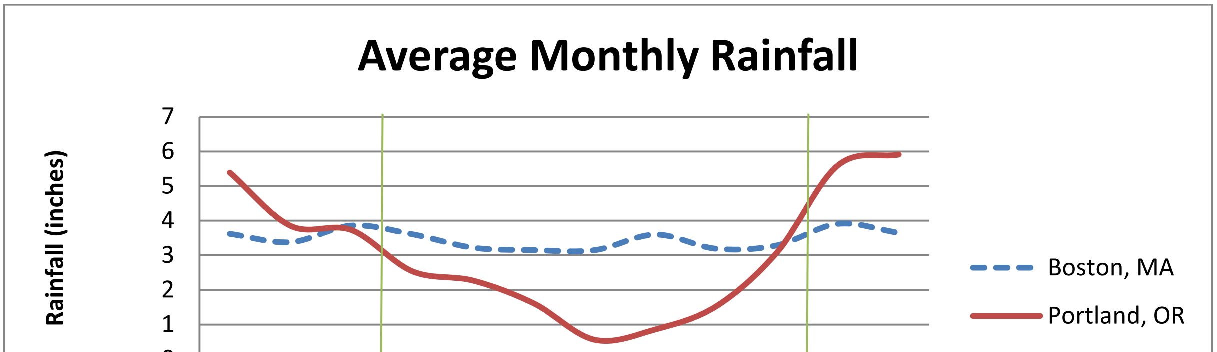
Table 2: Average annual rainfall totals for Boston, MA (City of Boston, 2013) and Portland, OR (WRCC, 2013). Avg. Missed is the percentage of the average annual precipitation that falls during the leaf-off season, and is therefore not subject to interception by a deciduous tree. Avg. Int. is the percentage of the average annual rainfall that falls during the leaf-on season, and therefore is subject to intercpetion by a deciduous tree.

		Average total rainfall (inches)			
	Annual Total	Leaf-On (Apr-Oct)	Leaf-Off (Nov-Mar)	Avg. Missed	Avg. Int.
Portland	36.94	12.46	24.48	66.27%	33.73%
Boston	41.63	23.21	18.42	44.25%	55.75%

Figure 2 plots the average monthly rainfall for Boston, MA and Portland, OR. Figures 3 and 4 depict the changes in canopy cover over a year for both cities, with the images on the left showing the canopy cover in the leaf-on season, and the images on the right showing the canopy cover in the leaf-off season (LandsatLook Viewer, USGS, 2013). Assuming that the majority of deciduous trees have a full leaf canopy from April to October, and little or no leaf canopy from November to March, it is evident that a significant amount of rainfall is missed by deciduous trees in both cities. Table 2 shows the percentages of average annual rainfall subject to interception in either city. Under these assumptions, on average, the deciduous trees in Portland miss 66.27% of the annual rainfall, and they miss 44.25% of the annual rainfall in Boston.

Figures 2 and 3 illustrate the differences in canopy cover for Portland and Boston. Both cities have nearly equal tree canopy cover during the leaf-on season, at 29.9% for

Portland (Portland Parks and Recreation, 2012) and 29% for Boston (Urban Ecological Institute, 2008). However, figures 3 and 4 show a contrast between canopy cover during the leaf-off season, with Portland having more cover. This is due to the native vegetation types that dominate the regions, and grow more in natural areas and forest remnants. Portland is located in the Pacific Lowland Mixed Forest province and is closely bordered on the east and west by the Cascadian Coniferous Forest province. Boston is located in the Eastern Broadleaf Forest province relatively isolated from other forest types (Bailey, 1994). This suggests that although Portland has few conifers as street trees, it may have a much higher proportion in parks, natural areas, and on private property which continue to intercept rainwater throughout the year. Conversely, it suggests that Boston has essentially no significant evergreen foliage to help mitigate the interception losses incurred by the loss of canopy during the leaf-off season (Xiao *et al*. 1998). A more detailed study of the canopy composition of each city is needed to make more specific conclusions.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Boston, MA	3.62	3.38	3.86	3.61	3.22	3.15	3.15	3.6	3.19	3.29	3.91	3.65
Portland, OR	5.39	3.85	3.73	2.54	2.27	1.61	0.56	0.86	1.53	3.09	5.6	5.91

Figure 2: Monthly average rainfall for Boston, MA (City of Boston, 2013) and Portland, OR (WRCC, 2013). The vertical lines denote the change in season with the areas from April to October being the leaf-on season and the area from November to March being the leaf-off season.

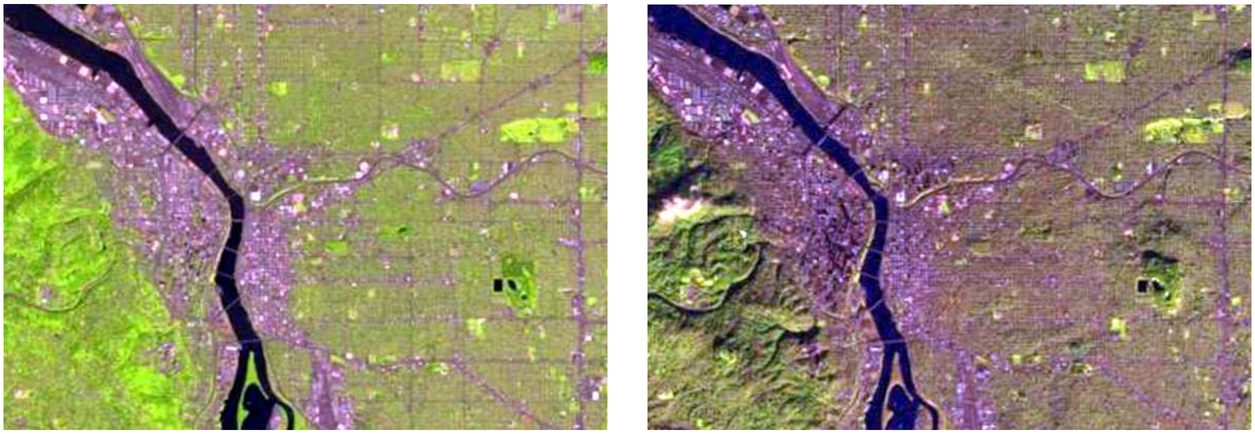


Figure 3: Landsat images of Portland, Oregon. Amount of green indicates the amount of photosynthesizing plant material during each time of the year. The photo on the left was taken on January 2, 2005 and the photo on the right was taken on June 1, 2007 (LandsatLook Viewer, USGS, 2013).

