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20 years later: Does reduced soil area change overall tree growth?

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ABSTRACT

Urban conditions have been thought to affect tree growth, but there is little conclusive evidence as to the severity of those influences or how various species respond differentially to urban stress. Reduced growth expectations are important to understand, because they affect design choices for the urban tree canopy, particularly as required by legislative mandate. Five tree species (*Acer rubrum*, *Prunus serrulata*, *Pyrus calleryana*, *Quercus pallustris* and *Zelkova serrata*) grown in parking lots ranging from 18 to 23 years old in central and northern New Jersey, USA were studied. Tree height, diameter at breast height (DBH), and canopy radius were measured, as was apparent plant available soil (nonpaved planting zone area). Tree DBH, commonly recorded for many municipal inventories, was found to be a useful predictor of canopy area. Data were normalized within site, to facilitate multiple site analysis. Across different parking lots, reductions in tree size were consistently associated with reduced apparent soil access. A previous study from Florida, USA was used for comparison of regional data, permitting conclusions on canopy reductions, relative to specification of design space for tree establishment.

Introduction

Environmentally sustainable development and legislation has increased as urbanization continues in the United States. Many urban design considerations for imperious (paved) surfaces are present as an important component in sustainable urban planning. Formulae exist for the minimum number of trees to plant, required for ordinances or credits for design goals (Sustainable Sites Initiative, 2009; US Green Building Council, 2009; Windhager et al., 2010). Such formulae tend to use percent canopy cover, trees per number of parking spaces, or numbers of trees per paved area (Harris and Dines, 1998; Kuser, 2000). Typically, there are a number of years associated with achieving these requirements (Arlington County Chesapeake Bay Preservation Ordinance, in press; McPherson, 2001). When predicting the canopy area coverage in a design plan, it is uncommon to take into account the diminishing returns on tree growth, due to the smaller biotic capacity of the planting site when small places are used in design, as compared with large lawn-type planting spaces (McPherson, 2001; Grabosky and Gilman, 2004; Celestian and Martin, 2005).

In urban areas, parking lots are also a dominant feature of the landscape (Davis et al., 2010). Parking lots usually provide minimal locations for tree canopy establishment in design, albeit limited by space concerns and maximum parking capacity issues (Hill et al., 2010). In designed ecosystems, such as heavily paved urban cores, where environmental stresses are often exaggerated, more data is needed on growth expectations and service life of trees. To date, lacking hard data on the environments in question, designers have relied on published botanical observations, obtained under garden conditions, or have used similar estimates from indexed texts (Gerhold et al., 1993; Gilman, 1997; Bassuk, 1998; Porter, 2000; Dirr, 2009) on landscape plant materials, nursery trade sales literature, or commercially available software based on horticultural growth expectations.

It is unreasonable to assume that trees planted in parking lots will reach the same size dimensions as forest trees, or trees in park settings, or even published expectations. The design vision or planting plan may meet a proposed benchmark for expected canopy coverage minima, but the reality over time is infrequently in line with the design expectation. Few trees in paved environments reach their intended canopy dimensions prior to being replaced (Schwets and Brown, 2000). A reduction of size over time had been observed even when well-adapted species such as *Ulmus parvifolia* (Chinese elm) are planted as parking lot trees. In Gainesville, FL, the canopy size of *U. parvifolia* was restricted when the unpaved surrounding fell below 80 m^2 (Grabosky and Gilman, 2004).

This study explored the relationship between tree growth and available soil in NJ parking lots. The goals of this study were to determine (1) relationship between canopy area to DBH and (2) the reduction of growth expectations based on site restrictions as represented by apparent available soil in the planting zone of the

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Table 1
Site project age and species present for canopy analysis in central and northern New Jersey parking lots.

Town	Age (years)	*Acer rubrum*	*Prunus serrulata*	*Pyrus callaryana*	*Quercus palustris*	*Zelkova serrata*
Bridgewater	18	26	30	–	–	32
Princeton	19	–	49	70	67	–
Princeton	20	68	16	32	–	–
Freehold	22	–	62	12	–	42
Elizabeth	20	12	–	–	–	72
North Brunswick	23	–	41	37	21	–
North Brunswick	21	35	13	–	17	10
Woodbridge	22	–	30	52	9	13
Paramus	23	–	60	–	16	27
Paramus	19	18	–	67	–	17
Hackensack	20	–	12	40	31	–
Princeton	23	30	–	25	–	9
Piscataway	22	7	–	34	12	–
Edison	19	–	–	41	23	56
Edison	21	37	–	17	13	76
Total		**233**	**313**	**427**	**209**	**354**

parking lot. It was hypothesized that there would be a decrease in expected tree canopy volume as non-paved soil area decreases. This information was used to evaluate the expectation of growth in varied design details for planning parking lot tree planting spaces. We compared the results in two planting scenarios with those seen in Florida (Grabosky and Gilman, 2004), in an attempt to extract general patterns across different regions in the United States.

