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A rapid urban site index for assessing the quality of street tree planting sites

Bryant C. Scharenbroch[a,b,*], David Carter[c], Margaret Bialecki[d], Robert Fahey[b,e], Luke Scheberl[a], Michelle Catania[b], Lara A. Roman[f], Nina Bassuk[g], Richard W. Harper[h], Les Werner[a], Alan Siewert[i], Stephanie Miller[j], Lucy Hutyra[k], Steve Raciti[l]

[a] College of Natural Resources, University of Wisconsin-Stevens Point, 800 Reserve Street, Stevens Point, WI 54481, USA
[b] The Morton Arboretum, 4100 Illinois Route 53, Lisle, IL 60532, USA
[c] Department of Forest Resources, University of Minnesota, Green Hall, 2005 Upper Buford Circle, St. Paul, MN 55108, USA
[d] Department of Geography, Environment, and Society, University of Minnesota, 414 Social Sciences 19th Avenue S., Minneapolis, MN 55455, USA
[e] Department of Natural Resources and the Environment, University of Connecticut, 1376 Storrs Road, Storrs, CT 06269, USA
[f] US Forest Service, Philadelphia Field Station, 100 N. 20th Street, Philadelphia, PA 19103, USA
[g] Urban Horticulture Institute, Horticulture Section, School of Integrative Plant Science, Cornell University, 134A Plant Science, Ithaca, NY 14853, USA
[h] Department of Environmental Conservation, University of Massachusetts, 160 Holdsworth Way, Amherst, MA 01003, USA
[i] Ohio DNR Division of Forestry, Region 3, 11800 Buckeye Drive, Newbury, OH 44065, USA
[j] Ohio DNR Division of Forestry, Region 4, 952-B Lima Avenue, Findlay, OH 45840, USA
[k] Department of Earth & Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA
[l] Department of Biology, Hofstra University, 227 Gittleson Hall, Hempstead, NY 11549, USA

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ABSTRACT

Urban trees experience site-induced stress and this leads to reduced growth and health. A site assessment tool would be useful for urban forest managers to better match species tolerances and site qualities, and to assess the efficacy of soil management actions. Toward this goal, a rapid urban site index (RUSI) model was created and tested for its ability to predict urban tree performance. The RUSI model is field-based assessment tool that scores 15 parameters in approximately five minutes. This research was conducted in eight cities throughout the Midwest and Northeast USA to test the efficacy of the RUSI model. The RUSI model accurately predicted urban tree health and growth metrics ($P < 0.0001$; R^2 0.18–0.40). While the RUSI model did not accurately predict mean diameter growth, it was significantly correlated with recent diameter growth. Certain parameters in the RUSI model, such as estimated rooting area, soil structure and aggregate stability appeared to be more important than other parameters, such as growing degree days. Minimal improvements in the RUSI model were achieved by adding soil laboratory analyses. Field assessments in the RUSI model were significantly correlated with similar laboratory analyses. Other users may be able to use the RUSI model to assess urban tree planting sites (< 5 min per site and no laboratory analyses fee), but training will be required to accurately utilize the model. Future work on the RUSI model will include developing training modules and testing across a wider geographic area with more urban tree species and urban sites.

1. Introduction

1.1. Urban tree stress and mortality

Poor site conditions can cause urban tree stress leading to reduced establishment, growth, health and ultimately premature mortality. Roman and Scatena (2011) found that street trees typically live only 20 years. It is unclear exactly how much urban tree stress is attributable to site conditions, but Patterson (1977) suggested that as much as 90% of all urban tree health issues are soil-related. Regardless, urban trees in poor site conditions are predisposed to other tree stress agents, like diseases or insects (Cregg and Dix, 2001). Site conditions in streetscapes

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Abbreviations: AHOR, A horizon; EC, electrical conductivity; ERA, estimated rooting area; EXP, exposure; GDD, growing degree days; INFR, infrastructure; MAI, mean annual increment; PEN, penetration; PPT, precipitation; RUSI, rapid urban site index; RAI, recent annual increment; SOM, soil organic matter; STRC, structure; SURF, surface; TRAF, traffic; TC, tree condition; TCI, tree condition index; UTH, urban tree health; WAS, waterstable aggregates

* Corresponding author at: College of Natural Resources, University of Wisconsin – Stevens Point, 800 Reserve Street, Stevens Point, WI 54481, USA.