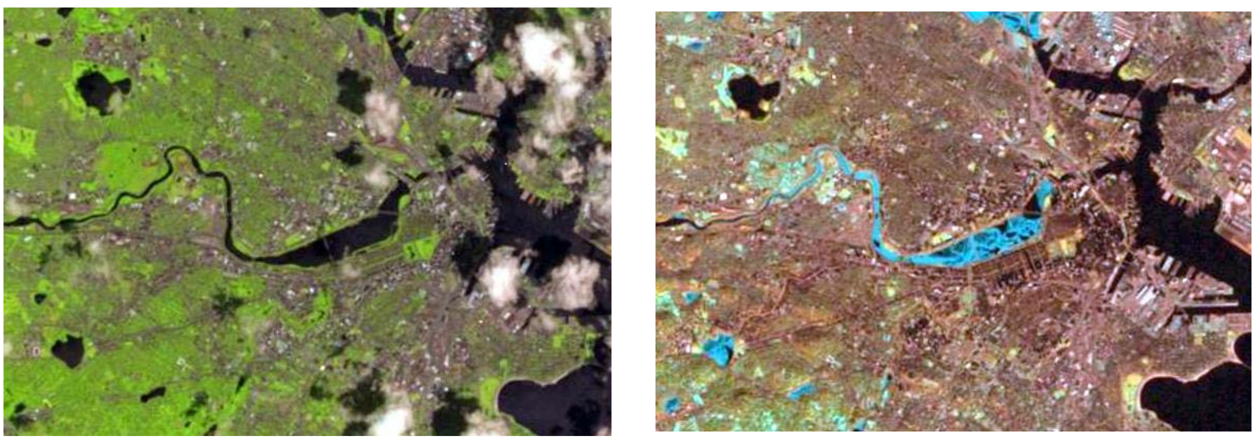


Figure 4: Landsat images of Boston, Massachusetts. Amount of green indicates the amount of photosynthesizing plant material during each time of the year. The photo on the left was taken on January 5, 2011 and the photo on the right was taken on June 30, 2001 (LandsatLook Viewer, USGS, 2013).

By reviewing the amount of rainfall missed by deciduous trees, it is readily apparent that evergreen trees offer the opportunity to capture more rainfall over an entire year. Recalling that the main factor in the ability of a tree (or a group of trees) to intercept rainwater is the LAI, it is reasonable to suggest that trees with a higher LAI will intercept more rainwater during a storm event. This is important because it allows the tree to capture and hold more water for longer periods of time before it reaches its saturation point and begins to drip rainwater to the ground (Asadian and Weiler, 2009).

Several studies have investigated the amount of rainwater intercepted by forest canopies in natural and plantation forests (Heal *et al*, 2004; Whelan and Anderson, 1996; Link *et al*., 2004; Xiao *et al*., 2000), but due to densities of the crown, as well as branch architecture in forest trees (as contrasted with open-grown or less densely-planted street trees), these values may not be applicable to urban trees (Xiao *et al*., 2000). Notably, however, some of these studies directly compared evergreen conifer cover types with deciduous broadleaf cover types. A study by Bryant *et al*. (2005) compared interception rates of five forest types in the Southeast USA and concluded that the pine (*Pinus* spp.) forest (non-plantation) intercepted 22.3% of gross precipitation compared with 18.6, 17.7, 17.6, and 17.4% for mixed forest, lowland hardwood, pine plantation, and upland hardwood forest types, respectively. Zinke (1967) found that conifers intercept between 20 and 40% of annual rainfall, while hardwoods intercept only about 10 to 20% of annual rainfall. Though these are values for forest trees, they demonstrate a distinct and significant difference in rainfall interception by vegetation type, with evergreen conifers having the greater impact.

A study by Asadian and Weiler (2009) which examined rainwater interception of conifers in the urban area found that across varying tree structural types (dominant, co-dominant, single tree, and forested types) and species, the average canopy interception was 49.1% for Douglas-fir (*Pseudotsuga menziesii*) and 60.9% for western redcedar (*Thuja plicata*), two common urban and natural coniferous forest species found in the northwestern US. The study also found that urban conifers generally intercept more rainwater than forest-grown conifers. The differences were attributed to higher temperatures in urban areas, differences in crown architecture, and isolation from other trees.

The year-round interception potential for evergreen tree species, coupled with the unique canopy architecture and spatial distribution of conifer species in urban areas, show that this phylum of trees could be an extremely important component of an urban forest relative to canopy-dependent ecosystem services. The ability to intercept rainfall throughout an entire year, and the ability to collect and store more rainfall per unit of ground area, allows evergreen conifers to offer substantial rainwater interception benefits that deciduous broadleaf trees cannot.

These findings exhibit the potential for urban conifers as important pieces of green infrastructure, however the benefits associated with some of their attributes may be limited. The two conifer species examined by Asadian and Weiler (2009) are naturally dense trees with relatively high leaf area indices, consequently these findings are not necessarily representative of interception rates of all conifers. The many studies conducted concerning rainwater interception on forest trees are also not reflective of urban conditions. There is a dearth of research-based information concerned with the role that conifers play in the urban forest and their affiliated ecosystem benefits.

It should be noted that research in urban forestry lags behind that of traditional forestry. To that end, research in rainwater interception for non-urban forests has moved away from calculations based on LAI in favor of methods using total crown storage capacity measures. In order to fully quantify the rainwater benefits that urban trees can provide, further study is required which applies newer, and perhaps more accurate, methods of estimating crown storage capacity. Indeed, this also includes investigations comparing urban conifers to urban broadleaf species, in addition to other types of conifers.

Finally, due to differences in transpiration rates between deciduous broadleaf trees and evergreen conifers, there may be a more significant effect on rainwater storage in the ground where evergreen conifers are present. Conifers will transpire whenever conditions are optimal, whereas deciduous trees only transpire during the growing season. By taking up such amounts of water throughout the year, conifers may free up more space in the soil for water to infiltrate, thus allowing for more water to be stored during heavy rain events (Barton, 2014).

Pollution

As previously indicated, urban areas are large producers of pollutants and greenhouse gases (NOAA, 2007). Studies have shown the positive impact that urban forests have on mitigating pollution in two ways: directly through the absorption or interception of the pollutants, and indirectly by shading buildings and roads to avoid the use of air conditioning (Nowak *et al*., 2006; Geiger, 2005; Heisler, 1986[1]; Akbari, 2002). Similar to rainwater interception, pollution absorption is a canopy-dependent ecosystem service. It differs notably, however, from rainwater interception because the tree actively absorbs these compounds, while it only passively captures rainwater simply by intercepting it on its path to the ground (Nowak *et al*., 2006). Trees do passively intercept falling particulate matter, as well.

Leaf area index (LAI) is an important factor in the ability of a tree to absorb and intercept pollutants (Nowak *et al*., 2006). Based on a similar understanding to that of rainwater interception, deciduous trees offer essentially no pollution mitigation benefits during the leaf-off season. Evergreen trees with high, year-round LAIs, will offer greater benefits for urban areas throughout the year in terms of particulate matter interception.

