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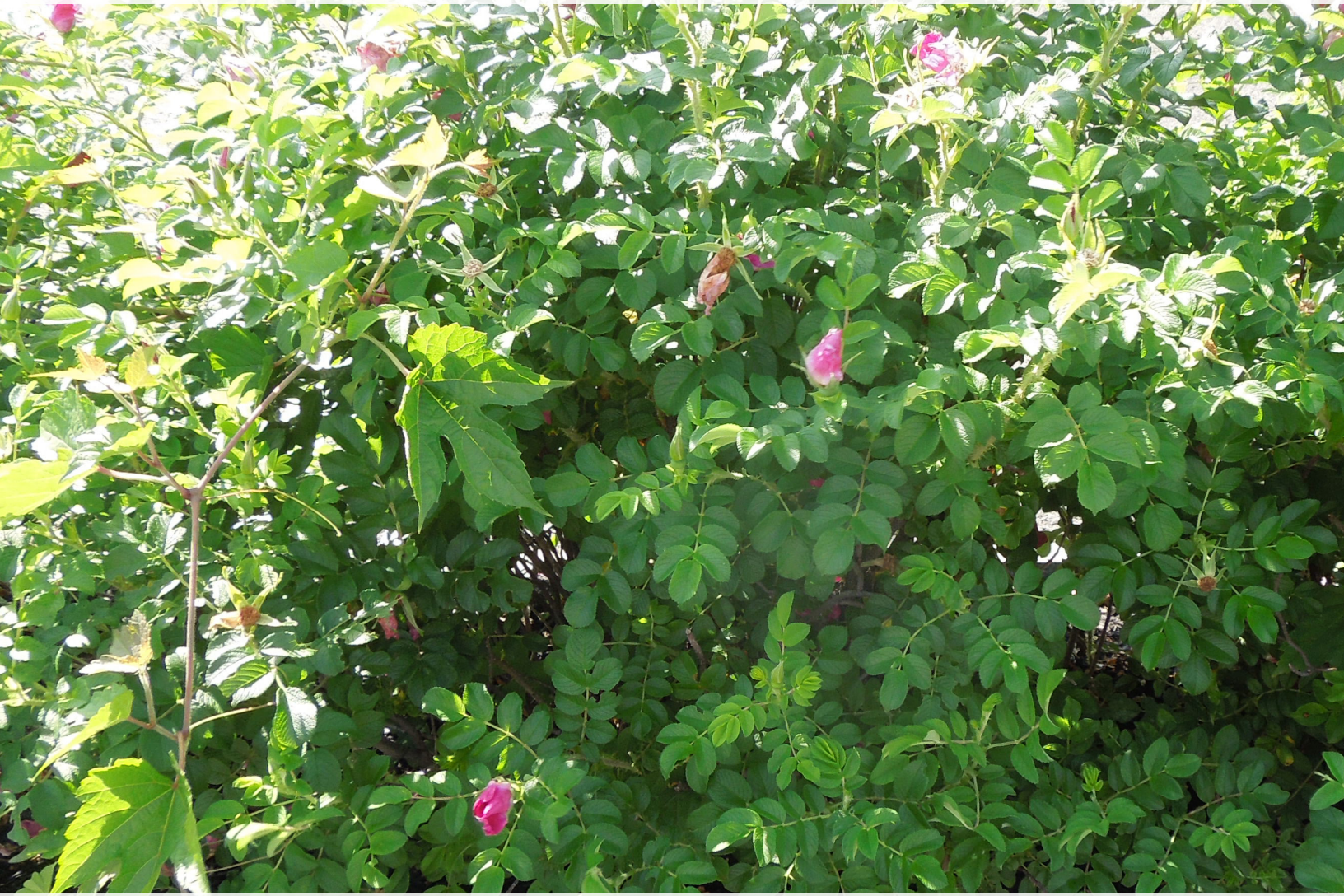
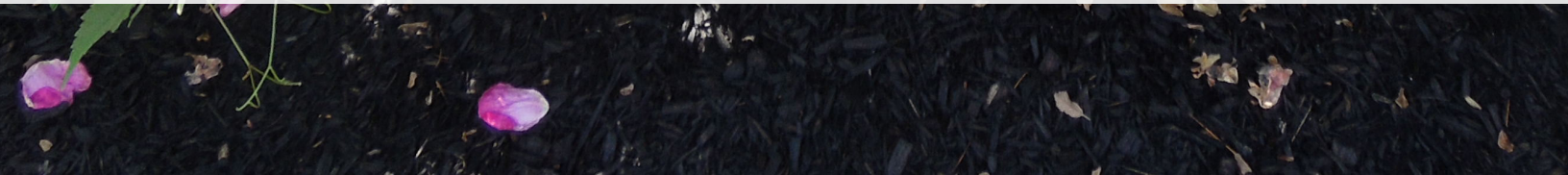


Comparing the Performance of Shrubs and Trees in Parking Lot Plantings: Implications for Design

Jennifer Ryan[a*] and JeanMarie Hartman[b]



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Front cover photo courtesy of Jennifer Ryan.

Comparing the Performance of Shrubs and Trees in Parking Lot Plantings: Implications for Design

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Abstract

Greening parking lots has many benefits such as reducing stormwater runoff; increasing evapotranspiration, infiltration, and interception; lowering urban heat island effects; and making a harsh environment more habitable. Historically, trees represented most parking lot greenery. Unfortunately, much of the intended cover by trees is not realized because of inadequate soil volume, low quality soil, drought conditions, and parking lot management practices. This project compares tree versus shrub performance in parking lots and parks. Our primary question is: Would shrubs sometimes provide faster and more reliable ecosystem services than trees in parking lots?

The transpiration rates of individual leaves of trees and shrubs were measured during the summer of 2016 in Middlesex County, NJ. The study sites included parking lots and nearby parkland. The species investigated include common species of trees and shrubs utilized in this area. Specifically, the study examined three tree species (*Acer rubrum* [Red Maple], *Gleditsia triacanthos var. inermis* [Thorness Honeylocust], and *Zelkova serrata* [Japanese Zelkova]) and four shrub species (*Euonymous alatus* 'Compacta' [Winged Euonymous], *Ilex glabra* [Inkberry Holly], *Spiraea japonica* 'Gold Mound' [Gold Mound Spiraea], and *Rosa rugosa* [Saltspray Rose]). Transpiration rates were combined with canopy measurements to calculate rates of total tree transpiration per day. The results show surprising similarities between the amount of transpiration from parking lot trees and shrubs: When comparing whole canopy transpiration rates, similar transpiration rates could be achieved by dense planting of shrubs in existing tree pits or strips or individual trees in poorly designed tree pits or strips.

