Street Tree Assessment and Stewardship Report
Radford, Virginia

Prepared
By
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About this Report

This report was written by students in the Virginia Tech Department of Forest Resources and Environmental Conservation under the guidance of urban forestry professor, Dr. Eric Wiseman. Data presented here were collected over a three-year period from 2008 through 2010 in cooperation with Jim Hurt (City Engineer, Radford City), David Richert (RC&D Forester – Western Virginia, Virginia Department of Forestry), and citizen volunteers affiliated with the Radford Beautification Committee. The recommendations in this report are based solely on observations and judgments made by the authors and are not endorsed by Virginia Tech or the Department of Forest Resources and Environmental Conservation. While every effort has been made to offer current and accurate information in this report, this information is provided "as is", with no guarantees of completeness, accuracy, or timeliness, and without warranties of any kind, expressed or implied.

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Executive Summary

An assessment of street trees in Radford, Virginia was conducted by Virginia Tech urban forestry students from 2008 through 2010 using i-Tree Streets, a software application developed by the U.S. Forest Service. Street tree data were collected using a sample inventory protocol in which a representative sample of city streets was randomly selected and all trees within the public right-of-way along those streets were tallied. For tallied trees, attributes describing the trees' identity, condition, growing environment, and management considerations were recorded. Inventory data were then analyzed using i-Tree Streets to estimate street tree abundance, composition, condition, and monetary worth of functional benefits.

Based on the assessment, it is estimated that 12,724 (± 1,157) street trees reside within Radford's public right-of-way. These trees provide approximately 154 acres of canopy, which cover roughly 2.5% of Radford's total land area. Eastern white pine accounts for the majority of street trees (12%), followed by flowering dogwood (6.1%), Japanese zelkova (5.1%), black locust (4.7%), and eastern hemlock (4.6%). Maple species account for about one-fourth of street tree leaf area and canopy cover in the city. The majority of street trees are either immature (42%) or mature (43%) and only 12.5% were classified as young (having been planted within the previous three years). Over three-fourths of street trees reside in residential areas. The majority of street trees are in fair (41%) or good (38%) structural condition, and nearly 90% of trees are in fair to good health. Each year, Radford's street trees intercept 24 million gallons of rainfall, sequester 3 million pounds of carbon dioxide, and remove 3,900 pounds of pollutants from the air. Annual environmental and real estate benefits of Radford's street trees are estimated at $817,360, or about $64 per tree.

Roughly 500 dead or dying street trees exist in the right-of-way. In addition, about 10% of the street trees are conflicting with overhead power lines. To fully mitigate concerns about tree structure, health, or site use conflicts, about 1,000 street trees would have to be removed. In addition, about 446 small trees (< 18 in. diameter) and about 210 large trees (> 18 in. diameter) would require some form of immediate maintenance. The most common maintenance needs are pruning to remove hazardous dead branches, provide roadway/sidewalk clearance, and eliminate conflicts with utility lines, buildings, and signs.

Radford has a high quality street tree population and future stewardship efforts should focus on sustaining the abundance, diversity, and condition of these trees. Key priorities for street tree stewardship include:

- Adopt policies to protect street trees from injury during construction and lawn maintenance
- Establish standards and specifications for tree planting contracts to ensure that high-quality trees are planted properly
- Seek accreditation as Tree City USA from National Arbor Day Foundation
- Contract arborists certified by the International Society of Arboriculture to perform tree services
- Increase street tree stocking by 10% over the next five years by planting 300 street trees annually

Introduction

An urban forest comprises naturally occurring and planted trees residing in and around dense human development. This natural resource is critical to the economic and environmental sustainability of a community. Among the environmental benefits attributed to urban forests are energy conservation (McPherson and Rowntree 1993), carbon storage (Nowak and Crane 2002), air pollution abatement (Nowak et al. 2006), and stormwater runoff reduction (Xiao et al. 1998). Urban forests are also known to enhance real estate value (Anderson and Cordell 1988), tourism and commerce (Wolf 2005), and citizen quality of life (Kuo 2003).