Fausto *et al.* (2012) found that urban conifers growing in Rome, Italy, absorb tropospheric ozone throughout the year, outperforming other tree functional types in the study (broadleaf evergreen and deciduous broadleaf species) in terms of milligrams of ozone removed normalized by area tree cover of each type. These results were consistent with other studies (Nowak *et al*., 2000; Nowak *et al*., 2006). They also found that conifers maintained a consistent level of absorption through drought conditions that continued through winter when deciduous broadleaf trees were dormant and contributed no pollution absorption benefits.

Along with directly impacting pollution absorption, urban conifers with high LAIs also offer the indirect benefits of cooling ambient and surface air temperatures, thereby reducing the amount of greenhouse gases that are associated with the use of air conditioning systems. The urban heat island effect describes the phenomenon of urban areas being significantly warmer than surrounding areas, and notably wooded areas (Landsberg, 1981). Rapidly heating surfaces in urban areas absorb ambient heat and radiate it back into the air, causing it to warm (Kim, 1992). Due to this excess heat, more air pollution is then emitted to run air conditioning systems in these urban centers.

Urban trees help address the issue of the urban heat island effect in two ways: by shading streets and buildings, and by cooling the air via transpiration (Akbari, 2002; Akbari *et al*., 1997; Peters *et al*., 2010). Peters and McFadden (2010) found that urban sites with high LAIs had lower soil and surface temperatures by 7°C (12.6° F) and 6°C (10.8° F), respectively, as compared to areas with lower LAIs. They also note that this significant cooling effect may have implications in the efflux of CO_2 from urban soils due to the seasonal changes in LAI. This means that having a higher LAI not only lowers the ambient air temperature, as well as the soil and surface temperatures, but it can also help keep CO_2 in the soil from moving into the atmosphere. In addition, Akbari *et al*. (1997) found a savings of between 17% and 57% on energy loads by adding just three trees around single story buildings in US cities.

This data shows that the amount of cooling that is observed in ambient air, and in urban soils and surfaces, is greater where urban tree canopies exist. It also demonstrates that there is a direct relationship between the LAI and cooling levels. The associated shading benefit from conifers, coupled with the benefits from reducing ozone levels, could significantly reduce the amount of CO_2 produced to cool buildings during the summer (Akbari, 2002), and reduce pollution levels year-round, rather than only in the leaf-on season.

Diversity

Diversity of species in natural forest systems are intimately related to the stability of those natural systems. Ecological stability in terms of primary production can be defined several ways depending on the ecosystem and the types and severities of perturbations (or disturbances) (Ives and Carpenter, 2007). Justus (2008), speaking about ecological stability in a more classical sense, describes it as the ability of a system to withstand disturbance and bounce back from it (called tolerance, or resistance), and how quickly it does so (called resilience). The stability of an urban forest can be described in the same terms, especially with consideration to its ecosystem benefits: the more stable an urban forest is, the better it is able to resist disturbance and the quicker it is able to return to its original level of ecosystem service after a disturbance. Diversity contributes to stability by ensuring that a single pest or disease, which would affect perhaps one species, genus, or a relatively small group of unrelated trees, does not threaten large portions of urban forest.

Historically, detrimental pest invasions have decimated populations of non-diverse urban trees. A well-documented example is the American elm (*Ulmus americana*) and Dutch elm disease (*Ophiostoma ulmi*). Cities lined their streets and filled their parks with American elms, due to many of their desirable traits, including unique growth habit (Gibbs, 1978). When Dutch elm disease was introduced in the early 20th century, it wiped out millions of American elm trees across the United States and Canada (Gibbs, 1978). What were once robust urban forests were left barren, and many of the associated ecosystem benefits were lost (Raupp *et al*., 2006). The effects of this disease were so detrimental largely because urban forests lacked diversity.

A present-day comparison could be made with the Asian longhorned beetle (*Anoplophora glabripennis*). Asian longhorned beetle (ALB) attacks a range of tree species, but is limited to 6-12 main genera, half of which are listed as occasional hosts (Sawyer, 2010). Nowak *et al*. (2001) calculated that if ALB infestations spread across the United States, 30% of the urban trees may be at risk, valued at $669 billion dollars. To combat these types of outbreaks, municipalities should plant a large diversity of species and genera.

Common diversity metrics for urban forests vary, but some have come as standard ranges. Miller and Miller (1991) recommend an urban forest have no more than 10% of any one species, while Grey and Deneke (1986) recommend a looser range of no more than 10-15% of any one species. Barker (1975) suggests no more than 5% of any species; Ryan and Bloniarz (2008) suggest no more than 10% of any one genus, that would include a diversity of species; Moll (1989) recommends no more than 10% of any one genus and no more than 5% of any one species; and Santamour (1990) recommends no more than 10% of any one species, 20% of any one genus, and 30% of any one family be present in an urban forest. In general, however, urban foresters use the metric by Miller and Miller (1991) of no more than 10% of any one species as it is the more generally favored metric in the literature.

Though important, these species abundance metrics only approach the issue of urban tree diversity from a single perspective. They establish maximum abundance limits (%) that should not be exceeded. However, there is no mention of a minimum numbers of total species. Thus, a municipality which adheres to the metric of no more than 10% of any one species can meet its goal with only ten species making up its entire urban forest, and these could be from just a single genus. Miller and Miller (1991) also note that there are natural limits to how many species can be planted in an urban area due to species suitability for that area (i.e. climate limitations, design needs, or plant architectural features). Species abundance metrics do not encourage diversity, but merely discourage overuse, while limits to what species can be planted only specify already accepted tree species for a given region. Neither address diversity in terms of increasing underplanted species.

In the temperate regions of North America, conifer species are underplanted, and thus underrepresented, as public street trees. Raupp *et al*., (2006) analyzed inventories from 12 different cities and college campuses in the eastern U.S. for diversity of tree species present. Only three genera of conifer were found (spruces [*Picea*], firs [*Abies*], and pines [*Pinus*]) throughout each city, and only *Picea* was found in an abundance of more than 10% of all trees inventoried (Lincolnshire, IL, 12%), followed by *Pinus* at 9% (Lincolnshire, IL). Species of *Abies* were only found in Ann Arbor, Michigan at 0.2 % of all trees inventoried. Inventories in Minneapolis, MN, USA (McPherson *et al*. 2005[3]), Charlotte, NC, USA (McPherson *et al*., 2005 [2]), and in Berkeley, CA, USA (Maco *et al*., 2005) identified that conifers represented 0.3%, 8.5%, and 4% of the street tree populations, respectively.