Introduction

Standard parking lot design often entails large expanses of asphalt punctuated by trees in pits or strips that cap ends of parking bays or guide cars through the lot. Frequently, the number and spacing of trees follow local building ordinances that specify trees per number of parking spaces or amount of shading within a specified time (Swiecki and Bernhardt 2001). Shrubs are generally discussed as a way to screen the view of cars from the street (U.S. Environmental Protection Agency 2008).

Despite optimistic predictions of parking lots fully shaded by trees, many trees do not reach full canopy in the harsh conditions of the built environment (Roman 2014). The inhospitable heat and wind constricted growing space of the standard tree pit, compacted soil, and reduced ability to access water and transpire often restrict the growth of trees and lead to early decline and death (Coder 2000).

The purposes of this study were to (1) determine the ecological services of stormwater capture and cooling and shading provided by trees in parking lots and (2) compare this result to that of parking lot shrubs, which are less costly and more easily replaced.

One way of understanding how trees and shrubs provide ecological services is to assess their transpiration. The amount of water available to a plant is relative to the amount of water transpired. More paving around a plant increases temperatures and the amount of solar radiation and lowers air humidity (Konarska et al. 2015). Higher amounts of paved root area correlate with lowered ability to conduct water, photosynthesize, and access nutrients (Osone et al. 2014).

This study aimed to quantify and compare the transpiration of common parking lot trees and shrubs with limited water access resulting from impermeable surfaces and constricted root zones with those of corresponding plants in more park-like settings and to understand implications of tree/shrub pit design in harsh environments on plant growth and stormwater uptake. This article is based on a thesis completed during graduate work by the first author (Ryan 2017).

Methods

Transpiration in trees and shrubs was compared between park-like settings and parking lots in Middlesex County, New Jersey, during the summer of 2016. Plants selected were common plantings in local parking lots and included three tree species (*Acer rubrum* [Red Maple], *Gleditsia triacanthos var. inermis* [Thorness Honeylocust], and *Zelkova serrata* [Japanese Zelkova]) and four shrub species (*Euonymous alatus* 'Compacta' [Winged Euonymous], *Ilex glabra* [Inkberry Holly], *Spiraea japonica* 'Gold Mound' [Gold Mound Spiraea], and *Rosa rugosa* [Saltspray Rose]). The first three shrub species are locally common, whereas *Rosa rugosa* is a rather novel plant in parking lots in this region but is a highly tolerant plant and, therefore, included in this study. All selected species are considered tolerant plants adaptable to a range of conditions and not likely to decline by disease or cultural conditions.

Parking lot plants grew in strips or pits. Strips had root restriction on two sides, while pits had restriction on four sides, either by pavement edge or the root system of another plant. Park-like conditions had no restriction to roots or minimal restriction on one side (e.g., planted near a pond or next to a sidewalk but not under the dripline) (Figure 1).

Nine replicates of each tree species were identified, and all plantings were at least ten years old, located in full sun growing conditions, and had no additional irrigation other than rainwater. Of these nine, three were growing in an unrestricted park-like setting, three in a parking lot strip, and three in a parking lot pit. Shrubs were of indeterminate age but were located in planting beds that were at least ten years old, in full sun growing conditions, and had no additional irrigation other than rainwater. For each shrub species, six replicates were chosen—three in a park-like setting and three in a parking lot strip. Shrubs had a similar size and had not been excessively shaped or pruned at the beginning of the growing season.

Trees in parking lots tended to be much smaller than trees in park-like settings. To ensure that transpiration measurements were from the healthiest trees in all settings, plants were assessed with the Urban Tree Health Index, a rating system for evaluating observations of five parameters of tree health (Bond 2012). Likert scale scores were tallied and used to assign a final health score of Fair, Poor, or Critical. Those with no deviations were labelled Healthy.

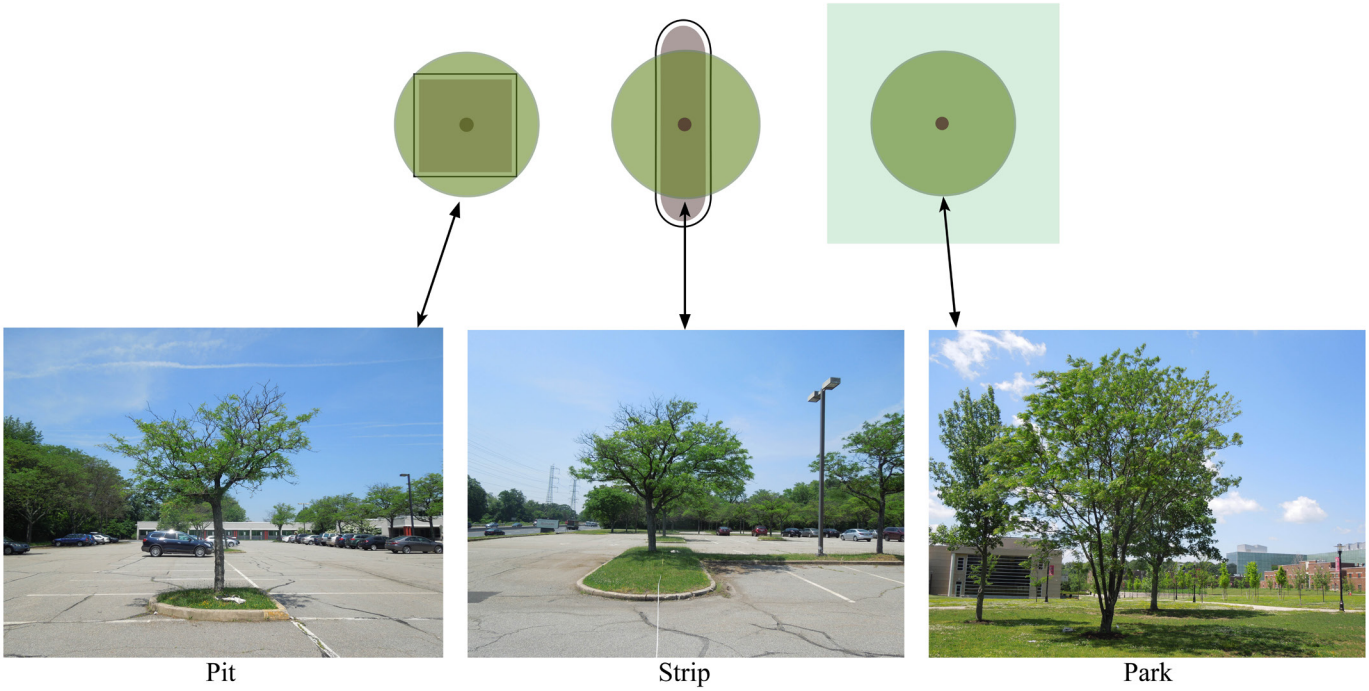

Figure 1. Plants grew in either a pit, strip, or park setting, depending on the amount of root restriction.