Materials and methods

New Jersey has been described as either entirely urban or completely occupied (Nowak and Walton, 2005) with approximately 2072 km^2 as impervious surfaces. New Jersey is dominated by suburban sprawl and infrastructure, with vast portions of the area as impervious parking lots for shopping malls. Fifteen parking lots throughout central and northern New Jersey (Table 1) were selected on three criteria: (1) age, (2) variety of plant spaces (described below), and (3) the presence of species common to other lots in the study. Eighteen to twenty-three year-old parking lots throughout the study area were selected. All study sites had trees in the paved zone, as well as trees on the exterior of the lot (non-limited soil areas). Tree species selected are commonly used by landscapers as acceptable parking lot trees as demonstrated by their frequent use in New Jersey: *Acer rubrum* (ACRU), *Prunus serrulata* (PRSE), *Pyrus calleryana* (PYCA), *Quercus pallustris* (QUPA), and *Zelkova serrata* (ZESE).

Tree planting sites were classified as: (a) planting strip (soil limited on 2 sides of the tree, average width of 4 m with varying lengths), (b) tree pit (soil limited on all sides of the tree, average surface area of 6 m^2), (c) or nonlimited (tree not restricted by amount of soil), as well as by (d) the measured open soil area of the planting site. All trees of the selected species were measured, with the exception of trees that were known to be replaced (and therefore not old enough to have reached the target age class, 18–23 years from planting). DBH was measured with a diameter tape at a height of 1.37 m above the ground and to the nearest 0.1 cm. Tree height was measured using a LaserAce 501 (MDL laser, Aberdeen, UK) to the nearest 0.31 m. Canopy radius was measured in four directions, North, South, East and West using a linear tape from the center of the trunk to the branch tip; the four measures were averaged to determine radius. Apparent available soil was measured as the non-paved soil surface area available to the tree in question. When trees shared a non-paved area, such as a linear planting strip, a calculation of average available soil per tree had to be determined. This was done by measuring the total available soil for the entire linear strip and dividing by the number of trees that the area was designed for the intended use of it. When trees fit into a non-limited soil category, the soil area was defined as twice the area within the drip line of the canopy from the trunk of the tree.

All trees within each species were combined to generate simple linear regression models relating DBH to canopy radius and DBH to height. Measured tree parameters were normalized within their respective sites for each species. The normalization allowed for multiple site analysis and comparisons. It also allowed a simple method if meaningful relationships were detected because data would represent a percent reduction from expected growth. An average DBH by species was developed within each parking lot opening category, as openings tend to repeat in dimensions within but not necessarily among parking lots. Simple linear regression models were used to test differences in tree DBH, based on apparent available soil, as determined by area of non-paved surface for all parking lots. Using the average canopy radius of all trees in non-limited soil as the upper limit (set at 100%) for any given lot, we calculated relative canopy radius for all the other trees in the lot to gauge the differences in tree canopy size among the various planting situations. Data were then examined over all sites to determine the mean canopy radius, relative to non-paved soil surface area. Note that the data points in regressions representing the non-paved soil area represent average values for the species in a given parking lot using that specific sized opening, and thus represent varied population counts and variances for each data point.

For comparison to the Florida study, two planting scenarios were established. Scenarios were: 20 m^2 for linear strips, as a 2 m wide by 10 m spacing of trees and 6 m^2, as a spacing of 2 m by 3 m. These represented average openings in linear strips and tree pits, respectively. Results were compared to establish benchmarking for canopy growth reduction. All analyses were performed in MiniTab 14.2 (2005). All data and residuals were checked for statistical analysis assumptions with an alpha level of 0.05, and did not violate assumptions.

Results

DBH was closely related to tree height and canopy width across all the site types and for all five species (Figs. 1a and b, 2a and b, 3a and b, 4a and b, 5a and b). Table 2 illustrates the reduction of canopy area calculated like a circle, based on observed radii. Inventory data on DBH for these species could potentially function as surrogates for canopy coverage, if the latter were not directly available, at least for younger trees within the size range observed. There was a positive correlation between space available and tree size in all species (Figs. 1c and d, 2c and d, 3c and d, 4c and d, 5c and d).