Throughout 2011 and 2012, the city of Portland, Oregon completed inventories in 9 districts around the city. Of the 38,373 street trees inventoried, evergreen conifers were found to comprise an average of 2.22% of the total street trees in all districts (standard deviation of 0.0126, max of 3.7%) (Street Tree Inventory Reports, Portland, OR, 2011-2012). The USDA Forest Service Northern Research Station conducted a street tree inventory and analysis of Chicago's urban forest and found that evergreen conifers make up about 9.1% of the species distribution, yet only 3.9% of the total leaf area across the city. These conifers are comprised of five different species over two families (Nowak *et al.,* 2010). The city of Boston, Massachusetts conducted a street tree inventory in 2005 and 2006 and found no conifer species represented in the top 25 of the 123 urban tree species present. The top 25 species (comprised of 15 genera) accounted for 96.7% of all the street trees in the city, and the top ten species accounted for approximately 83% (Urban Ecological Institute, 2008).

These findings demonstrate that conifers are widely underrepresented as street trees, and that there is an overabundance of certain broadleaf deciduous species (i.e. maples [*Acer*] and ash [*Fraxinus*], according to Raupp *et al*., 2006). Raupp *et al*. (2006) found that many of the species that make up the urban forests they surveyed (49.75% on average, with a standard deviation of 0.142) are at risk of possible emerald ash borer (EAB) (*Agrilus planipennis*) or ALB infestations. None of the conifers in their survey were identified as being susceptible to either of these insect pests, demonstrating that they are a viable alternative means of helping urban forests remain stable through an outbreak.

Conifers, being of different physiological and taxonomical descent from broadleaf species, are not at risk from the same diseases and pests. Though conifers, like all trees, are susceptible to their own suite of insect and disease pests, they add unique diversity to the urban forest. Such diversity inhibits insect and disease outbreaks from destroying large parts of the urban forest. For example, if an urban forest in one of the cities or campuses that Raupp *et al*. (2006) surveyed has 60% broadleaf, deciduous species and 40% conifers, then at most only 30% of the species will be at risk in the event of an outbreak of EAB or ALB; the conifer species will be completely unaffected. Conversely, if an outbreak of needle blight or other conifer-specific disease occurs, then only the conifers will be effected (up to 40% of the urban forest in this scenario), and specifically only the susceptible species will be at risk.

Conifers are a very large group of plants, and there are several genera across mainly two families that grow well in the temperate regions of the northern hemisphere. As with broadleaf species, there are few insects or diseases that detrimentally affect all species. Thus, by diversifying the urban forest across phyla (e.g. conifers, or Pinophyta, versus broadleaf species, or Magnoliophyta) urban foresters are increasing urban forest capacity against diseases of other phyla. By diversifying within phyla (e.g. pines, firs, spruces, cypress [*Cupressus*], etc. for Pinophyta and maples, oaks [*Quercus*], lindens [*Tilia*], mulberries [*Morus*], etc. for Magnoliophyta) urban foresters are even further strengthening the stability of the urban forest.

In addition to strengthening stability against invasive pest and disease outbreaks, diversifying the urban forest using conifers may also strengthen its stability in terms of resistance to severe storm damage (Downs, 1938). Hauer *et al*. (1993) inventoried parkway trees in Urbana, Illinois, USA after a severe ice storm and found that only 0.6% of the 501 gymnosperm species found as parkway trees were injured during the storm, as compared to 4.8% of the 10,100 species of angiosperms. The lower damage susceptibility of the conifers is attributed to their excurrent growth form, characterized by a strong central leader and layered horizontal branches (Horn, 1971; Harris, 1992). The implications of this resistance to damage during ice storms of this kind are that populations of coniferous street trees with this growth habit will maintain a higher degree of their associated ecosystem benefits post-storm event, whereas the population of broadleaf trees will suffer a loss of canopy-dependent ecosystem service.

Hauer *et al*. (1993) cite several studies that document conifers being more resistant to ice storm damage, yet also cite studies that found conifers to be more susceptible. The body of research that pertains to ice and wind storm damage is extremely variable. Most research has focused on forest trees, and concludes that susceptibility is highly dependent on size of the tree, species, canopy dominance, and growing conditions (i.e. closed forest or open-grown) (Horn, 1971; Hauer *et al*. 1993). Due to the variability in findings and the influence of specific conditions, this is a subject area that requires further study. The exploratory study by Hauer *et al*. (1993), and the general excurrent growth habit of many conifer species, provides evidence that conifer species may be well-suited to withstand the heavy ice and snow loads often correlated with severe winter weather events. Urban foresters should take general and extreme climactic conditions of their area into consideration, as well as how conifers that grow in that area react to these conditions, when deciding where conifers can be most effectively used.

Finally, strengthening the diversity of urban forests by planting more conifers will help increase the biodiversity of wildlife. The abundance, spatial distribution, connectivity, and structure of vegetated landscapes are key components in maintaining biodiversity for many wildlife species in urban areas (McKinney, 2002).

Savard *et al*. (2000) summarize the literature on biodiversity in urban areas and notes that biodiversity is a complex issue that is separated into hierarchical scales (Allen and Star, 1982). However, these levels are all interdependent, therefore a change at one level affects other corresponding levels (Savard, 1994). These scales range from city-wide or regional (i.e. entire urban forest), to the plot or single tree (i.e. street trees, small parks, or clumped plantings), so it is important to add tree species diversity in as many levels as possible to derive maximum benefit. Bird species are heavily dependent on urban conifers for winter thermal cover, as well as for nesting sites due to the dense, evergreen foliage (Savard, 1978). Other wildlife species derive these same year-round benefits, for nesting cover, escape cover, thermal cover, and food (Clatter and Harper, 2009).

Design and Management Recommendations

Whether landscaping or engineering, the proper function begins with the proper design. Arborcultural research is becoming increasingly interested in tree function and physiology and is investigating urban trees from the perspectives of mechanical and structural engineering (Kane and James, 2011). Though much of this research is specific to tree failure and risk tree evaluation, approaching arboriculture and urban forestry from an engineering perspective has implications that include mechanical and structural engineering, as well as civil and environmental engineering perspectives. Rather than investigating how trees react to outside stimuli (i.e. wind gusts and gravity), a perspective derived from civil and environmental engineering would investigate trees' effects on their surrounding environment.