Transpiration was measured every one to two weeks using a LI-COR 6400XT Portable Photosynthesis System (LI-6400) (LI-COR Biosciences 2012), which analyzes gas exchange of individual plant leaves and calculates transpiration from carbon dioxide uptake and condensation release, in addition to other measurements, including leaf temperature. Three single leaves exposed to full to part sun were measured from each specimen during the prime growing season of June to August. Shrub leaves were sampled while still attached to the plant, and tree leaves were either sampled on the tree or excised, retrimmed under water, and sampled while in a container of water. Measurements were taken at photosynthetically active radiation of 1,500 μmol and temperature 26 to 30 degrees C (78–86°F).

Most of the tree and shrub leaves were large enough to fill the 6 cm^2 area of the LI-6400 chamber. Those that were smaller than the chamber (i.e., *Gleditsia triacanthos* and *Ilex glabra*) needed adjustment to the leaf area. These leaves were photographed under a replica gasket of the same size and then pixels within the total area of the gasket and the leaf were counted using Photoshop. The ratio of gasket area to leaf area was then used to calculate the actual photosynthesis and condensation.

Pan evapotranspiration rate, average temperature, and precipitation for the growing period from June through August was obtained from a local weather station (Office of the New Jersey State Climatologist at Rutgers 2016). Date of measurement was used as a proxy to show the water deficit that occurs as increased summer heat dries the soil. Within each species, groups were compared by planting type—pit, strip, or park—and date of measurement using a general linear model calculated with the 2017 version of Minitab® statistical software. The threshold for significant difference was below $p = 0.05$.

To understand the transpiration rate of the entire tree or shrub, the individual leaf transpiration measurements were multiplied by the plant's leaf surface area (LSA). Several plant measurements were taken to calculate LSA: The height of the tree was measured using a Suunto clinometer to the nearest 0.31 meter (1 foot [ft]) while standing at a distance of 10 to 20 meters (32.8 to 65.6 feet), depending on the available distance from the tree. Average diameter of the trunk of the tree was measured at 1.37 meters (4.5 ft) above the ground using a diameter tape. Canopy radius was measured using a meter tape, from trunk center to branch tip, at the four cardinal directions. Diameter was calculated by averaging the sums of the north-south and east-west measurements.

Total water use was extrapolated from these measurements using Lindsey and Bassuk's (1992b) formula:

$$\text{Daily tree water use} = \text{LSA} \times T_s$$

where:

LSA = Leaf Surface Area

T_s = Total transpiration

LSA was measured using Lindsey and Bassuk's (1992a) photographic analysis technique. A photograph of each tree was scaled from a known measurement in Autodesk AutoCAD® software. Next, Adobe Photoshop CC was used to derive a ratio of foliage pixels to standard frame area to calculate LSA.

Shrub LSA measurements were calculated using the derived canopy formula (Thorne et al. 2002).

$$CV = {}^{2}/_{3}\pi H({}^{A}/_{2} \times {}^{B}/_{2})$$

where:

H = height

A and B= diameter at 50% height at right angles.

Height was measured from the ground to the apex of the shrub using a meter tape. Diameter was taken at cardinal points from the center of the shrub using a pole through the plant at 50% height to the nearest centimeter.

Once each plant's LSA was calculated, the individual leaf transpiration measurements were averaged and converted to kg m^{-2} s^{-1}, then multiplied by the LSA to arrive at the total plant's transpiration in liters day^{-1} (Pearcy, Schulze, and Zimmermann 1989). This method suffers from a lack of precision by not taking the variations in wind speeds, leaf temperatures, vapor pressures, and radiation levels in the canopy into account; rather, it is meant to roughly illustrate the amount of transpiration per plant as well as highlight the impact of decreased LSA on a tree's ability to transpire (Pearcy, Schulze, and Zimmermann 1989).

Planting treatments were measured and assigned to a type based on root constriction. When trees shared a planting pit, the total pit area was divided by the number of trees in the pit to determine planting zone. This method of pit selection, used only for *Acer rubrum*, may have reduced the divergence

in transpiration measurements in parking lot trees because trees do share root space and resources in smaller growing locations. (Coder 1996)

Results

Parking lots ranged in size from 0.2 ha (0.5 acres) to a 10 ha (27 acre) series of lots. Planting pits ranged from 3.24 m^2 (35 square feet [ft^2]) to 20 m^2 (215 ft^2) in area, while the strips ranged from 57 (613 ft^2) to 225 m^2 (2,421 ft^2) (Table 1). Trees ranged in size, with park-like trees generally bigger and healthier than trees in parking lots (Table 2, Figure 2, Figure 3). Shrubs in park-like settings tended to be of equal size and health compared to those in parking lots (Table 3, Figure 4).