Street trees are an important component of the urban forest. These trees are found in medians, planting strips, sidewalk planters, and lawns adjacent to the roadway and typically comprise a large proportion of the publicly owned urban forest. Because of their proximity to pedestrians, cars, sidewalks, and other urban infrastructure, street trees can be both major assets and major liabilities. With their canopies overhanging the roadway, street trees help protect asphalt from deterioration by sunlight (McPherson and Muchnick 2005) and reduce stormwater runoff from impervious surfaces (Xiao et al. 1998). Their shade keeps pedestrians, parked cars, and nearby buildings cool in the summer (Scott et al. 1999; Akbari 200). Street trees can also help buffer the sights and sounds of nearby roadways (Fang and Ling 2003) and reduce driving stress (Wolf 2003) . The appearance of commercial areas is also improved by the presence of street trees (Laverne and Winson-Geideman 2003).

Although street trees provide many tangible benefits for communities, they can also create liabilities, particularly when they are not properly selected, placed, and maintained. The most common issues with street trees are branch and root conflicts with infrastructure and site use. Errant branches can obstruct roadways, sidewalks, utility lines, signs, and buildings, and roots can heave pavement and infiltrate sewer lines. In addition, street trees often drop leaves and litter upon cars and sidewalks and may harbor unwanted wildlife. Because the growing environment is often harsh, street trees are also prone to an assortment of pests and may develop structural defects that pose hazards to roadways and adjacent properties.

Despite these potential liabilities, purposeful stewardship of street trees can create a natural resource of considerable value for communities. Research in numerous cities across the United States has shown that the monetary worth of street tree benefits often exceeds their costs by a margin of two to one, or even greater (McPherson et al. 2005). However, this return on investment is only possible when proper choices are made about the selection, placement, protection, and maintenance of street trees. These activities are most efficient and successful when guided by a stewardship plan that is based upon an assessment of the resource.

This report contains the findings of a street tree assessment conducted in Radford, Virginia from 2008 through 2010. This assessment, based on a statistical sampling method, estimates the abundance, composition, condition, and value of trees residing within the public right-of-way of the

city. Based upon the assessment, this report also provides recommendations for enhancing the value of the street tree resource through outreach, policy, and management practices. Because this report is based on a sample rather than complete street tree inventory, it is not intended to identify management needs of specific trees, but rather identify trends in management issues and create a baseline for evaluating future management efforts.

Assessment Methods

The assessment of Radford's street trees began in 2008 and was conducted by undergraduate and graduate students studying urban forestry in the Virginia Tech Department of Forest Resources and Environmental Conservation. Three cohorts of students worked on the assessment during the spring semester (January – May) of 2008, 2009, and 2010. Each year, the students surveyed street trees in roughly one-third of the city to characterize their abundance, composition, condition, and benefits. For this project, a street tree was defined as any self-supporting woody plant residing within the public right-of-way that was either greater than 8 ft. tall or single-stemmed within 1 ft. of ground line. Data were collected using the software tools and protocols of i-Tree Streets (http://www.itreetools.org/streets), a street tree assessment program developed by the U.S. Forest Service. Each year's portion of the assessment was conducted in three stages: planning, inventory, and analysis.

Planning

Street tree data were collected using a sample inventory protocol in which a representative sample of city streets was randomly selected and all trees within the public right-of-way along those selected streets were tallied. First, GIS software was used to draw a random sample of streets from a database provided by the Virginia Department of Transportation. A 12% sample was drawn, totaling 212 sampled street segments. This sampling intensity was chosen with the intent of deriving a statistical estimate of the total street tree population with a ± 10% margin of error. The street segments were inventoried over three years: 2008 (51), 2009 (61), and 2010 (101).

After the sampled street segments were delineated in the GIS, paper maps were created to use in the field for distinguishing trees within the public right-of-way. Using tax parcel boundary data and aerial imagery provided by Radford City, the location of discernable landmarks at the road edge were manually digitized along each street segment in the GIS. A GIS spatial tool was then used to calculate the distance between these landmarks and the adjacent property boundary. Numerical distances were plotted on the map for each landmark along with a line designating the extent of the street segment overlaid on the aerial imagery (Figure 1).

Inventory

Students were placed in two-person teams to collect field inventory data. Each team was assigned about 12 street segments. Data were collected using a handheld computer running the i-Tree Streets

field utility program. Segments were inventoried by walking along their entire length and tallying trees within the public right-of-way on both sides of the street. A tape measure was used to verify the location of each tree. For tallied trees, attributes describing the trees' identity, condition, growing environment, and management considerations were recorded. Each tree's trunk diameter at 4.5 feet above ground line was measured with a tape and recorded. The full list of tree attributes recorded in the inventory is provided in Appendix A.