Much of the research previously discussed appears to derive from the perspective of environmental engineering, and indeed is directly presented as rationale for using conifers to positively affect their surrounding environment (i.e. provide urban ecosystem benefits). However, as a whole, few municipalities view and use their urban forests as engineered components of their civil infrastructure. Indeed, even at a small scale, beyond curb appeal, few buildings are designed to specifically interact with and use trees as a part of their structural efficiency and integrity. This is not to say that trees are frivolous in this manner, as they have been shown to increase property value (Donovan and Butry, 2010), provide safer neighborhoods (Kuo, 2003), and have an effect on the healthy birth weights of newborns (Donovan *et al*., 2011), but it is to say that with specific design choices, designers can employ trees as a part of the engineered, functional building system. By expanding this concept to an entire urban forest and municipal infrastructure system, the urban designer can effectively and efficiently use trees as legitimate infrastructure. By using evergreen conifers more frequently and more deliberately, the urban designer can increase the efficiency of the urban forest as an engineered and designed system.

Design Aspects at the Individual Building Scale

As previously indicated, pieces of green infrastructure should be specifically designed and implemented just as pieces of gray infrastructure are. To achieve this, designers and urban foresters should consider the function(s) that the infrastructure is meant to perform, and how the infrastructure interacts with its immediate environment, or microclimate. A microclimate consists of the temperature of solar and surface radiation, moisture content, and relative humidity of a small outdoor area (Brown and Gillespie, 1995). Microclimates can affect the overall climate of a city by cooling areas, purifying the air, and encouraging people to go outside, which helps create a healthy social ecology (Nikolopoulou *et al*., 2001). Conifers are well-suited to positively affecting urban microclimates due to their positive impacts on surface temperatures and ambient air temperature due to their high LAIs (Peters and McFadden, 2010), air purification (Fausto *et al*., 2012; Nowak *et al*., 2006), and their shading of buildings, which helps to reduce heat radiation (Akbari *et al*., 1997; Akbari, 2002; Donovan and Butry, 2009).

Panagopoulos (2008) provides a summary and identifies specific design elements that must be taken into consideration due to their direct effect on microclimate. These elements include the amount of solar radiation penetrating the space, the shape of the element (i.e. width, height, and form of the tree), as well as the amount of soil and type of vegetation. Evergreen conifers add permanent, year round plant structures to a site and function as "evergreen structure" amongst a non-living or seemingly "dead" landscape. This is a landscape element that designers use to create the sense that there is always something living amongst an otherwise dormant landscape. The design choice of using evergreen conifers to positively affect the microclimate around a building also has implications for the efficient functionality of the building itself.

Used as part of a landscape design that encompasses aspects of the building's design, conifers offer a wide range of functional uses. Notably, evergreen conifers affect wind speeds year-round. In an area with prevailing winds during certain times of the year, planting evergreen conifers close to buildings will reduce the speed of the wind hitting the building, thus reducing the amount of heat loss due to infiltration of the cold air, as well as by reducing the heat conduction away from the building by passing wind and reducing the amount of heat dissipated from sunlit surfaces (Neimeira, 2009; Akbari, 2002). By planting evergreen conifers as windbreaks further away, a building will not be subject to winter time shading, and can save up to 25% in heating costs (Niemiera, 2009; Akbari, 2002). The windbreak coupled with ample available surfaces to be warmed by the sun can offer significant reductions in heating costs during the winter time.

Winter time shading, however, can cause a significant reduction in the solar radiation striking a building. The shading effect of a tree is dependent on the crown area, distance from the building, and aspect in relation to the building (Donovan and Butry, 2009; Simpson and McPherson, 1996). Though this effect is positive in regards to cooling during the summer time, the same effect during the winter time may be negative in regards to heating the building. Deciduous trees offer the opportunity for summer shading and solar penetration during the winter due to their temporal canopy changes. More research is needed, however, to understand the impact that winter time shading has on buildings in comparison to the effects that thermal buffers have. Buildings that are well-insulated or have no windows on a side that receive the most sunlight (i.e. industrial or commercial buildings) may benefit more from the extra thermal cushion around them, as well as added rainwater interception offered by conifers, especially when impervious surfaces (such as parking lots) surround them.

Concerns relative to winter shading and increased heat consumption in a building may be addressed by placing conifers around the building in a manner that minimizes or even precludes the shading of the building. Donovan and Butry (2009) found that trees planted on the north side of a house (in the northern hemisphere) did not reduce energy use because they did not cast a shadow over the structure. This would allow evergreen conifers to act as windbreaks and thus thermally benefit the building without inhibiting the heat gain from winter solar radiation allowed in through the leafless deciduous trees (Heisler, 1986[2]). Figure 5 shows an example of such a design.

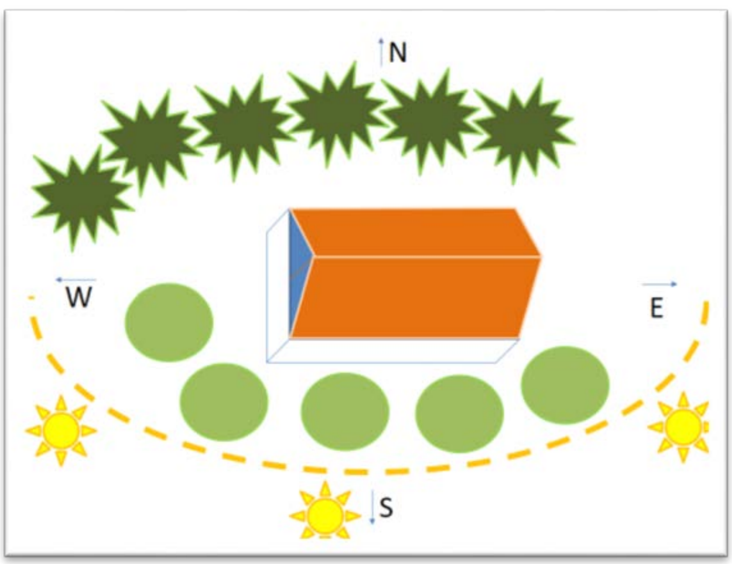


Figure 5: Aerial illustration of a possible planting design that optimizes thermal protection with evergreen conifers on the northern and northwestern exposures of a building, and optimizes summer shading and winter solar radiation benefits with deciduous broadleaf species on the southeastern, southern, and southwestern exposures.

Along with the energy benefits associated with the design in figure 5, the unique benefits discussed in the rainwater, pollution, and diversity sections are also gained. By incorporating such design features in individual site plans (i.e. through ordinance or other local regulation), urban foresters can affect their overall diversity and net ecosystem benefits at a fundamental level in urban development. More research is required to better understand the relationship that this sort of design offers relative to different types of structures (i.e. single or multiple family homes, commercial and industrial buildings, etc.) and to what degree the tree functional type affects net ecosystem benefits at this level.

Design Aspects at the Street Level

As street trees, conifers can play a unique role. As previously indicated, conifers are underrepresented as street trees across the US. Their increased use can lead to more annual rainwater interception, pollution absorption, and diversity throughout the urban forest on a national scale. However, conifers' unique structural and physiological traits can also serve additional purposes. By accomplishing several functional goals with a single piece of infrastructure, urban designers and urban foresters can improve the efficiency of the urban forest as infrastructure, thereby strengthening the case to use and invest in it.