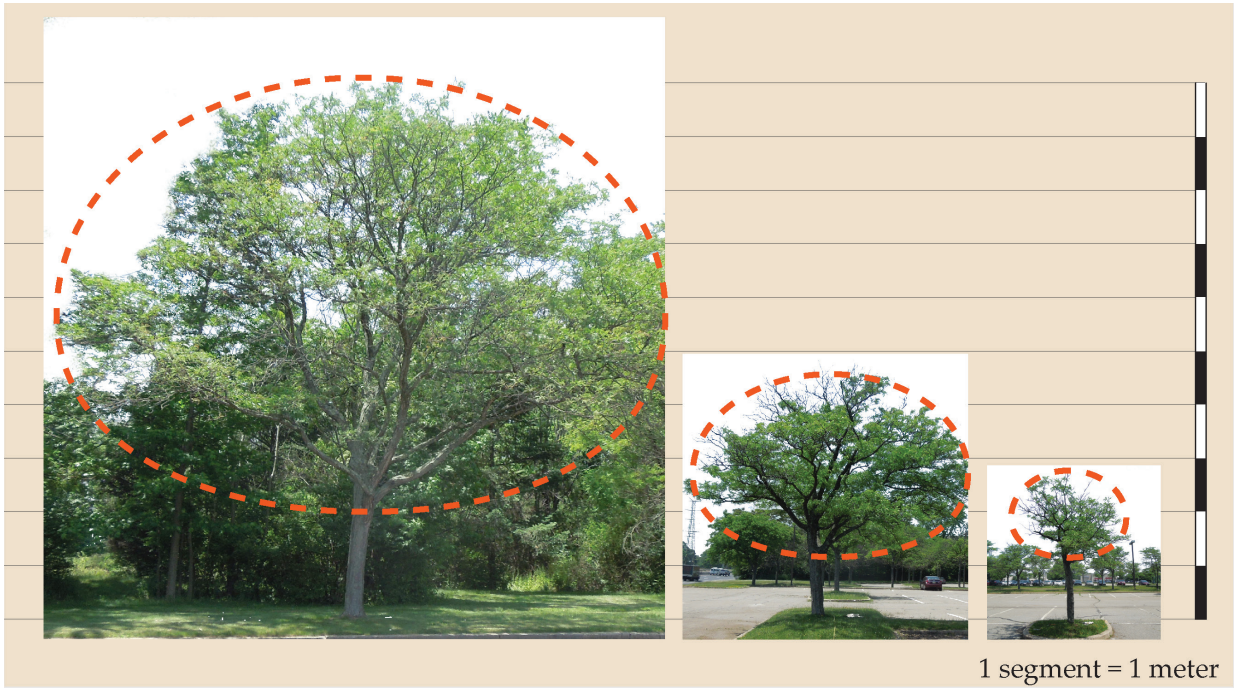

Figure 2. Trees from pits and strips in parking lots were generally much smaller and in poorer health than those in park-like settings. In this example, Gleditsia triacanthos *in the same location and the same age grew much larger with unrestricted root grown on the left compared to same age trees in strips, center, and pits, right.*

Figure 3. Though the trees in pits and strips were smaller than those in park-like settings, the researcher chose the healthiest of the trees of the same age and location in the parking lots. Shown here, Zelkovas *on the right and left were selected for the study, while the tree in the center was obviously unhealthy and not selected for the study. The unhealthy tree ultimately died late in the summer.*

Figure 4. Shrubs from park-like settings and parking lots were of similar size and health regardless of age. This image shows Ilex glabra *from a parking lot on the left and at Rutgers Gardens on the right.*

Table 1. Type of plant sampled, number of replicates, area of growing space, and number of measurements.

Species	Total Specimens/ Species	Range of Bed Area in m^2			Number of Measurement Days/Total Samples
		Pit	Strip	Park	
Trees:		3	3	3	
Acer rubrum	9	25–28.75	57–81	N/A	7/189
Gleditsia triacanthos	9	5.4	16–53.3	N/A	6/162
Zelkova serrata	9	3.25–20	76.4–225	N/A	7/189
Shrubs		3		3	
Euonymous alatus 'Compactus'	6	2.25		N/A	5/73
Ilex glabra	6	1.21		N/A	6/108
Rosa rugosa	6	1.35–1.5		N/A	6/108
Spirea japonica 'Gold Mound'	6	1.21		N/A	7/126

Table 2. Trees and range of measurements for trunk diameter, canopy diameter, height, health and sample number.

Tree and Number of Specimens	Bed	Diameter of Trunk (cm)	Diameter of Crown (m^2)	Height (m)	Health Index Score
Acer rubrum					
3	Park	5.5–23.1	2.0–6.0	4.8–15.0	Healthy/Fair
3	Strip	9.0–10.2	2.8–4.0	6.0–9.0	Poor/Critical
3	Pit	5.2–8.2	2.0–2.5	3.5–8.0	Fair/Poor
Gleditisia triacanthos					
3	Park	12.3–17.0	4.0–7.0	8.23–14.0	Healthy/Fair/Poor
3	Strip	10.6–12.5	3.2–5.1	3.8–6.8	Poor/Critical
3	Pit	8.2–11.0	1.9–3.5	2.5–4.8	Poor/Critical
Zelkova serrata					
3	Park	13.8–22.0	4.3–7.8	10.0–12.00	Healthy/Fair
3	Strip	10.0–16.2	3.7–5.3	7.5–12.0	Healthy/Fair/Poor
3	Pit	8.6–10.4	1.0–3.0	4.0–7.5	Fair/Poor/Critical

Table 3. Shrubs and measurements for canopy diameter, height, type of treatment, and Health Index score.

Shrubs	Bed	Canopy Diameter (m^2)	Height (m)	Health
Euonymous alatus 'Compactus'				
3	lot	1.3–1.6	1.2	Healthy
3	park	1.7–2.0	1.6	Fair
Ilex glabra				
3	lot	1.8–3.0	1.4	Fair/Poor
3	park	0.1–6.1	1.8	Healthy/Fair
Rosa rugosa				
3	lot	0.1–1.6	1	Fair
3	park	0.4–1.0	1.8	Poor
Spirea japonica 'Gold Mound'				
3	lot	0.2	0.6	Healthy /Fair
3	Park	0.4–0.6	0.8	Healthy

All single leaves tested transpired during the study period. Leaf transpiration rates for each species of tree or shrub were compared between planting treatments and day of measurements, and comparisons were developed with a general linear model. Date of measurement was significant ($p = 0.000–0.001$) for all species, as the warmer summer temperatures gradually dry the soil with a corresponding decrease in the amount of transpiration. When comparing individual leaf measurements, planting treatment was significant for three out of four species of shrubs—*Euonymous alatus*, *Ilex glabra*, and *Rosa rugosa* ($p = 0.000–0.006$) but not for any tree species (Table 4). Because there were only two treatments for shrubs, no further confidence testing was needed.

Table 4. Range, mean, and median of transpiration rates and significance of planting treatment on transpiration rate.