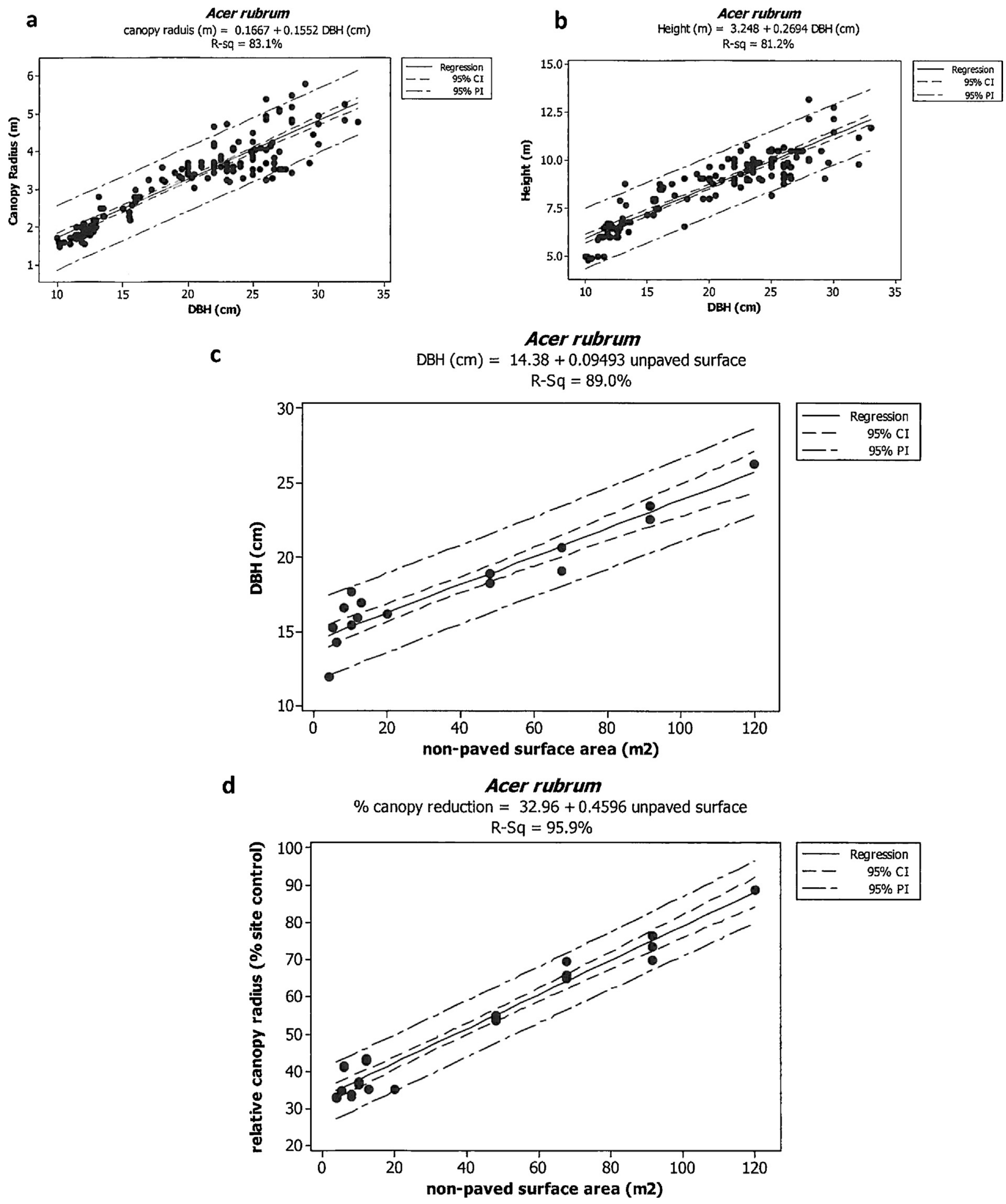

Fig. 1. Canopy size relationships of *Acer rubrum* in northern and central New Jersey parking lots. CI = Confidence interval for the regression line from the existing data set at $a = 0.05$; PI = prediction interval for the new observations at $a = 0.05$ for trees observed beyond the data set subject to the same criteria of treatment, species, age, region, and analysis. (a) Simple linear regression relationship canopy radius to DBH; (b) simple linear regression of tree height to DBH; (c) simple linear relationship of DBH to open soil space in design detail. DBH data represents mean DBH within pavement size opening groups, normalized to mean canopy DBH for on-site control groups to fit multiple sites into analysis; (d) simple linear regression of canopy radius to open soil space in design detail. Canopy radius data represents mean radius data points within pavement size opening groups, normalized to mean canopy radius for on-site control groups to fit multiple sites into analysis.

Acer rubrum

Maximum height observations in the range of 12 m and radius in the 5–6 m range are below (Hightshoe, 1988) or on the low end (Dirr, 2009) of published height and width expectations. Soil openings less than 50 m^2 displayed a reduction in trunk diameter (Fig. 1c), but the relationship between soil opening and canopy radius was even more definitive (Fig. 1d); a 50 m^2 opening was associated with a 45% reduction in canopy radius and a 70% reduction in canopy area (Table 2).