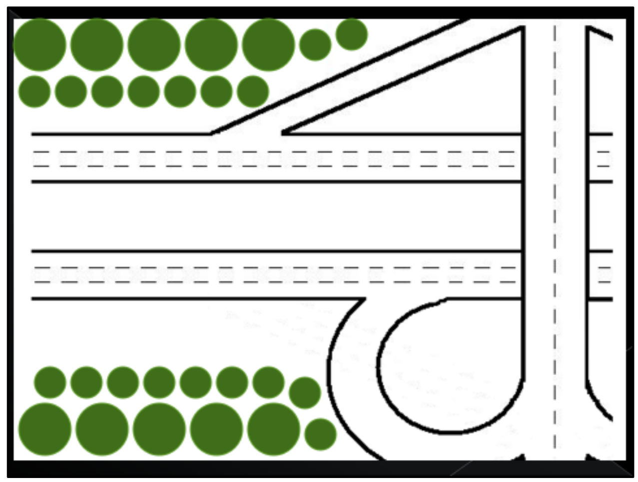


Figure 6: Aerial view of an example evergreen buffer planting around a typical freeway in the United States.

Figure 7: Use of evergreen conifers to create a privacy block from a main road in Portland, OR.

Conifers are regarded for their use as barriers due to their dense, evergreen foliage (Niemiera, 2009; Grey and Deneke, 1986; Wyman, 1965). They are used as auditory and visual barriers to muffle unwanted noise and block unsightly views (Grey and Deneke, 1986; Robinette, 1972). If planted along a road corridor, for example, dense evergreen conifers can muffle both the sight and sound produced by heavy vehicular traffic (Figures 6 and 7).

In addition to functioning as barriers to unwanted noise and sound, conifers can also act as physical barriers to salt spray along roads during the winter time. Many conifers are resistant to salt spray and soil salinity that arise from salting roads during winter time storms (Wyman, 1965; Miyamoto *et al*., 2004; Appleton *et al*., 2009). Table 3 identifies evergreen conifers that are listed as salt-tolerant by three different resources. Due to their dense foliage and salt tolerance, these conifers can serve as effective barriers to help prevent salt spray from moving into natural areas or areas of vegetation that are more susceptible to salt burn, and which can help protect adjacent structures from damage associated with salt spray.

Table 3: List of conifers sorted by author and type (tree or shrub) that tolerate salt spray and saline soils. Wyman (1965) lists the presented species as "Trees for Seashore Planting". The trees shown here may not be best suited to all areas. This list is merely meant to exhibit finding and recommendation that others have found.

Wyman, 1965	Miyamoto et al., 2004	Appleton et al., 2009
Trees	**Trees**	**Trees**
Cryptomeria japonica	*Pinus halepensis*	*Cryptomeria japonica*
Cupressus macrocarpa	*Pinus strobus*	*Juniperus virginiana*
Araucaria spp.	*Cupressus arizonica*	*Picea pungens*
Juniperus excelsa stricta	*Pinus eldarica*	*Pinus nigra*
Juniperus lucayana	*Pinus edulis*	*Pinus palustris*
Juniperus virginiana	*Cupressus sempervirens*	*Pinus thunbergii*
Picea asperata	*Pinus pinea*	**Shrubs**
Picea pungens glauca	*Pinus thunbergii*	*Chamaecyparis pisifera*
Pinus halepensis	*Juniperus chinensis*	*Juniperus chinensis*
Pinus nigra	*Juniperus scopulorum*	*Juniperus communis*
Pinus pinaster	*Juniperus deppeana pachyphlaea*	*Juniperus conferta*
Pinus radiata		*Juniperus horizontalis*
Pinus rigida		*Pinus mugo*
Pinus sylvestris		*Taxus baccata*
Pinus thunbergii		
Thuja occidentalis		
Thuja orientalis		

The possible negative effects of conifers as street trees, such as winter shading and lack of visibility, may indeed restrict their use in certain situations. Just as with broadleaf deciduous trees, however, conifers can be pruned to permit under-canopy clearance and to facilitate visibility. Around power lines they can also be pruned to acceptable standards to reduce utility conflicts. Due to the excurrent form of most conifer species that are suitable for planting in North America, their limbs can be pruned back to the central leader without severely damaging the tree's form (figure 8). Indeed, due to the upright, or conical, growth habit of excurrent trees, many conifers can be planted next to power lines and will not grow outward and cause infrastructure conflicts. Conversely, when decurrent trees are pruned to avoid power lines, their form can be severely damaged, and this can cause a negative impact both to the tree's health and to the aesthetic quality of the planting (figure 9). This is not to say that infrastructure conflicts do not occur when conifers are planted directly under power lines, but rather illustrates their potential use as upright, conically shaped trees.

Figure 8: Eastern white pines (*Pinus strobus*) pruned to avoid power lines in Amherst, MA.

Just as with any piece of infrastructure, negative side effects must be considered along with the positive. In order to maximize the benefits and minimize the negative impacts, the urban forester must consider the site that is being planted along with the benefits and trade-offs that are associated with a given planting option. The positive effects of summer time shading and year-round rainwater interception come with the

Figure 9: London planetree (*Platanus x acerifolia*) pruned to avoid power lines in Corvallis, OR.

possible negative effect of winter time shading for evergreen trees. Figure 8 shows a planting of evergreen conifers on the south side of a street in Amherst, Massachusetts which shades the road throughout the year, inhibiting the melting of snow and ice. Informed planting choices help alleviate these conflicts by placing trees in the proper location not only in terms of compatibility (i.e. 'right tree, right place') but also in terms of gaining the most net benefit.

Net benefit refers to the total benefit value left over after subtracting the total value of the negative impacts. Depending on the location of a given municipality, the value of the negative and positive impacts can vary greatly. For example, during winter in the US Midwest and Northeast, ice buildup on the roadway is top concern, while in places in the US Pacific Northwest and Southeast where such conditions are more rare, it is much less of an issue. Smart design in planting choice is crucial in gaining the highest net benefit, and one must consider the all the tree species available, the diversity in the area, surrounding buildings, road orientation, as well as intrinsic and temporal characteristics of a given tree.