Tree	Transpiration			Significance Comparing Treatments (p = 0.05)
	Range (mmol H_2O m^{-2} s^{-1})	Mean (mmol H_2O m^{-2} s^{-1})	Median (mmol H_2O m^{-2} s^{-1})	
Acer rubrum	0.12–4.73	1.43	1.28	p = 0.06
Gleditsia triacanothos	0.31–7.30	3.47	3.46	p = 0.09
Zelkova serrata	0.07– 4.64	1.50	1.22	p = 0.43
Euonymous alatus 'Compactus'	0.06– 3.13	1.06	0.97	p = 0.00
Ilex glabra	0.12–4.72	1.73	1.51	p = 0.00
Rosa rugosa	0.26–5.88	2.74	2.62	p = 0.01
Spiraea japonica	0.11–4.88	2.06	2.02	p = 0.33

Transpiration rates shifted abruptly from one observation to the next in several results. These shifts tended to occur after rain, on cloudy days, and due to differences in timing of measurements, placement of plants, or maintenance considerations. For example, measurements of *Rosa rugosa* were affected by combinations of these factors that may have skewed measurements: During measurement 5, on August 18th, at 8:30 to 8:45 in the morning in the parking lot, leaf temperature averaged 26°C (79°F), and transpiration ranged between 1.74 mmol H_2O m^{-2} s^{-1} to 5.88 mmol H_2O m^{-2} s^{-1}. Four hours later in the park, leaf temperature averaged 30°C (86°F), and transpiration ranged from 0.54 mmol H_2O m^{-2} s^{-1} to 2.24 mmol H2O m^{-2} s^{-1}, potentially indicating drought stress. In the park-like setting, weedy vines began to grow over the plants as the season progressed, while in the parking lot, the shrubs were pruned severely in the latter half of the summer, beginning with the measurements on August 18. Additionally, although not directly irrigated in the parking lot, some of the measured shrubs were near an irrigated planting bed that splashed water onto the ground. Water potentially seeped into the ground through a crack between the asphalt and concrete curb and provided an additional water source for the plants in parking lots. The effect of leaf temperature and time of day likely influenced transpiration rates, but significant differences could have also happened from irrigation, pruning (which has been shown to increase transpiration per unit area [Kramer 1983]), or leaf shading from the vines.

Scaling to Canopy

Whole plant transpiration rates have design implications when considering stormwater capture. When the measurements

of transpiration from individual leaves are combined to reflect the whole tree or shrub canopy, plants with less LSA, regardless of species, are limited in the total amount of water they can transpire (Tables 5 and 6, Figures 5 and 6). Trees with unrestricted roots generally had the largest LSA, and trees with partial constriction on average had larger LSA than pit trees. Three individual trees—two *Gleditisia* and one *Zelkova*—growing in pits actually had less surface area than shrubs; these were noticeably smaller than average trees. Shrubs tended to have similar canopy volumes in the two settings, except *Ilex*, which ranged from 1.0 to 6.1 m^2 (10.7 to 65.7 ft^2) in the park compared to parking lot *Ilex* shrubs which averaged 1.9 to 2.9 m^2 (20.5 to 31.2 ft^2). This may have been due to prior management; the parking lot shrubs were pruned in late summer, while those in the park were not.

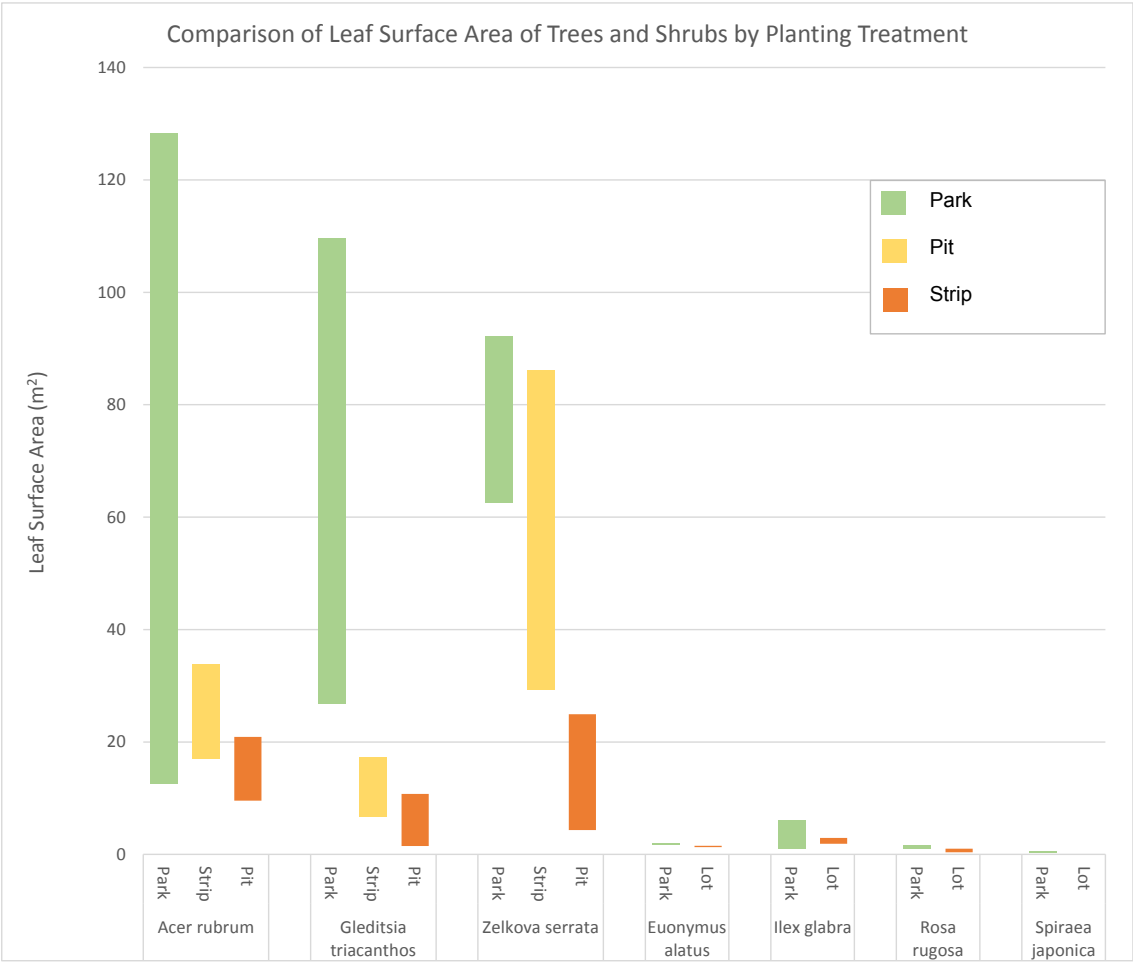

Figure 5. Comparison of leaf surface area of trees and shrubs by planting treatment.

