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Rationale for the increased use of conifers as functional green infrastructure: A literature review and synthesis

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Green infrastructure is the aggregate of plants and green spaces in the urban landscape. This infrastructure provides many 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 benefits accrued. According to available data from street tree inventories, most species that make up street trees in urban forests in the United States and Canada are broadleaf, deciduous species. Since many urban tree benefits are attributed to the tree canopies, benefits effectively drop to negligible levels during the leaf-off period. When a rain event occurs during this season, the canopy cover afforded by evergreen tree species, in concert with the canopy architecture and density of evergreen conifers will help to maintain canopy-dependent benefits. 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 the urban environment. As one of the major non-point sources of air and water pollution, our urban ecosystems are out of balance, as they contribute to the problem of pollution while depending heavily on the surrounding natural systems as a source of mitigation (Douglas, 1983; National Oceanic and Atmospheric Association, 2007). Urban areas contribute to global climate change and deforestation by using enormous amounts of resources for energy (Rees & Wackernagel, 1996). By harbouring 83.7% of the US population (Mackun & Wilson, 2011), our urban areas demand the greatest use of natural capital and produce the greatest amount of depleted capital (i.e. waste; Rees & Wackernagel, 1996). Due to such resource demands, they also require the greatest remediation efforts (Rees & Wackernagel, 1996). Urban forests play an invaluable role in both helping to mitigate the environmental impacts of urban areas, as well as serving as a key resource relative to the social health of the citizens.

There are various benefits of urban trees including the following:

1. Filtering of pollutants from the air (examples include ozone [Nowak et al., 2000; Taha, 1996], carbon monoxide, carbon dioxide, particulate matter [microscopic dust] and sulphur dioxide [Geiger, 2005; Nowak, Crane, & Stevens, 2006]);
2. Intercepting and storing rainwater (Hirabayashi, 2013; Xiao & McPherson, 2002; Xiao, McPherson, Simpson, & Ustin, 1998; Xiao, McPherson, Ustin, Grismer, & Simpson, 2000);

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(3) Mitigating urban heat island effects (Konopacki & Akbari, 2001; Peters & McFadden, 2010; Peters, McFadden, & Montgomery, 2010);
(4) Reducing stress and increasing the happiness of urban residents (Kaplan & Kaplan, 1989; Kuo, 2003; White, Alcock, Wheeler, & Depledge, 2013);
(5) Playing a role in the healthy development of children (Donovan, Michael, Butry, Sullivan, & Chase, 2011; Sebba, 1991).

Urban trees indirectly affect carbon emissions by shading buildings, thereby reducing the amount of energy needed relative to summer cooling (Akbari, 2002; Heisler, 1986b). Urban trees are increasingly being researched for their potential as traffic control mechanisms (Grey & Deneke, 1986; Wolf & Bratton, 2006). They have long been examined as functional landscape features that offer visual and auditory benefits acting as wind barriers, movement control mechanisms and buffers (Grey & Deneke, 1986; Niemiera, 2009; Robinette, 1972).

The aggregate of these benefits, called ecosystem services (Costanza et al., 1997), can be given an economic value (McPherson, Simpson, Peper, Maco, & Xiao, 2005; Nowak, Crane, & Dwyer, 2002). 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 are 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 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 and employing staff) in New York City returned $5.60 in ecosystem services (Peper et al., 2007). This is true for several cities across the United States (Table 1).

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 temporal (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 potential benefits earned if a different tree was planted in the same spot. This may be the case in regards to planting evergreen conifers in the urban area. Their denser, evergreen foliage, coupled with unique crown architecture, can provide canopy-dependent ecosystem services while broadleaf, deciduous trees are out of leaf.

Table 1. The ratios for returns on investment in several cities across the United States.