E-mail addresses: Bryant.Scharenbroch@uwsp.edu, bscharenbroch@mortonarb.org (B.C. Scharenbroch), david.r.j.carter@gmail.com (D. Carter), biale009@umn.edu (M. Bialecki), rfahey@mortonarb.org, robert.fahey@uconn.edu (R. Fahey), Luke.L.Scheberl@uwsp.edu (L. Scheberl), mcatania@mortonarb.org (M. Catania), lroman@fs.fed.us (L.A. Roman), nlb2@cornell.edu (N. Bassuk), rharper@umass.edu (R.W. Harper), Les.Werner@uwsp.edu (L. Werner), alan.siewert@dnr.state.oh.us (A. Siewert), Stephanie.Miller@dnr.state.oh.us (S. Miller), lrhutyra@bu.edu (L. Hutyra), steve.raciti@gmail.com (S. Raciti).

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are particularly poor (Jim, 1998) and these landscapes often have the most severe site limitations inhibiting establishment, growth, health and longevity of urban trees.

Streetscape trees are negatively affected by a wide variety of site constraints. These landscapes have limited above- and belowground growing space (Jim, 1997), leading to reduced tree growth (Sanders and Grabosky, 2014). Poor soil structure, high bulk densities, low hydraulic conductivity and low aeration from compaction can negatively impact trees in these landscapes (Day and Bassuk, 1994). Streetscapes are often underlain by engineered soils comprised of coarse materials optimal for supporting infrastructure, but with poor water and nutrient holding capacities (Grabosky and Bassuk, 1995). Nutrient availability for trees may be affected by alterations in organic matter cycling and biological activity in streetscapes (Scharenbroch and Lloyd, 2004; Scharenbroch et al., 2005). Streetscape soils often are often alkaline due to weathering of concrete (Ware, 1990). The salinities of these soils are often high due to application of de-icing salts (Hootman et al., 1994; Czerniawska-Kusza et al., 2004). Management activities to maintain infrastructure (e.g., road salts, tree trimming) in these landscapes may induce urban tree stress (Randrup et al., 2001). The aforementioned scenarios outline some of the major site conditions limiting trees in streetscapes. Although site conditions are often degraded in streetscape plantings, this is not always the case and a wide range of site qualities exist in streetscapes (Scharenbroch and Catania, 2012).

1.2. *Improving the urban forest through site assessment*

The ability to detect differences across the range of site qualities in streetscapes would benefit both the planning and management of the urban forest. Furthermore, urban tree species have a wide range of tolerances to site conditions (Bassuk, 2003; Sjöman and Nielsen, 2010). Better matching of species tolerances with site conditions may increase urban forest health and diversity. Trees with low hardiness might be planted in high quality sites. By doing so, these trees will have better chance to establish and grow to maturity. New tree species to the urban environment might be planted in the highest quality sites, since limited information may be known on their tolerances to urban site conditions. Trees with high tolerances to urban stress might be planted in the lowest quality sites, thereby maximizing the total canopy cover of the urban forest.

The ability to detect site quality differences would also benefit individual urban trees. Soil management is often required for urban trees since so many urban landscapes are degraded (De Kimpe and Morel, 2000), and these soil treatments have been shown to enhance tree growth and health (Scharenbroch and Watson, 2014; Layman et al., 2016). However, assessment tools are limited and inaccurate to assess the efficacy of these management actions towards improving soil quality for urban trees (Scharenbroch et al., 2014). Improved assessment tools will enhance soil management efforts, which in turn will promote the health and growth of trees in urban landscapes.