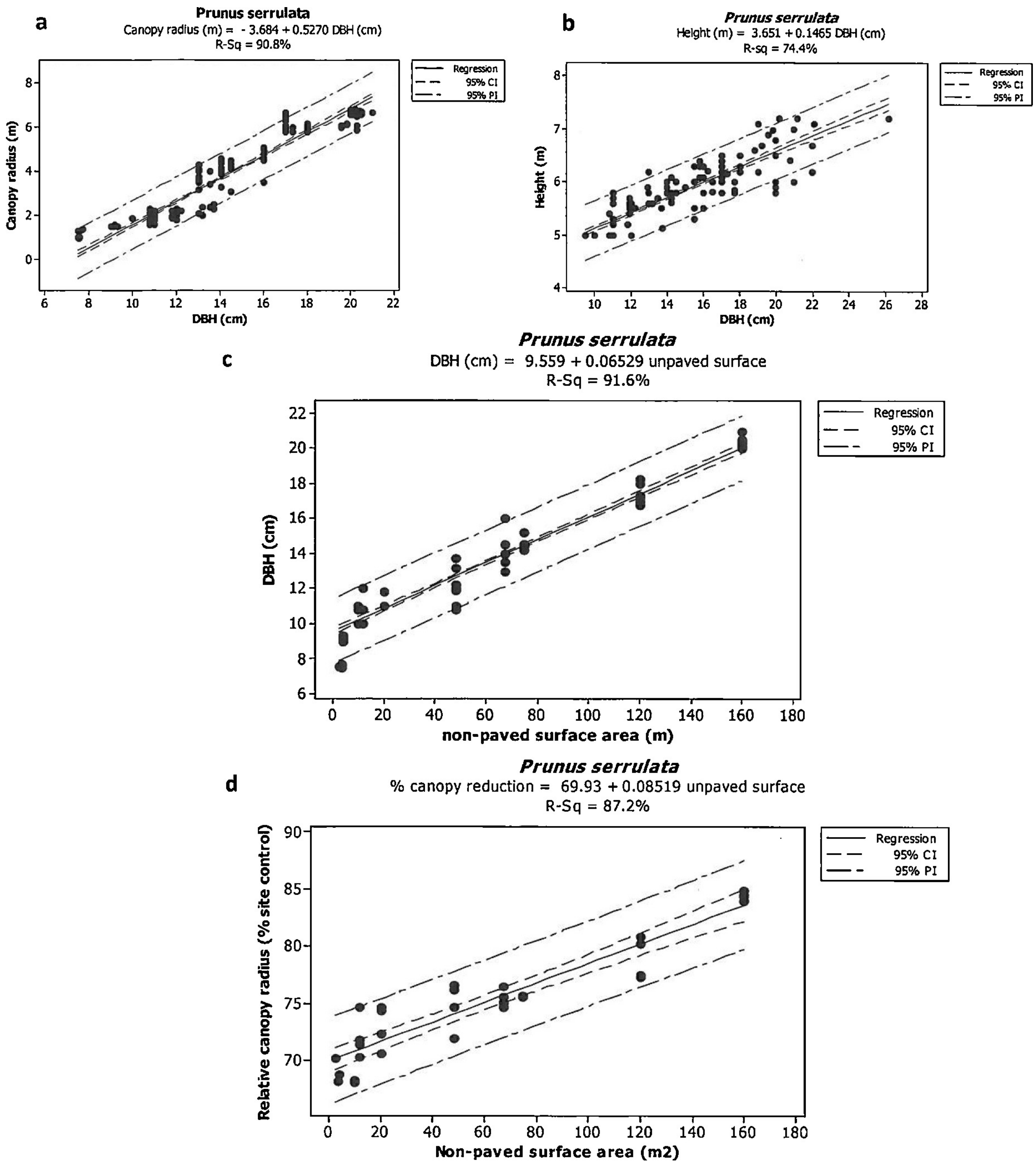

Fig. 2. Canopy size relationships of *Prunus serrulata* in northern and central New Jersey parking lots. CI = Confidence interval for the regression line from the existing data set at $a = 0.05$; PI = prediction interval for the new observations at $a = 0.05$ for trees observed beyond the data set subject to the same criteria of treatment, species, age, region, and analysis. (a) Simple linear regression relationship canopy radius to DBH; (b) simple linear regression of tree height to DBH; (c) simple linear relationship of DBH to open soil space in design detail. DBH data represents mean DBH within pavement size opening groups, normalized to mean canopy DBH for on-site control groups to fit multiple sites into analysis; (d) simple linear regression of canopy radius to open soil space in design detail. Canopy radius data represents mean radius data points within pavement size opening groups, normalized to mean canopy radius for on-site control groups to fit multiple sites into analysis.

Prunus serrulata

Maximum height observations of 7 m and radius in the 6 m range are below 15–22 m height and width expectations for this vase-shaped form (Dirr, 2009). Soil openings less than 60 m^2 displayed a 45% reduction in trunk diameter (Fig. 2c). The relationship between soil opening and canopy radius was less sensitive (Fig. 2d), and a 100 m^2 opening was associated with a 22% reduction in canopy radius, or 40% reduction in canopy area (Table 2).

Pyrus calleryana

Maximum height observations in the range of 12 m and radius of 8 m range are in line with published size expectations of 12.5 m