City	Investment return ratio (investment:return)	References
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, Simpson, Peper, Maco, and Xiao (2005)
Glendale, AZ	1:2.41	McPherson, Simpson, Peper, Maco, and Xiao (2005)
Cheyenne, WY	1:2.09	McPherson, Simpson, Peper, Maco, and Xiao (2005)
Bismarck, ND	1:3.09	McPherson, Simpson, Peper, Maco, and Xiao (2005)
Charlotte, NC	1:3.25	McPherson, Simpson, Peper, Gardner, et al. (2005)
Minneapolis, MN	1:1.59	McPherson, Simpson, Peper, Maco, Gardner, et al. (2005)

Note: The ratio corresponds to the dollar amount returned to the municipality through ecosystem services per one US dollar invested.

In addition to these direct ecological benefits, ones that are more indirect 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. It is these benefits that urban forest managers strive to increase and maintain. When urban trees are lost or severely damaged due to pest pressures or severe weather, the amount of ecosystem benefits associated with the affected areas can reduce significantly. In areas severely damaged by a tornado in Springfield, MA, USA, in 2011, preliminary findings in terms of canopy loss and ambient temperature changes show that increases in temperature can be as much as 2°C (3.6°F; Brooks & Bloniarz, 2011). Estimates of potential canopy loss due to Asian long-horned beetle (*Anoplophora glabripennis*) show that urban forest damage and benefit loss in the United States could range from $81 million in San Francisco, CA, USA to $2.25 billion in New York City, NY, USA (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 resilient and stable through changing climactic conditions and pest outbreaks.

Finally, urban trees themselves are components 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 & McMahon, 2006). Conversely, grey 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.

During specific times of the year, evergreen conifers can provide specific design functions and ecological values that broadleaf, deciduous trees cannot offer. Noting limitations due to pre-existing structures or other goals, by first describing the objectives of a site and the wider urban area, urban foresters can employ evergreen and deciduous conifers as specific infrastructure components to accomplish unique goals. Importantly, they 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 more often when they will be better suited to a given site as components of urban infrastructure.

Findings

Rainwater interception

Rainwater management is a growing concern for municipalities. Runoff from urban areas must meet specific regulatory standards (Clean Water Act, 1972) that often require 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 plant function (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.

LAI is a measure of how dense tree canopy is. It is achieved by identifying the amount of foliage that covers a given unit of ground area. The higher the LAI, the more dense the tree canopy, and more effective it is at intercepting and holding rainwater. Xiao et al. (2000) showed that when a tree loses its leaves, its LAI drops to a negligible amount. 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 1 year. The evergreen tree continued to offer the temporal benefit of rainwater interception throughout the leaf-off season, whereas the deciduous tree offered negligible benefit associated with its branches and trunk. According to Xiao et al. (1998), similar results were obtained when modelling urban forest interception in Sacramento, CA, USA, where they concluded that urban forests in rural and urban areas had a lower storage capacity due to a lower average LAI because the deciduous trees were leafless. This led to a 14% reduction in interception benefits in the rural area and a 26% reduction in the city area.

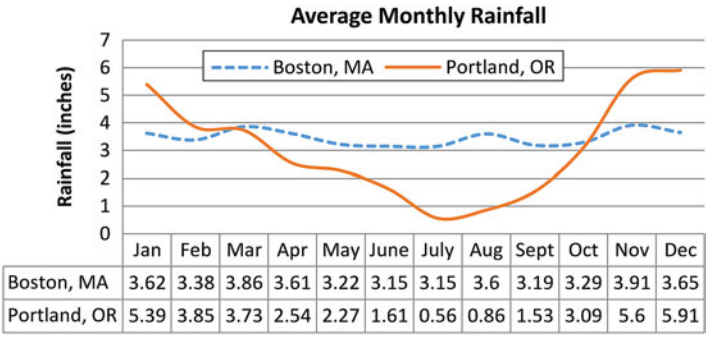
It can be readily observed that a forest dominated by deciduous species loses a significant amount of its rainwater interception benefits for nearly half the year. Thus, the percentage “missed” by the deciduous species can be substantial. A city with rainfall that occurs roughly uniformly throughout the year (Boston, MA, USA), and that has an urban forest dominated by deciduous tree species, would only intercept rainfall for roughly half the year – effectively nearly 50% of average annual rainfall (Table 2). In a city with rainfall that occurs mostly in the winter time (Portland, OR, USA), an urban forest dominated by deciduous tree species would provide an even smaller amount of rainfall interception relative to the total amount of average annual rainfall (Table 2).