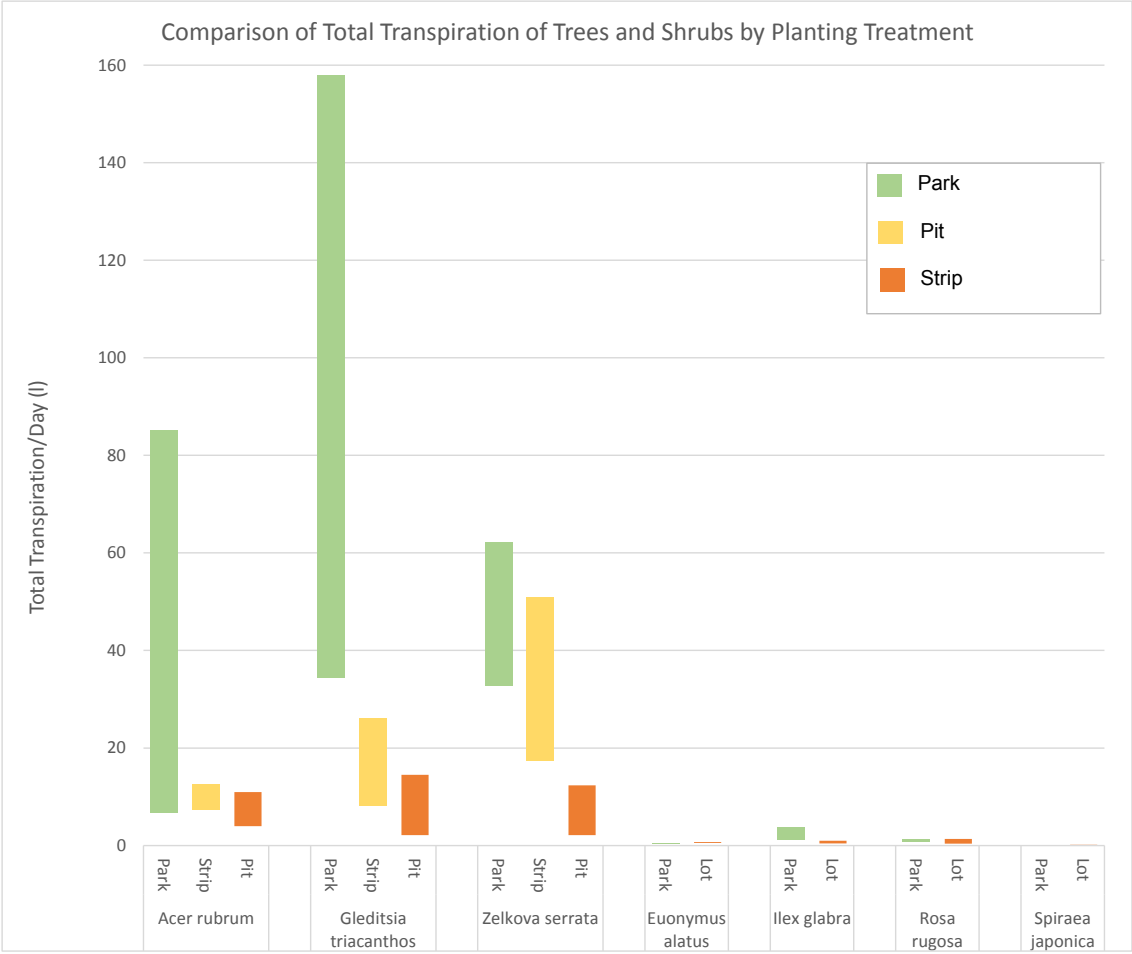

Figure 6. Comparison of total transpiration from trees and shrubs by planting treatment.

Table 5. Tree leaf surface area and estimated whole canopy transpiration rate.

Tree and Number of Specimens	Bed	Leaf Surface Area (m^2)	Transpiration/Day (Estimate) (l)
Acer rubrum			
3	Park	12.5–128.2	6.7–85.2
3	Strip	17.0–30.8	7.4–12.7
3	Pit	9.5–20.9	4.0–11.0
Gleditisia triacanthos			
3	Park	26.8–109.7	34.4–158.0
3	Strip	6.7–17.3	8.0–26.0
3	Pit	1.5–10.7	2.2–14.5
Zelkova serrata			
3	Park	62.5–92.2	32.8–62.3
3	Strip	29.2–86.0	17.3–50.8
3	Pit	4.3–26.9	2.1–12.3

Table 6. Shrub leaf surface area and estimated whole canopy transpiration rate.

Shrubs and Number of Specimens	Bed	Leaf Surface Area (m^2)	Transpiration/Day (Estimate) (l)
Euonymous alatus 'Compactus'			
3	lot	0.2	0.2
3	park	0.4-0.6	0.3
Ilex glabra			
3	lot	1.9-2.9	0.4-1.0
3	park	1.0-6.1	1.1-6.7
Rosa rugosa			
3	lot	0.4-0.9	0.4-1.4
3	park	0.9-1.6	0.9-1.4
Spirea japonica 'Gold Mound'			
3	lot	1.3-1.5	0.5-0.7
3	park	1.6-1.8	0.5

Although this scaling procedure did not consider transpiration variability in sun versus shade leaves, or wind or humidity differences within the canopy, a rough estimate of canopy transpiration was made for the purpose of illustrating the effect of larger canopy on water relations. These amounts roughly align with other reports of tree transpiration (Cermak et al. 2000; Halverson and Potts 1981; Pataki et al. 2011). A whole tree with a larger canopy size has more leaves, which results in higher rates of transpiration, larger growth, more ecosystem services, and better health and longevity per tree (McPherson, Nowak, and Rowntree 1994). *Gleditisa*, of which seven out of nine trees were of the same age and location, provides the most accurate comparison of variation in transpiration between larger and smaller trees. A tree growing at the edge of the parking lot with adequate space for root growth and access to more rainwater and better soil transpired 84.7 l d^{-1}. The parking lot trees in strips with some root growth and water restriction averaged 15.2 l d^{-1}. The parking lot trees in pits averaged 3.5 l d^{-1} (Figure 7). Shrubs transpired about a liter a day.

Discussion

This study found differences in amount of water transpired by shrub leaves when comparing plants growing in parks versus parking lots, but these differences had little effect on the health or growth rate. Two species of shrubs, *Ilex glabra* and *Euonymous alatus* 'Compacta', had higher leaf transpiration in park-like areas compared to parking lots. *Rosa rugosa* had higher transpiration in the parking lot setting, which was likely influenced by day and time of measurement, maintenance issues in the park, and nearby irrigation in the parking lot. *Spiraea* was not affected by planting treatment. While more study needs to be done on additional individual species, this research indicates that shrubs can tolerate smaller pit sizes in a parking lot.