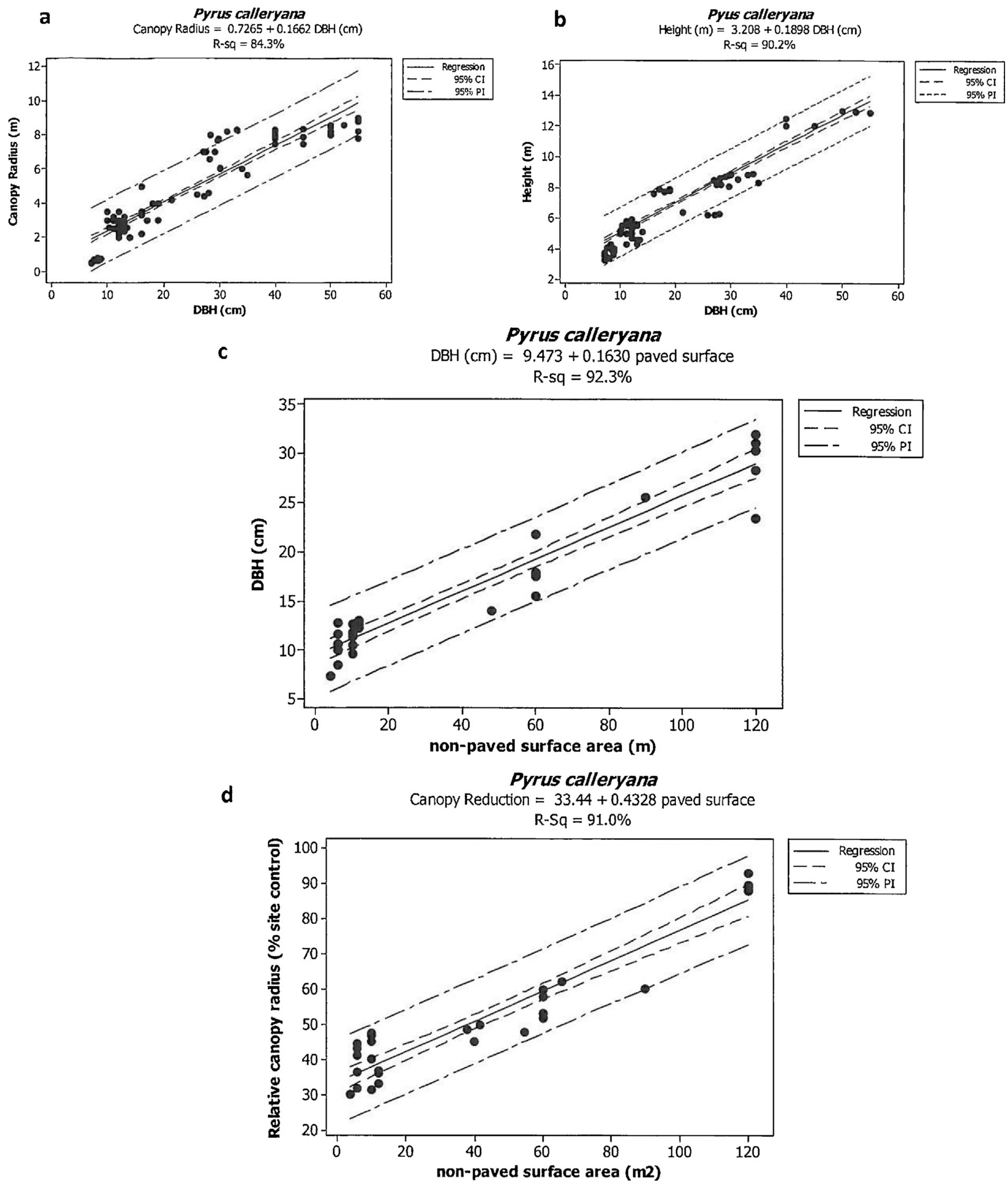

Fig. 3. Canopy size relationships of *Pyrus calleryana* in northern and central New Jersey parking lots. CI = Confidence interval for the regression line from the existing data set at $a = 0.05$; PI = prediction interval for the new observations at $a = 0.05$ for trees observed beyond the data set subject to the same criteria of treatment, species, age, region, and analysis. (a) Simple linear regression relationship canopy radius to DBH; (b) simple linear regression of tree height to DBH; (c) simple linear relationship of DBH to open soil space in design detail. DBH data represents mean DBH within pavement size opening groups, normalized to mean canopy DBH for on-site control groups to fit multiple sites into analysis; (d) simple linear regression of canopy radius to open soil space in design detail. Canopy radius data represents mean radius data points within pavement size opening groups, normalized to mean canopy radius for on-site control groups to fit multiple sites into analysis.

(Dirr, 2009). From the significant regression relationship between DBH and planting soil access (Fig. 3c) soil openings less than 60 m^2 displayed a reduction in trunk diameter. The similarly strong correlation relationship between soil opening and canopy radius showed a 60 m^2 opening associated with a 40% reduction in canopy radius (Fig. 3d), or a 64% reduction in canopy area (Table 2).

Quercus palustris

Maximum height observations of about 16 m (Hightshoe, 1988) and radius of 5–6 m are below published height and width expectations (Dirr, 2009). Despite the fact that trees in this species were the largest in size expectation behind *Z. serrata* (Dirr, 2009), soil