Figure 1 plots the average monthly rainfall for Boston and Portland. Both cities have nearly equal tree canopy cover during the leaf-on season, at 30% for Portland (Portland Parks and Recreation, 2012d) and 29% for Boston (Urban Ecology Institute, 2008). Assuming a full deciduous canopy leaf cover from April to October with little or no leaf canopy from November to March, deciduous trees in both cities miss a significant amount of rainfall. Table 2 shows the percentages of average annual rainfall subject to interception

Table 2. Average annual rainfall totals for Boston, MA (City of Boston Weather, 2014) and Portland, OR (WRCC, 2013).

	Average total rainfall (in.)				
	Annual total	Leaf-on (April–October)	Leaf-off (November–March)	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

Notes: Avg. missed is the percentage of the average annual rainfall 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 interception by a deciduous tree.



	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 1. Monthly average rainfall for Boston, MA (City of Boston Weather, 2014) and Portland, OR (Western Regional Climate Center [WRCC], 2013).

in either city. On average, the deciduous trees in Portland fail to have an interception impact on 67% of the annual rainfall, and 44% of the annual rainfall in Boston.

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. Trees with a higher LAI will intercept more rainwater during a storm event. This facilitates the capturing and holding of more water for longer periods before it reaches its saturation point and begins to drip rainwater to the ground (Asadian & Weiler, 2009).

Several studies have investigated the amount of rainwater intercepted by forest canopies in natural and plantation forests (Heal, Stidson, Dickey, Cape, & Heal, 2004; Link, Unsworth, & Marks, 2004; Whelan & Anderson, 1996; Xiao et al., 2000). However, 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). Some of these studies, however, directly compared evergreen conifer cover types with deciduous broadleaf cover types. Bryant, Bhat, and Jacobs (2005) compared interception rates of five forest types in the Southeast United States, concluding that non-plantation pine (*Pinus* spp.) forest intercepted 22.3% gross precipitation compared with 18.6%, 17.7%, 17.6% and 17.4% gross precipitation 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 10–20% of annual rainfall. Though relevant to forest trees, these values demonstrate a distinct and significant difference in rainfall interception by vegetation type, with evergreen conifers having the greater impact.

Asadian and Weiler (2009) examined rainwater interception of conifers in the urban area, finding that across varying tree structural types (i.e. 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 red cedar (*Thuja plicata*), two common urban and natural coniferous forest species found in the north-western United States. The study also found that urban conifers generally intercept more rainwater than do their forest-grown counterparts. This was due to higher urban temperature, 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, demonstrate that in terms of canopy-dependent ecosystem services they could be an important component of an urban forest. Intercepting rainfall throughout the year, and collecting and storing more rainfall per unit of ground area, offers substantial benefits of rainwater interception particular to evergreen conifers.

These findings exhibit the potential for urban conifers as important components of green infrastructure. However some benefits may be limited. The two conifer species examined by Asadian and Weiler (2009) are naturally dense trees with relatively high LAI, thus interception rates may be non-representative of conifers in general. The many studies conducted concerning rainwater interception on forest trees are also not reflective of urban conditions. There is little research on the potential role that conifers may play in the urban forest, as well as their affiliated ecosystem benefits. Thus, further study comparing both urban conifers to urban broadleaf species and to other types of conifers is required.

It should be noted that research in urban forestry trails that of traditional forestry, where rainwater interception is done using total crown storage capacity measures, rather than LAI. Thus, further study is required that applies more novel, and presumably accurate, methods of estimating the crown storage capacity of urban trees. This would also include investigations comparing urban conifers to urban broadleaf species, and other conifers.

Finally, due to differences in transpiration rates between deciduous broadleaf trees and evergreen conifers, evergreen conifers may increase rainwater storage in the ground. Conifers will transpire under numerous conditions while deciduous trees only transpire during the growing season. Thus, conifers may “free up” more space in the soil for water to infiltrate, thus allowing for increased water storage capacity during heavy rain events (Barten, P. K. 2014, Personal Interview, 5-1-2014).