A stronger correlation between shrub leaf transpiration and planting treatment, as compared to trees, could be a result of the better drought tolerance and adaptability by these shrub species. Evergreen leaves, such as *Ilex glabra*, could be better adapted to withstand highs and lows of temperatures, as well as drought and inundation (Schlesinger and Chabot 1977), while *Euonymous* and *Rosa* are both considered very tolerant

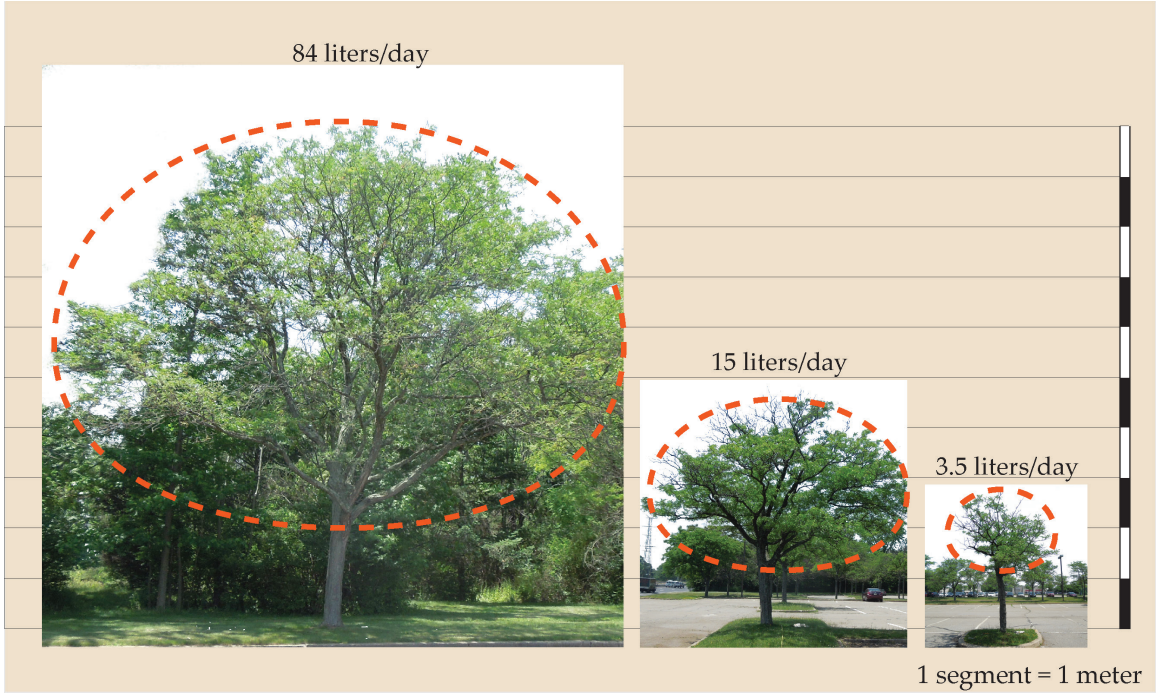

Figure 7. Images of same age and location Gleditisia triacanthos. *Larger trees transpire much more when roots are not restricted by pavement. Shrubs transpired about 1 liter per day.*

species (Dirr 2009). Shrubs provide ecological services in a parking lot beyond simply screening views of parked cars from the street. These benefits include stormwater capture, habitat for birds and other wildlife, and, as shrubs are often selected for their flowers or fruits, food for wildlife (Figure 8). Furthermore, they perform these services successfully and quickly while growing in relatively small parking lots pits.

The individual leaves of trees in parking lots, on the other hand, transpire similarly to leaves of trees in park-like settings, but, when considered as a whole, trees transpire less with higher amounts of root restriction. The results of this study support prior studies about trees in restricted growing spaces that find that trees in small pits and strips in paved environments grow to the size based on the volume of soil

Figure 8. Bee visiting the flower of Rosa rugosa *at the Costco parking lot, Edison, NJ. Photo by Jennifer Ryan.*