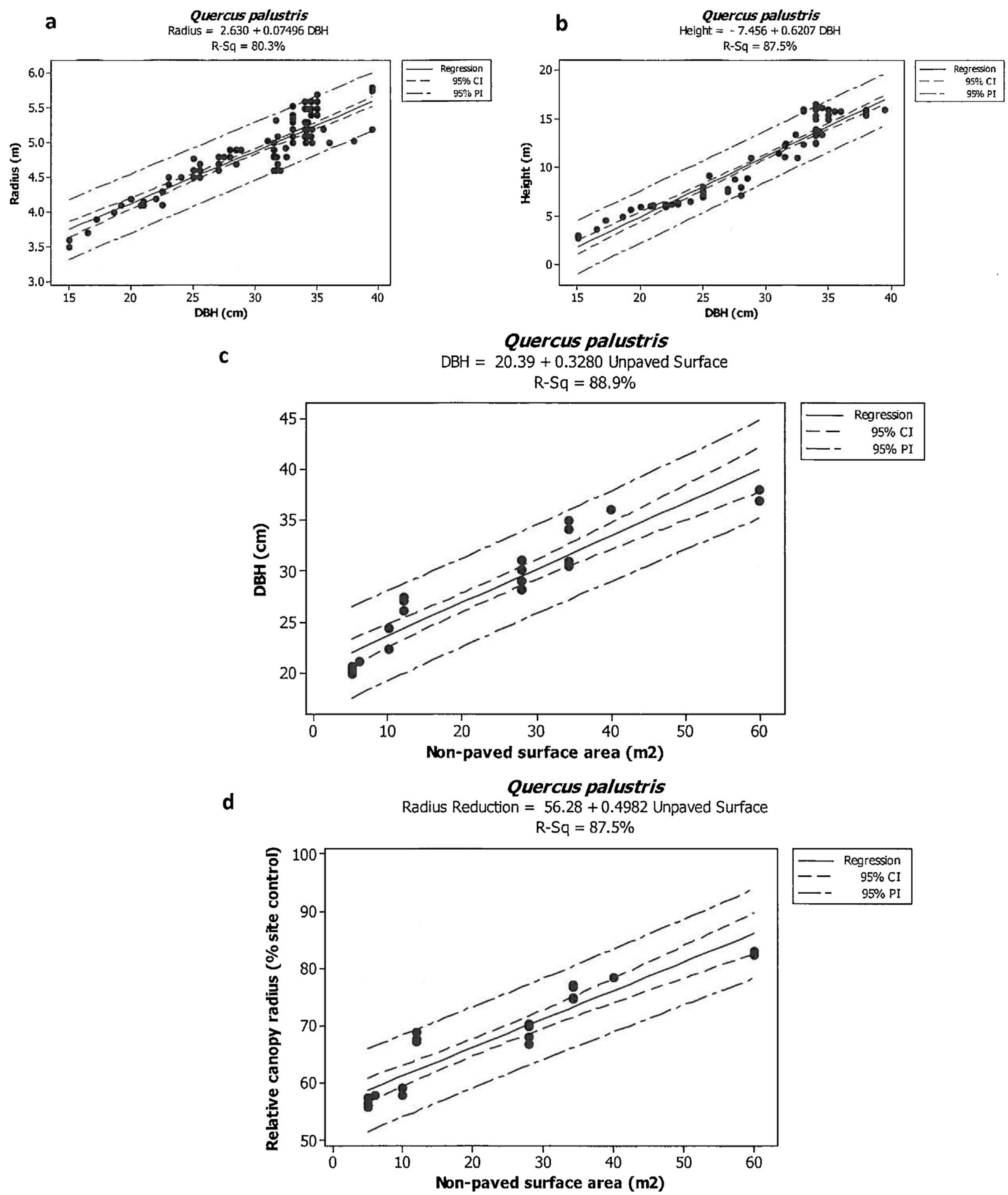

Fig. 4. Canopy size relationships of *Quercus palustris* in northern and central New Jersey parking lots. CI = Confidence interval for the regression line from the existing data set at $a = 0.05$; PI = prediction interval for the new observations at $a = 0.05$ for trees observed beyond the data set subject to the same criteria of treatment, species, age, region, and analysis. (a) Simple linear regression relationship canopy radius to DBH; (b) simple linear regression of tree height to DBH; (c) simple linear relationship of DBH to open soil space in design detail. DBH data represents mean DBH within pavement size opening groups, normalized to mean canopy DBH for on-site control groups to fit multiple sites into analysis; (d) simple linear regression of canopy radius to open soil space in design detail. Canopy radius data represents mean radius data points within pavement size opening groups, normalized to mean canopy radius for on-site control groups to fit multiple sites into analysis.

openings were limited to smaller areas in this species across the 9 parking lots in the study. There were robust relationships between soil opening and both DBH (Fig. 4c) and canopy radius (Fig. 4d). These showed canopy reductions in radius of 30% in 30 m^2 non-paved surface area pits.