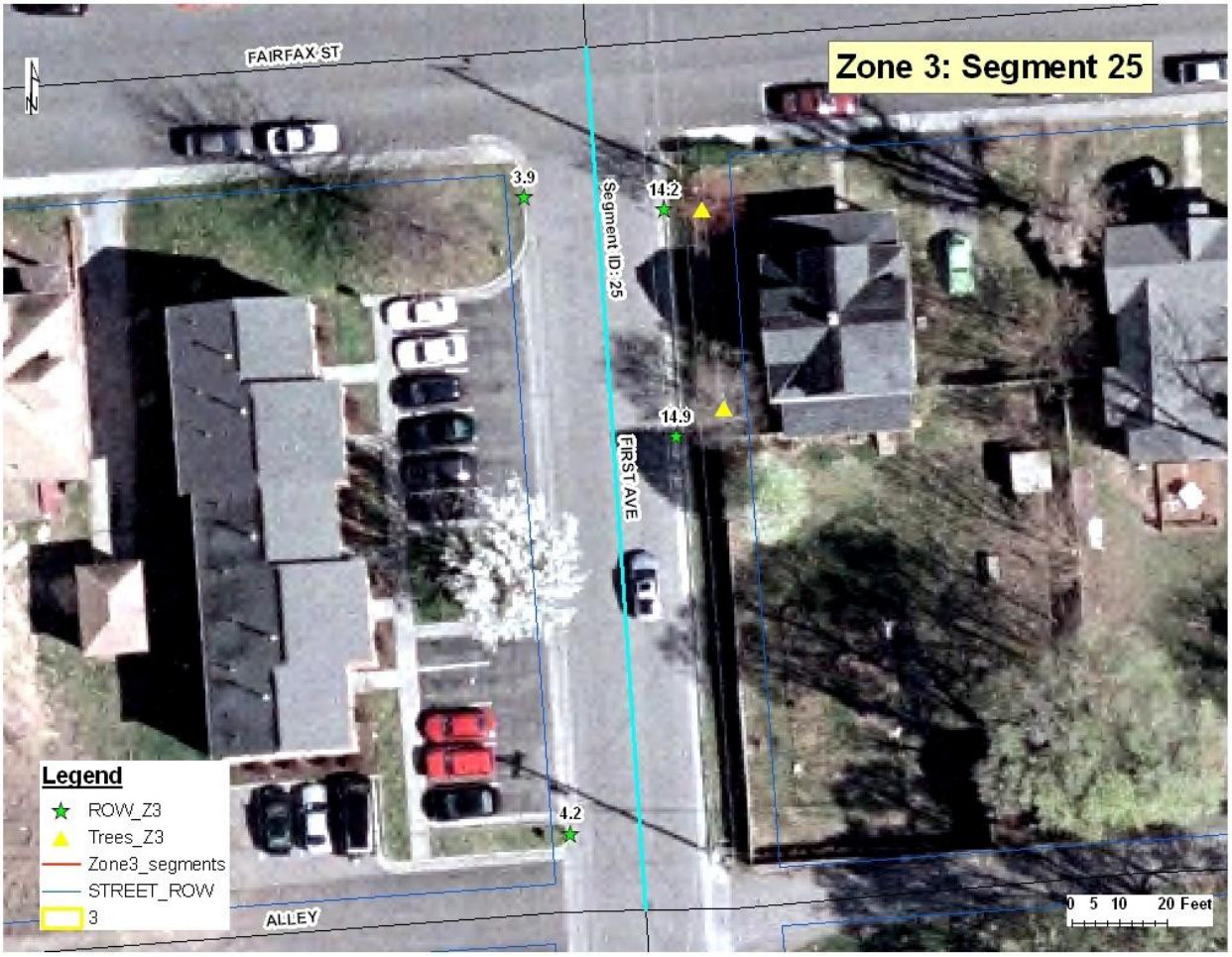

Figure 1: Example of a field map used by inventory teams to identify street trees located within the public right-of-way in Radford, Virginia. Green stars were manually digitized on the maps in GIS and then the distance to the adjacent parcel boundary (thin blue line) was computed and displayed on the map (measured in feet). Yellow triangles designate street trees within the right-of-way.