Pollution absorption

Studies have shown the positive impact that urban forests have on mitigating urban pollution in two ways: directly through pollutant absorption/interception and indirectly by shading buildings and roads to reduce the use of air-conditioning (Akbari, 2002; Geiger, 2005; Heisler, 1986b; Nowak et al., 2006). Similar to rainwater interception, pollution absorption is a canopy-dependent ecosystem service. However, it differs notably, since the tree actively absorbs pollutants, while only passively capturing rainwater through interception (Nowak et al., 2006). Trees also passively intercept falling particulate matter.

LAI is an important factor in the ability of a tree to absorb and intercept pollutants (Nowak et al., 2006). As with rainwater interception, deciduous trees offer essentially no pollution mitigation benefits during the leaf-off season. However, evergreen trees with high, year-round LAI, will offer year-round benefit in this regard.

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 normalised by area tree cover of each type. These results were consistent with other studies (Nowak et al., 2000, 2006), concluding that conifers maintained a consistent level of absorption throughout the year, as well as during drought conditions.

Urban conifers with high LAI also offer the indirect benefit of cooling ambient and surface air temperatures, reducing the amount of greenhouse gases associated with air conditioning. 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, radiating it back into the air, causing it to warm (Kim, 1992). Due to this heat compilation, more air pollution is then emitted to run air conditioning systems in urban centres.

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, Kurn, Bretz, & Hanford, 1997; Peters et al., 2010). Peters and McFadden (2010) found that urban sites with high LAI 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 LAI. They also note that, due to the seasonal changes in LAI, this significant cooling effect may have implications in the efflux of CO_2 from urban soils. Thus, a higher LAI lowers ambient air temperature, soil and surface temperatures, and helps to minimise CO_2 efflux between soil and air. Additionally, Akbari et al. (1997) concluded savings of between 17% and 57% on energy loads by adding as few as three trees around single story buildings in US cities.

These data elucidate 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 LAI and cooling levels. The associated shading benefit from conifers, coupled with the benefits from reducing ozone levels, may help to reduce CO_2 production associated with cooling buildings during the summer (Akbari, 2002), and help to reduce pollution levels year-round.

Urban forest diversity

Diversity of species in natural forest systems are intimately related to the stability of those natural systems. Ecological stability can be defined in several ways depending on the ecosystem and the types and severities of perturbations (or disturbances) (Ives & Carpenter, 2007). Justus (2008) described ecological stability in a classic manner 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 similarly, 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 afterwards. Diversity contributes to stability by ensuring, for example, that a single pest does not threaten large portions of urban forest.

Common diversity metrics for urban forests vary with the common reference being Miller and Miller (1991) that recommends an urban forest consist of no more than 10% of a single species. Grey and Deneke (1986) recommend no more than 10–15% of a species and Barker (1975) suggests no more than 5% of a 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 a species, 20% of a genus, and 30% of a family be present in an urban forest.

Though important, these species abundance metrics only approach the issue of urban tree diversity from a single perspective. They establish maximum abundance limits (as percentages) that should not be exceeded. However, there is no mention of minimum percentage 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 10 species making up its entire urban forest, 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 addresses diversity by advocating the increase use of under-planted species.

In temperate regions of North America, conifer species are under-planted, and thus under-represented, as public street trees. Raupp, Cumming, and Raupp (2006), analysed inventories from 12 different cities and college campuses in the eastern USA to better understand tree species diversity. Based on information from the total inventories performed, 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% (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, Simpson, Peper, Maco, Gardner, et al., 2005), Charlotte, NC, USA (McPherson, Simpson, Peper, Gardner, et al., 2005), and in Berkeley, CA, USA (Maco, McPherson, Simpson, Peper, & Xiao, 2005) identified that conifers represented 0.3%, 8.5%, and 4% of the street tree populations, respectively.