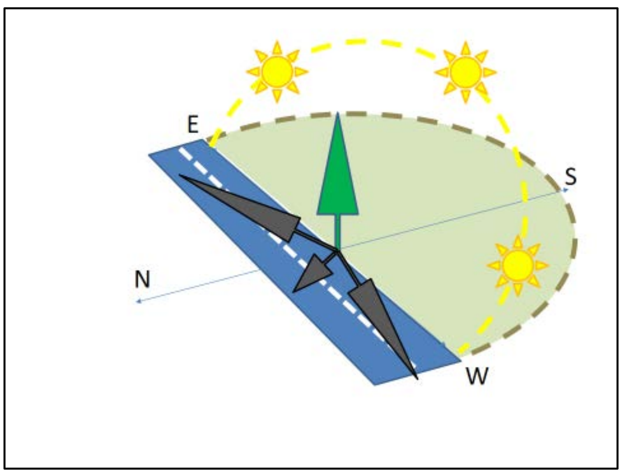


Figure 10: Shade diagram of an evergreen, coniferous tree planted in the northern hemisphere on the south side of a road oriented in an east-west direction. The shadow covers a large portion of the road surface.

In the northern hemisphere, the sun strikes objects on the southern exposure, casting a shadow to the north of east and west (figure 10) (Autodesk Sustainability Workshop, 2011). During the winter, the sun appears at a lower point in the sky, thereby casting a longer shadow. Evergreen conifers planted on the south side of a street will therefore shade the road during the winter, inhibiting the melting of ice and snow. Conversely, if evergreen conifers are planted on the north side of a street, their shadow will not fall on the street, but on the property adjacent to it. If this is a front yard, there will be little conflict. If the shadow falls on a building, however, a conifer may not be suitable for that location due to the winter time shading. However, this conflict will only arise if the building would otherwise gain a benefit from winter solar exposure.

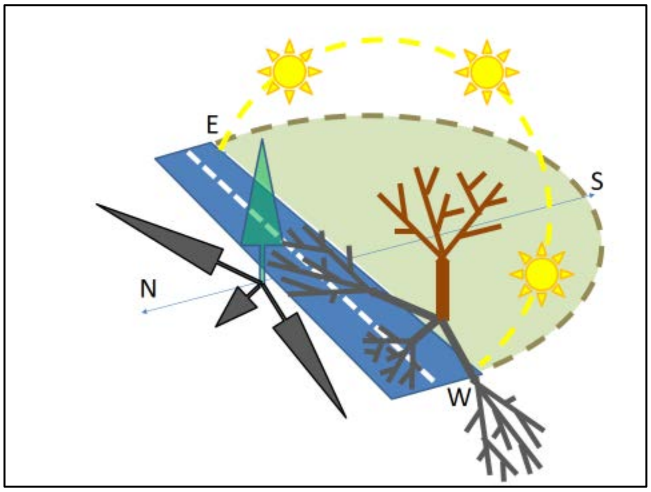


Figure 11: A winter shade diagram of an evergreen, coniferous tree planted on the north side of a street and a deciduous, broadleaf tree planted on the south side of a street.

By planting conifers on the north side of an east-west street and deciduous broadleaf trees on the south side, the urban forester can achieve summer shading on the street when the deciduous trees are in leaf, allow for the maximum amount of solar exposure during the winter time, and gain the added benefits associated with conifers including diversity and year-round canopy-dependent ecosystem services (figure 11).

On streets that are oriented north-south, the sun strikes the road surface uninhibited during the middle of the day regardless of the type of trees are planted along it. Evergreen conifers planted along the east side will shade the road in the morning, but not in the evening, and evergreen conifers planted on the west side will have just the opposite effect (figure 12). In these situations, the height of the tree and the distance away from the road play important roles in the shading. If a short tree is planted further away, it will allow in more sunlight for more of the day. Conversely, tall trees planted close to the road will create a narrower gap for the sun to shine through, lowering the amount of time sunlight can reach the road surface (figure 13). By taking into consideration the mature height of a tree as well as the width of the road and the distance between the plantings, the urban forester can make an educated design choice on what species will be suitable to plant based on the desired amount of solar exposure.

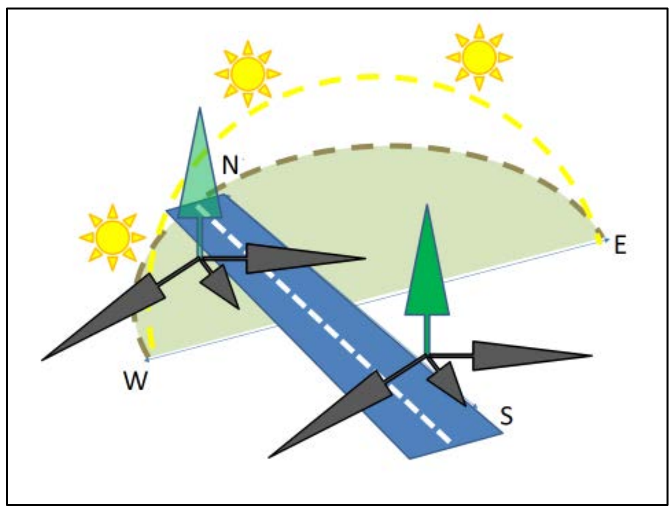


Figure 12: Shade diagram of evergreen, coniferous trees planted along the east and west sides of a north-south oriented street in the northern hemisphere.

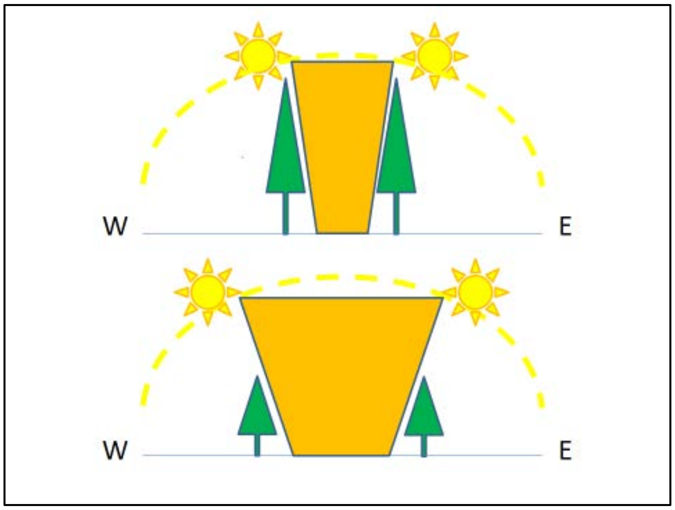


Figure 13: Shown here is a diagram showing how the height of trees and the distance between them affects how long sunlight can reach a surface between them. The taller trees planted closer together cast shadows over the road for most of the morning and evening. The shorter tree planted further apart cast shadows over the road for less of the day, allowing for more solar exposure over a day.