1.3. *Site indices for urban trees*

A practical and accurate site index for urban trees does not currently exist. Site indices are available for agronomic plants (Doran and Parkin, 1994; Doran et al., 1996) and timber species (Amacher et al., 2007). Agronomic site indices employ site indicators and interpret score values into integrated indices (Andrews et al., 2004; Idowu et al., 2009) to relate site conditions affecting plants in these landscapes. Forest site index reflects primary growth potential in dominant and co-dominant trees for a given species at an established reference age (i.e. 50 y). Such growth-based indices inherently reflect the collective influence of site and soil characteristics on growth. Indices from agriculture and forestry may have limited application for urban trees since the species and site conditions differ substantially in urban landscapes.

Efforts have been made to develop site indices for urban trees (Siewert and Miller, 2011; Scharenbroch and Catania, 2012). The Urban Site Index (USI) by Siewert and Miller (2011) is a field-based assessment comprised of eight observations producing a score of 0–20. Specific parameters in the USI include: vegetation, surface compaction, probe penetration, soil development, traffic speed, street lanes, parking, and length between traffic control devices. The USI model has not been tested outside of Ohio, USScharenbroch and Catania (2012) published a soil quality minimum data set (MDS) that predicted urban tree attributes on 84 sites throughout DuPage County, IL USA. The MDS included soil texture, aggregation, density, pH, conductivity, total soil organic matter (OM), and labile OM. The MDS is mostly field-based, includes only soil properties and does require some laboratory characterization. The MDS has not been tested outside of DuPage County, IL, USA.

An urban site index to assess streetscapes would be a useful tool for urban tree managers. Toward this goal, a team of scientists and practitioners developed a model called Rapid Urban Site Index (RUSI). The RUSI model was developed based on other urban (Siewert and Miller, 2011; Scharenbroch and Catania, 2012) and non-urban sites indices (Doran and Parkin, 1994; Doran et al., 1996; Andrews et al., 2004; Amacher et al., 2007; Idowu et al., 2009). This research was conducted to answer five questions on the RUSI model:

1. Can the RUSI accurately predict urban tree performance across different sites, species and cities?
2. Are all fifteen RUSI parameters useful for predicting urban tree performance?
3. Can additional laboratory analyses improve the ability of the RUSI model to predict urban tree performance?
4. Are the RUSI field assessments accurate in comparison to laboratory analyses?
5. Is the RUSI model accurate and practical for other users?

2. Materials and methods

2.1. *Study areas and sample plots*

Descriptions and data on human and tree populations, climates and geologies of the eight cities are provided in the Appendix. The first four questions were tested in five USA cities: Boston, MA; Chicago, IL; Cleveland, OH; Springfield, MA and Toledo, OH. These cities were selected based the wide range of urban tree species and site conditions and minimal logistical concerns to facilitate efficient sampling. The fifth question was tested in four USA cities: Chicago, IL; Ithaca, NY; New York City, NY and Stevens Point, WI.

Forty sample plots were identified in each city by first sorting respective city tree inventories to identify two of the most common street trees in each city. *Acer rubrum* L. was the 1st to 2nd most common species in all five cities, therefore twenty sample plots in each city had *Acer rubrum* trees. The remaining twenty plots in each city had either *Quercus rubra* L. or *Tilia cordata* Mill. trees. *Quercus rubra* was selected as the second species in Chicago, IL; Boston, MA and Springfield, MA and *Tilia cordata* was selected as the second species in Cleveland, OH and Toledo, OH.

Sample plots had to meet criteria of at least three trees of the same species and size (within 10 cm in diameter at breast height) on a location. A sample location was defined as a uniform site on one side of the block bounded by cross streets. Locations were commonly found between the street and the sidewalk. Google Earth was used to examine and verify the potential locations. Locations that did not meet the above criteria were excluded. A common reason to exclude a location was that a tree had died or was replanted and this change was not reflected in the current street tree inventory. Forty random plots in each city (twenty for each species) were selected from the locations that had met all criteria. An additional ten plots (five for each species) were selected in each city to be used as backup plots if field verification