Portland, OR completed inventories in nine districts around the city and of its 38,373 street trees, evergreen conifers comprised an average of 2.2% of the total street trees in all districts (standard deviation of 0.0126, maximum of 3.7%) (Portland Parks and Recreation, 2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2012a, 2012b, 2012c). The USDA Forest Service Northern Research Station conducted a street tree inventory and analysis of Chicago's urban forest and identified that evergreen conifers comprise about 9.1% of the species distribution, yet only 3.9% of the total leaf area across the city (Nowak, Hoehn, Crane, Stevens, & Fisher, 2010). Boston, MA identified no conifer species in the top 25 urban tree species of the 123 species present. The top 25 species (comprising 15 genera) accounted for 96.7% of all the street trees in the city, and the top 10 species accounted for approximately 83% (Urban Ecology Institute, 2008).

Conifers are a large group of plants, with several genera from two families that grow well in temperate regions of the northern hemisphere. As with broadleaf species, few pests are detrimental to all species. Thus, by diversifying the urban forest across phyla (e.g. conifers, or Pinophyta, vs. broadleaf species, or Magnoliophyta), urban foresters are increasing urban forest capacities to withstand pest outbreak. By diversifying within phyla (pines, firs, spruces, cypress [*Cupressus*], etc. for Pinophyta and maples, oaks [*Quercus*], lindens [*Tilia*], mulberries [*Morus*], etc. for Magnoliophyta) stability of the urban forest may be even further strengthened.

Recommendations and conclusion

To achieve the better design and implementation of green infrastructure, designers and urban foresters should consider the function(s) that these urban trees are chosen to perform, and how these components of infrastructure interact with their 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 & Gillespie, 1995). Microclimates can affect the overall climate of a city by cooling areas, purifying the air, and encouraging outdoor activity, which helps create a healthy social ecology (Nikolopoulou, Baker, & Steemers, 2001). Conifers are well-suited to positively influence urban microclimates due to their positive impacts on surface temperatures and ambient air temperature due to a high LAI (Peters & McFadden, 2010), air purification ability (Fausto et al., 2012; Nowak et al., 2006), and their shading of buildings, which helps to reduce heat radiation (Akbari, 2002; Akbari et al., 1997; Donovan & Butry, 2009).

Panagopoulos (2008) identifies specific design elements that should be considered in relation to their direct effect on microclimate. They include the amount of solar radiation penetration, the shape of the element (i.e. width, height and form of the tree), and the amount of soil and type of vegetation. Evergreen conifers add permanent, year round plant structures to a site and function as "evergreen structure" among a largely dormant landscape.

In an area with seasonally prevailing winds, planting evergreen conifers close to buildings will reduce wind speeds that intersect the building, thus reducing heat loss due to infiltration of the cold air. Heat conduction that occurs by passing wind and heat dissipation from sunlit surfaces may also be reduced (Akbari, 2002; Niemiera, 2009). By carefully locating evergreen conifers as windbreaks at the appropriate distance, a building will not be subject to wintertime shading, and can save up to 25% in heating costs (Akbari, 2002; Niemiera, 2009).

Winter shading may cause a significant reduction in the solar radiation that a building may receive. The shading effect of a tree is dependent on the crown area, distance from the building and aspect in relation to the building (Donovan & Butry, 2009; Simpson & McPherson, 1996). Deciduous trees offer the opportunity for summer shading and solar penetration during winter. However, to understand the impact that winter shading has on buildings in comparison to the effects of thermal buffers, more research is needed. 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.

The 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 minimises 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 facilitated by leafless deciduous trees (Heisler, 1986a). Figure 2 shows an example of such a design.

Conifers are highly regarded for their use as "barriers" due to their dense, evergreen foliage (Grey & Deneke, 1986; Niemiera, 2009; Wyman, 1965). If planted along a road corridor, for example, dense evergreen conifers can muffle both the sight and sound produced by heavy vehicular traffic (Figure 3; Grey & Deneke, 1986; Robinette, 1972). Furthermore, conifers can also act as physical barriers to salt spray along roads during the wintertime. Many conifers are resistant to salt spray and soil salinity from salting roads during wintertime storms (Appleton et al., 2009; Miyamoto, Martinez, Padilla, Portillo, & Ornelas, 2004; Wyman, 1965; Table 3).