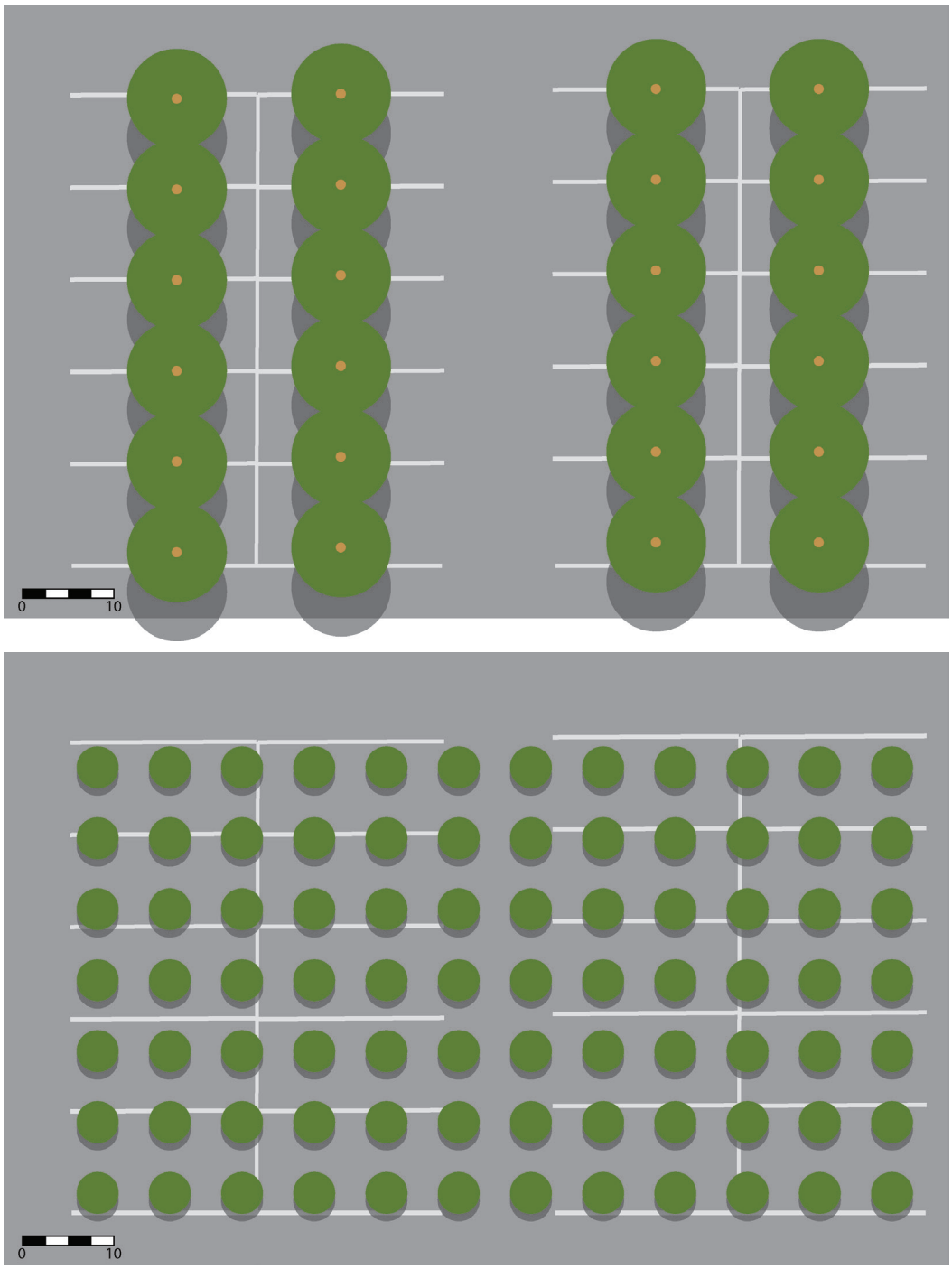

Figure 9. To match the transpiration rate of a mature tree, 24 small trees typical of parking lot pits or 84 shrubs would need to be planted.

in which they are growing and the amount of water they receive (Grabosky and Gilman 2004; Lindsey and Bassuk 1992b; Lupu and Draghia 2016). A tree may grow to fill the space given during times of ample soil moisture, but periods of drought, which tend to happen in the prime growing season in the Northeast and Midwestern United States, damages the xylem, which in turn limits water access to the full height of the tree (Breda et al. 2006). After several years of repeated drought, the upper reaches of the crown die and are subsequently pruned out. It follows that full canopy transpiration would be low in these conditions because the LSA would be lower.

The greater number of leaves and, subsequently, the greater LSA, found on mature trees that receive adequate rainwater and space to grow, is larger than that of trees with restricted water and root space due to restricted soil volume. This exponential increase in LSA greatly increases the ecological

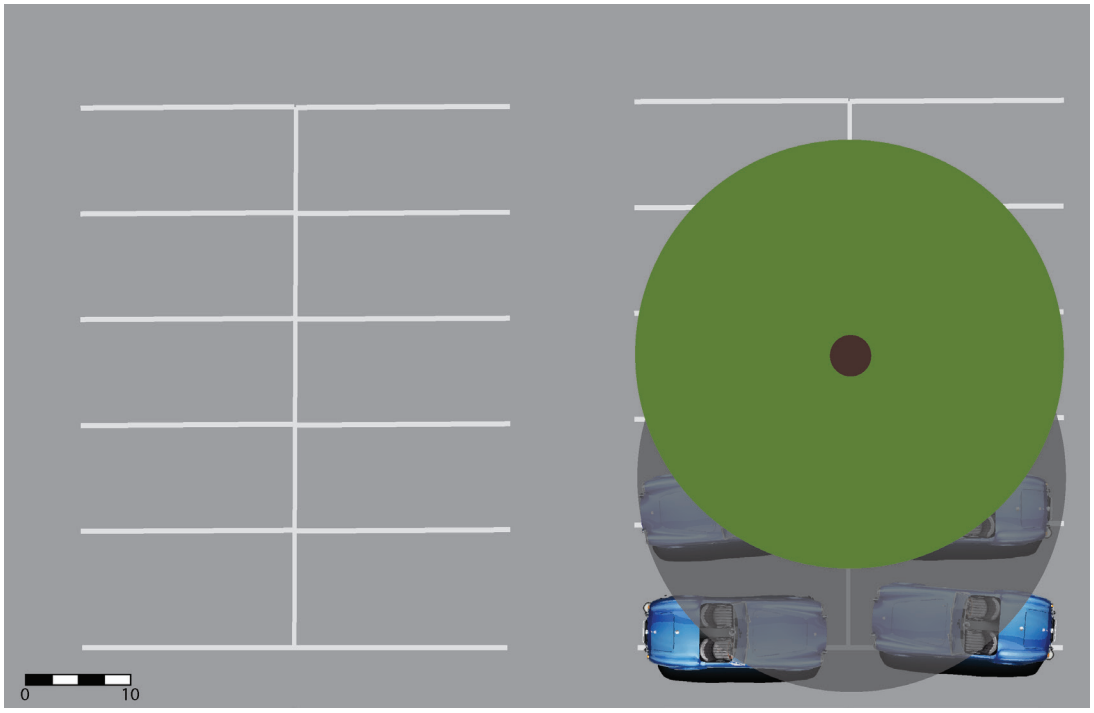

Figure 10. Larger trees provide more ecological services including stormwater capture, carbon sequestration, and cooling and shading in a smaller footprint.

services provided. More LSA will sequester more carbon, provide more cooling, and capture and transpire more water all in a relatively small on-ground footprint (Figures 9 and 10). Furthermore, trees in less restricted environments have better health and live longer, avoiding the costs of replacement (McPherson, Nowak, and Rowntree 1994).

This research supports that both types of tree planting will provide ecological services—a tree will transpire an amount relative to size—but designers and clients must be aware of these implications and costs of their pit design choices. Focusing on the quality of tree canopy rather than quantity of trees can provide more ecosystems services per square meter of tree pit. To produce larger canopies, trees need adequate soil space and water. Although irrigating trees in small tree pits is an option, the amount of water needed to irrigate a mature tree would be prohibitively expensive and not environmentally sustainable. One of the least expensive ways to provide more water is to allow rainwater to infiltrate into the soil in parking lots.

Conclusion

This study found that vegetation in parking lots provides the ecological service of reducing stormwater runoff. Individual leaves from trees in parking lots strips and pits transpire at a similar rate to leaves from trees in parks. However, trees growing in parking lot pits or strips with constricted root growth are much smaller (i.e., have smaller canopies and therefore fewer leaves) and less healthy than those growing in parkland with no restriction to root growth.

Shrubs in parking lots and parks had only modest differences in appearance of health, though they used water at different rates. In other words, an increase in use of shrubs in parking lots can provide ecosystem services such as evapotranspiration and pollinator and wildlife resources and habitat. Although shrubs will result in lower canopy cover compared to the potential canopy of healthy mature trees, they are cost effective in situations in which planting pits and strips are too small to support full tree growth and should be considered when re-planting or retrofitting existing parking lots.

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