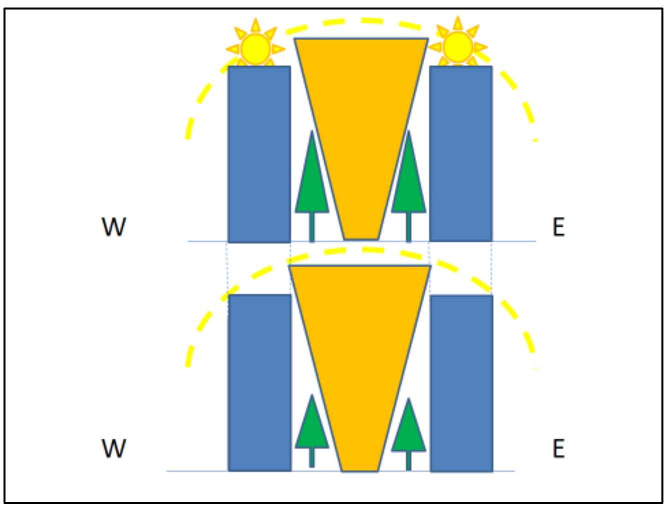


Figure 14: The taller buildings next to the trees cast shadows over the road. This shading effect would happen regardless if the trees were deciduous or evergreen.

In areas of a city that have buildings that are taller than the trees along the streets, such as apartment complexes or commercial buildings, the shading effect caused by the buildings eclipses the effect that the trees would have. Depending on how wide the trees are, they will have a minimal effect on the shadow cast over the road at any one point during the day. In these situations, the winter time shading will occur regardless of the type of tree planted along the street, thus the urban forester can select an evergreen coniferous tree to attain the desired benefits associated with it without concern that it will cause shading.

This applies on streets that are oriented east-west, as well. If one imagines tall buildings on the south side of the road in figure 10, the shading caused by the evergreen conifer will be eclipsed by the shading caused by the structure. This will remove the limitation of winter shading by street trees because the shading will occur regardless of the tree functional type (evergreen or deciduous). The urban forester is thus able to select evergreen conifers based on their compatibility for the site, as well as their added benefits value.

A second means of approaching the issue of winter time shading is by using deciduous conifers. These types of trees can be used to achieve similar benefits that deciduous broadleaf trees provide, with the additional benefit of diversity at higher taxonomic levels. Genera such as larch (*Larix*), dawn-redwood (*Metasequoia*) and baldcypress (*Taxodium*) all are coniferous species, yet all have deciduous needles. Notably, baldcypress is tolerant of urban conditions due to its adaptations for surviving in swampy areas (Gilman and Watson, 1994). Where site conditions are suitable, these conifer species can offer unique interest to the urban area, yet not detract from the traditional offerings of more common deciduous street trees.

It should also be noted that conifers are available in varying forms and size, depending upon species and cultivars (Wyman, 1965). Though for street tree planting it may be favorable to have larger-growing trees that shade the roadway in the summer and capture rainwater, this may not be an option due to local site conditions/constraints. In these situations, smaller-growing conifers may be used to effectively create evergreen structure, act as salt spray barriers, or to help guide pedestrian movement by providing a physical barrier between the sidewalk and vehicular traffic. Many genera of conifers remain small or are easily and quickly trimmed into hedges like yew (*Taxus*), juniper (*Juniperus*), arborvitae (*Thuja*), as well as some species or cultivars of pine (*Pinus*), hemlock (*Tsuga*), spruce (*Picea*), and cypress (*Cupressus*).

Design Aspects at the Park or Greenway Level

Planting evergreen conifers at the Park or Greenway level offers advantages that are otherwise constrained at the previous two levels. In parks and greenway plantings, there are fewer issues regarding shading and infrastructure conflicts, as well as larger above- and below-ground space, so the urban forester is better able to take advantage of a larger planting selection.

At this level, urban foresters may employ conifers to their full potential and obtain year-round ecosystem benefits without any of the aforementioned drawbacks. Larger mass planting of conifers will provide dense closed canopies that maintain high LAIs throughout the year, which in turn provide essential canopy-dependent ecosystem services. When native conifer species are intermixed with native broadleaf species, complex native forest canopies can be restored, adding to connectivity of habitat for threatened native wildlife (McKinney, 2002), as well increasing diversity at different hierarchical levels (Noss, 1990).

Planting in these types of parks and greenways is also important for stability of the park's ecosystem benefits. If an insect or disease pest infests the area, and many of species are susceptible, then the level of ecosystem service of the area could be greatly affected. By intermixing conifer and broadleaf species, the intensity of the disturbance can be lessened because a smaller percentage of the species composition would be at risk of infection.

This landscape planning technique also applies to parking lot plantings. Due to the amount of impervious cover by many parking lots, rainwater interception is important to consider as a design aspect. Many conifers may not be well-suited to this type of location because they do not spread out enough and capture rainwater over the top of cars. However, where suitable planting strips are located within the parking lot area, or around the periphery, conifers would be well-suited to help capture rainwater year-round, thereby lowering the amount of runoff from the parking lot surface.

Conclusion/Recommendations

Conifers may be able to play an important role in the urban forest of the future. We recommend that they be used whenever they can offer significant benefits and have minimal conflicts. In rain gardens or bioswales, conifers may offer significant benefits as additional means of intercepting water. These large-growing, dense trees will also help to create evergreens structure when deciduous components of the rain garden lose their leaves.

We also recommend that conifers be used as evergreen barriers. This landscape use offers several benefits, as stated above, and of course offers year-round canopy-dependent ecosystem services and diversity to the urban forest. This also helps to soften hard edges and generally muffle sounds of the city, helping to mitigate sound pollution issues.

In the various situations presented above, it is prudent for the landscape designer to use trees and planting layouts that will produce the greatest benefit throughout the whole year. Many times this requires specific design choices and the consideration of all plant functional types available, taking care to understand their associated temporal and intrinsic benefit values.

The purpose of this synthesis has not been to advocate that evergreen conifers are the appropriate choice for every situation; rather, the accepted practice of "right tree, right place" should be at the forefront when selecting what tree should be planted at a given site. Taking this concept to its natural conclusion, attributes of the individual building, the specific street, and the landscape as a whole should be considered, as well as how the selected trees will interact with each of these elements. By describing trees as part of the green infrastructure of an urban area, they become more appropriately categorized as useful and engineered structures that serve specific purposes. Thus, they should be incorporated and managed as such.

Conifers, both evergreen and deciduous, serve unique functions in the urban landscape. They have the potential to increase overall benefit values relative to rainwater interception, pollution absorption, and urban forest diversity. They also have functional design uses including physical barriers, windbreaks, and hedge buffers that deciduous broadleaf species are less adept at. By establishing conifers on par with more traditional deciduous broadleaf species in terms of urban tree planting selection, the urban forester has the opportunity to create more stable and efficient urban forests as designed infrastructure components of today's cities.

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