Just as with any component of infrastructure, negative perspectives must be considered along with the positive. In order to maximise the benefits and minimise the negative impacts, the urban forester must consider the site that is being planted along with the benefits and trade-offs associated with a given planting option. The positive effects of summer time shading and year-round rainwater interception come with the possible negative effect of winter shading for evergreen trees. 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 relative to gaining the most benefit.

In the northern hemisphere, the sun strikes objects on the southern exposure, casting a shadow to the north of east and west (Figure 4; 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

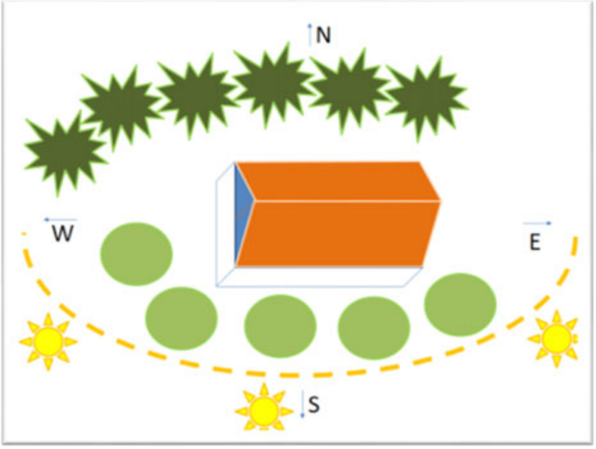


Figure 2. Aerial illustration of a possible planting design that optimises thermal protection with evergreen conifers on the northern and north-western exposures of a building, and optimises summer shading and winter solar radiation benefits with deciduous broadleaf species on the south-eastern, southern and south-western exposures.

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 or parking lot, there will be little conflict. However, if the shadow falls on a building, a conifer may not be suitable for that location due to the winter shading.

By planting conifers on the north side of a street running east-west, and deciduous broadleaf trees on the south side, the urban forester can achieve maximum benefits. This is because summer shading on the street when the deciduous trees are in leaf allows the maximum amount of solar exposure during the wintertime, and gains the added benefits associated with conifers including diversity and year-round canopy-dependent ecosystem services (Figure 5).

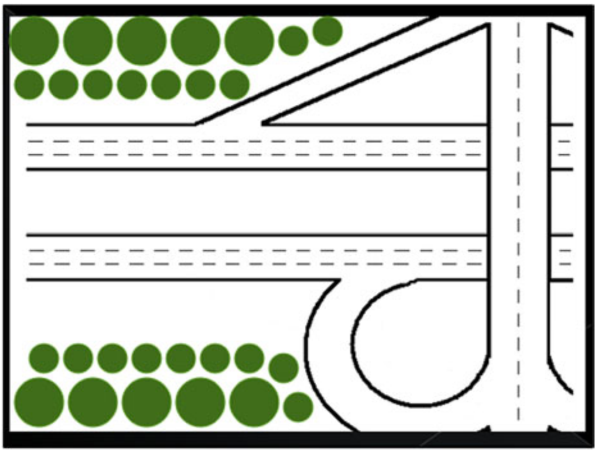


Figure 3. Aerial view of an example evergreen buffer planting around a typical freeway in the United States.

Table 3. List of conifers sorted by author and type (tree or shrub) that tolerate salt spray and saline soils.

Wyman (1965)	Miyamoto et al. (2004)	Appleton et al. (2009)
Trees	**Trees**	**Trees**
Cryptomeria japonica	*Pinus halepensis*	*Cryptomeria japonica*
Cupressus macrocarpa	*Pinus strobes*	*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*	
Picea pungens glauca	*Pinus thunbergii*	**Shrubs**
Pinus halepensis	*Juniperus chinensis*	*Chamaecyparis pisifera*
Pinus nigra	*Juniperus scopulorum*	*Juniperus chinensis*
Pinus pinaster	*Juniperus deppeana pachyphlaea*	*Juniperus communis*
Pinus radiate		*Juniperus conferta*
Pinus rigida		*Juniperus horizontalis*
Pinus sylvestris		*Pinus mugo*
Pinus thunbergii		*Taxus baccata*
Thuja occidentalis		
Thuja orientalis		

Notes: 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 demonstrates findings and recommendations that others have found.