Zelkova serrata

Maximum height observations of 14 m and radius of 5 m are below published height expectations (Dirr, 2009), however the canopy radius in texts are often representative of a large

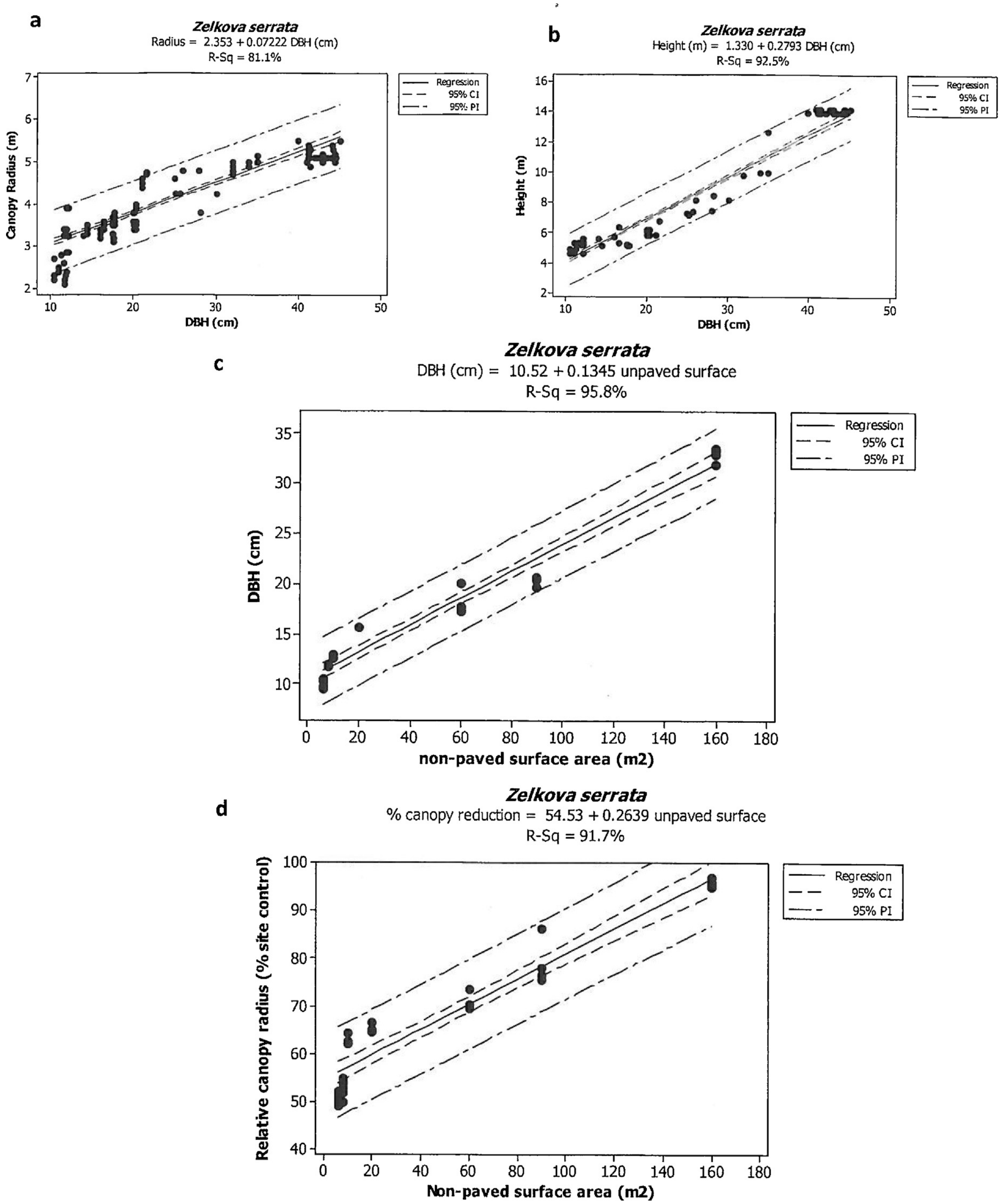

Fig. 5. Canopy size relationships of *Zelkova serrata* in northern and central New Jersey parking lots. CI = Confidence interval for the regression line from the existing data set at $a = 0.05$; PI = prediction interval for the new observations at $a = 0.05$ for trees observed beyond the data set subject to the same criteria of treatment, species, age, region, and analysis. (a) Simple linear regression relationship canopy radius to DBH; (b) simple linear regression of tree height to DBH; (c) simple linear relationship of DBH to open soil space in design detail. DBH data represents mean DBH within pavement size opening groups, normalized to mean canopy DBH for on-site control groups to fit multiple sites into analysis; (d) Simple linear regression of canopy radius to open soil space in design detail. Canopy radius data represents mean radius data points within pavement size opening groups, normalized to mean canopy radius for on-site control groups to fit multiple sites into analysis.

vase-shaped growth form which had not fully developed in the trees included in this study. DBH and soil openings are highly correlated (Fig. 5c). Soil openings of less than 50 m^2 were associated with a 30% reduction in canopy radius (Fig. 5d) or a 50% reduction in canopy area (Table 2).

Comparison to Florida parking lots

Both Florida and New Jersey studies show reductions of at least 19%, with the majority of reductions greater than 49% in 20 m^2 of soil (Table 3). Larger trees, as described by Dirr's manual (2009), are

Table 2
Calculated percent reduction of tree canopy area based on example scenarios.

Percentage of canopy radius	Example radius canopy area	Area of example	Percentage reduction
100	50	7854	0
90	45	6362	19
80	40	5027	36
70	35	3849	51
60	30	2827	64
50	25	1964	75
40	15	707	91
20	10	314	96
10	5	79	99

seen to have a proportionately larger reduction in canopy size both in radius and area. This was further illustrated at the 6 m^2 size with all reductions greater than 21% in canopy area, with the majority of reductions greater than 50% (Table 4).