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 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 the opposite effect (Figure 6). In these situations, the height of the tree and the distance away from the road play important roles relative to shading. If a short tree is planted further away, it will allow more sunlight for a longer period during the day. Conversely, tall trees planted close to the

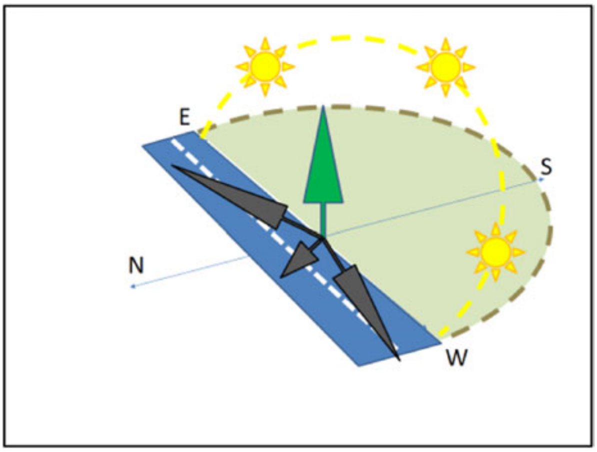


Figure 4. Shade diagram of an evergreen, coniferous tree planted in the northern hemisphere on the south side of a road oriented in an east-west direction. The shadow covers a large portion of the road surface.

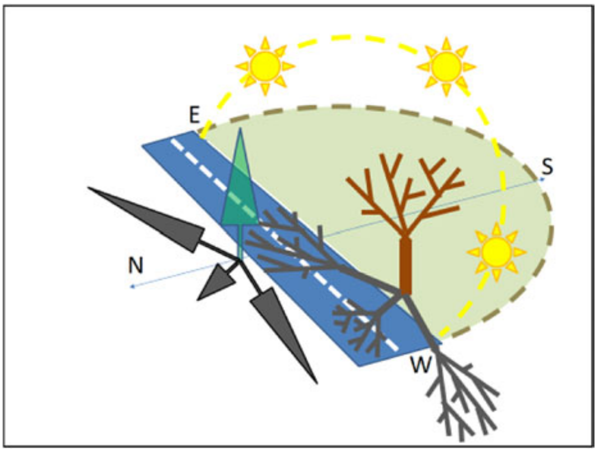


Figure 5. A winter shade diagram of an evergreen, coniferous tree planted on the north side of a street and a deciduous, broadleaf tree planted on the south side of a street.

road will create a narrower gap for the sun to shine through, lowering the amount of time sunlight can reach the road surface (Figure 7). By considering the mature height of a tree as well as the width of the road and the distance between the plantings, urban foresters can make educated design choices on what species will be suitable to plant based on the desired amount of solar exposure.

In areas of a city with buildings taller than the trees along the streets, such as apartment complexes or commercial buildings, the shading effect caused by the buildings eclipses the effect of the trees. Depending on how wide the trees are, their shadow cast over the road will be minimal. In these situations, the winter 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 its associated benefits, without concern relative to shading (Figure 8).

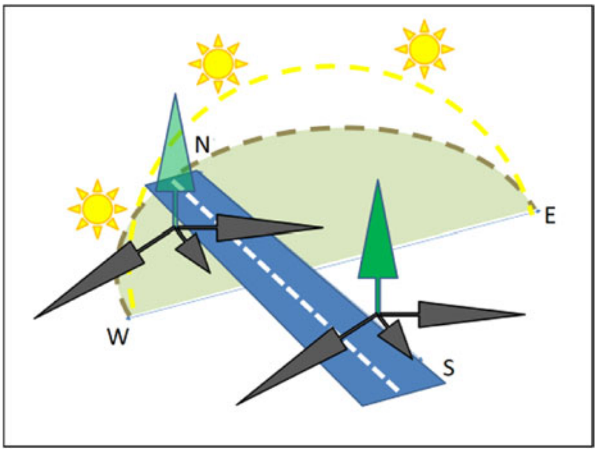


Figure 6. Shade diagram of evergreen, coniferous trees planted along the east and west sides of a north-south oriented street in the northern hemisphere.

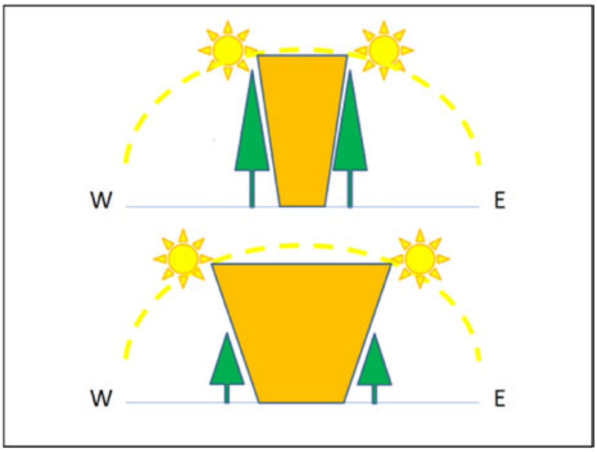


Figure 7. Shown here is a diagram showing how the height of trees and the distance between them affects how long sunlight can reach a surface between them. The taller trees planted closer together cast shadows over the road for most of the morning and evening. The shorter tree planted further apart cast shadows over the road for less of the day, allowing for more solar exposure over a day.

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

In parks and greenway plantings, there are fewer issues regarding shading and infrastructure conflicts, as well as larger above and below ground space for growth. Thus, the urban forester is better able to take advantage of a larger planting selection. At this

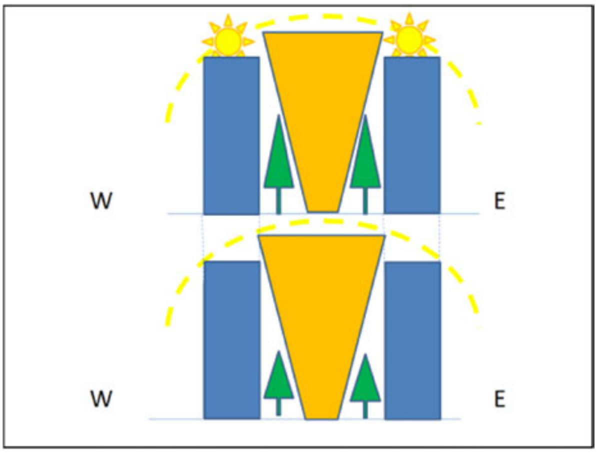


Figure 8. The taller buildings next to the trees cast shadows over the road. This shading effect would happen regardless if the trees were deciduous or evergreen.

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 LAI throughout the year, which 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), and increasing diversity at different hierarchical levels (Noss, 1990).

This landscape planning technique also applies to parking lot plantings where rainwater interception is important to consider as a design aspect due to the amount of impervious cover present. Though certain types of conifers may be ill suited to this location as they do not spread out enough and capture rainwater over the top of cars, where suitable planting locations would be available, conifers would be well suited to help capture rainwater year-round, where they would help to lower the amount of runoff from the parking lot surface.

In the various aforementioned scenarios, it is prudent for the landscape designer to use trees and planting layouts that will produce the greatest benefit throughout the whole year. This often requires specific design choices and the consideration of all plant functional types available, taking care to understand the associated temporal and intrinsic benefit values.

While evergreen conifers may not be exclusively applicable, the accepted practice of "right tree, right place" should encourage their use more frequently by municipal planners, foresters and commercial horticulturists. Should one wish to create an efficient, dynamic urban forest, then the significant gap in urban forestry literature on conifers and their interactions in the urban landscape is worth addressing.

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