Discussion

Increases in the area of open soil provided in the installation design were associated with increased size of the trees 18–23 years after installation. All species exhibited a smaller size than the published expectation, which suggests a lower size expectation for the urban tree canopy within the first 20 years (Dirr, 2009). This is reasonable if we expect trees to live longer than 20 years in order to reach a full mature size. The data suggested that the current legislative and design growth canopy expectations are not being met if the published mature size is expected within 20 years. Furthermore, the common planting zone soil access provisions resulted in much smaller tree sizes. In order to meet realistic expectations urban tree planting design, the influence of soil resource provision must be acknowledged. To meet the requirements for canopy legislation, either design choices could include larger planting spaces to yield greater size, or continue with current designs and lower size expectations, and compensate with an increase the total amount of trees planted.

The largest trees observed were found in non-limited soil in the edge of the parking lots in all species, which is not surprising. Regression analysis of tree size demonstrated significant relationships between DBH and both canopy radius and height. The largest trees in each species, although slightly smaller than published expectations, were still reasonable for the amount of time in ground. We compared the results from this study to a similar study done in Florida, US (Grabosky and Gilman, 2004), and although the species are different, our data in canopy size reduction mirror those of the earlier study (Tables 3 and 4).

There were no data collected to determine the exact cause of the diminished size in this study. Other researchers have investigated factors influencing diminished size, such as elevated soil temperature (Graves, 1994), tree gas exchange (Celestian and Martin, 2005), leaf chlorophyll concentrations (Celestian and Martin, 2005), soil limitation (Kristoffersen, 1999), soil water dynamics (Nielsen et al., 2007), and soil compaction (Randrup et al., 2001).

When breaking the data down into planting size typologies across species (pit, planting strip, amount of non-limited soil), it is apparent that there is a reduction in growth when there is less than 20 m^2 of soil surface. This 20 m^2 is typical of a linear strip of 2 m width, planted at 10 m spacing (Table 3). There is an extreme reduction in canopy size, with a tree pit of 2 m by 3 m (Table 4). For planting strips (linear strips or shared pits), small size and configuration changes of those strips can yield noticeable differences, 20 years later, consistent with findings in a terminal size study of tree species in central and northern New Jersey (Sanders et al., 2013).

The data are limited to central and northern New Jersey, but the conclusions of reductions be expanded to the mid-Atlantic United States as there is a framework for canopy reductions. The data in the present study provided parallel results from a similar study in Florida; however, more data from various locations across the US are needed in order to determine a comprehensive growth expectation model for a wide variety of locations for each species. While there are other factors at work, an important predictor for trees achieving maximum size, is to provide adequate planting space, including further research into the effect of additional depth for growth as well as other factors. The levels of growth achievable

Table 3
Comparison of canopy area reduction for trees in 20 m^2 soil in parking lots from New Jersey and Florida.

Species	State	No. trees	No. parking lots	Space relative to non-limited trees on parking edge	Canopy reduction at 20 m^2
Acer rubrum	NJ	233	8	42.2% of edge	80% reduction
Prunus serrulata	NJ	313	9	71.6% of edge	49% reduction
Pyrus calleryana	NJ	427	11	42.1% of edge	80% reduction
Quercus palustris	NJ	209	9	66.2% of edge	56% reduction
Zelkova serrata	NJ	354	10	59.8% of edge	64% reduction
Platanus occidentalis	FL	78	3	71.8% of edge	49% reduction
Ulmus parvifolia	FL	287	4	55.2% of edge	64% reduction
Quercus shumardii	FL	43	2	71.4% of edge	49% reduction
Quercus laurifolia	FL	41	1	89.9% of edge	19% reduction

Table 4
Comparison of canopy area reduction for trees in 6 m^2 soil in parking lots from New Jersey and Florida.

Species	State	No. trees	No. parking lot	Space relative to non-limited trees on parking edge	Canopy reduction at 6 m^2
Acer rubrum	NJ	233	8	35.7% of edge	85% reduction
Prunus serrulata	NJ	313	9	70.4% of edge	51% reduction
Pyrus calleryana	NJ	427	11	36.0% of edge	88% reduction
Quercus palustris	NJ	209	9	59.3% of edge	64% reduction
Zelkova serrata	NJ	354	10	56.3% of edge	67% reduction
Platanus occidentalis	FL	78	3	57.6% of edge	67% reduction
Ulmus parvifolia	FL	287	4	52.9% of edge	73% reduction
Quercus shumardii	FL	43	2	68.6% of edge	50% reduction
Quercus laurifolia	FL	41	1	87.6% of edge	21% reduction

with the current legislated planting requirements are limited. This study suggests that an improved planting design will better meet the intent for successful tree establishment. By providing a wider soil zone around trees, we can increase canopy coverage. There is a dramatic increase in canopy size when trees are planted in linear strips of at least 40 m^2 as opposed to 6 m^2 planting pits.

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