Analysis

Once the field inventory was complete, data were uploaded from the handheld computers to a desktop computer running the i-Tree Streets analysis software. Data were first screened for errors and omissions and corrected accordingly. Once the database was corrected and formatted for analysis, it was processed with the i-Tree program. The software uses biometric models to estimate the leaf area and canopy cover of each street tree along with statistical formulas to estimate the

street tree population size and composition. These data are then used as inputs to a second set of models that estimate street tree functional benefits and their monetary worth. Software outputs on street tree abundance, composition, condition, and benefits were reviewed to develop recommendations for the street tree stewardship report.

Assessment Results

Abundance and Composition

Student surveyors tallied 1,512 trees residing on the 212 sampled street segments. Based on this statistical sample, it is estimated that 12,724 (± 1,157) street trees reside within Radford's public right-of-way (Appendix B). These trees provide approximately 154 acres of canopy, which cover roughly 2.5% of Radford's total land area.

The most abundant structural class of street trees is broadleaf deciduous large trees, followed by broadleaf deciduous small trees and coniferous evergreen large trees; broadleaf evergreen trees were the least abundant (Appendix B). In terms of species relative abundance (Appendix C), eastern white pine accounts for the majority of street trees (12%), followed by flowering dogwood (6.1%), Japanese zelkova (5.1%), black locust (4.7%), and eastern hemlock (4.6%). From an importance standpoint (accounting for the number, canopy cover, and leaf area of each species), white pine is the most important species, followed by eastern hemlock, silver maple, Siberian elm, and Norway maple (Appendix D). These five species alone account for roughly one-third of the total street tree importance value. The majority of street trees are either immature (42%) or mature (43%) and only 12.5% were classified as young (having been planted within the previous three years) (Appendix E). About 70% of the street trees have trunk diameter less than 12 in. whereas fewer than 5% are larger than 24 in. trunk diameter (Appendix F).

Over three-fourths of street trees reside in residential areas (Appendix G). About 16% are found near park/vacant/forest lands and only 6% are located in commercial/industrial areas. The most common placement of street trees among maintained locations is in front yards or backyards adjacent to the street (about 56% total), followed by planting strips and medians (about 9% total). More than one-fifth of street trees reside in forest fragments or naturalized areas adjacent to the street (Appendix H). The majority of street trees are in fair (41%) or good (38%) structural condition, and nearly 90% of trees are in fair to good health (Appendix I).

Benefits and Values

The most valuable environmental benefit provided by Radford's street trees is stormwater mitigation (Appendix J). Each year, street trees intercept about 24 million gallons of rainfall (data not shown), a service that is valued at nearly $250,000. Energy savings and carbon dioxide mitigation are also important services. By reducing energy consumption for cooling and heating, street trees conserve about 772 MWh of electricity and 28,000 therms of natural gas annually for a savings of

about $79,000. Street trees also sequester about 3 million pounds of carbon dioxide annually at a value of about $23,000. Over 3,900 pounds of air pollutants (ozone, particulates, nitrogen dioxide, and sulfur dioxide) are offset annually by street trees at a value of about $1,900. These environmental benefits total over $350,000 annually, equaling about $28 per tree. Adding an additional $467,000 in real estate and aesthetic benefits to this total brings the annual street tree benefits in Radford to $817,360, or about $64 per tree.

Management Issues

Roughly 500 dead or dying street trees exist in the right-of-way. In addition, about 10% of the street trees are conflicting with overhead power lines. To fully mitigate concerns about tree structure, health, or site use conflicts, about 1,000 street trees would have to be removed. In addition, about 446 small trees (< 18 in. diameter) and about 210 large trees (> 18 in. diameter) would require some form of immediate maintenance. The most common maintenance needs are pruning to remove hazardous dead branches, provide roadway/sidewalk clearance, and eliminate conflicts with utility lines, buildings, and signs. Pest and disease management needs are very minimal (< 1% of street trees); however, inventory data were collected during the winter when signs and symptoms of pests are inconspicuous and therefore this estimate may not be highly accurate.

Summary of Street Tree Status

Overall, Radford has a high-quality street tree population. The assessment suggests that Radford's streets are generally well-stocked with trees. Having an adequate population of street trees allows the city to capitalize on the numerous environmental, economic, and social benefits that trees provide. Based on an estimated 95.7 street miles and 12,724 street trees, Radford has about 1 tree per 79 ft. of roadway on both sides of the street. Full street tree stocking is generally regarded as 1 tree per 50 ft. (McPherson et al. 2005). However, Radford's street tree stocking should be interpreted with caution. Over 20% of street trees reside in forest fragments and naturalized areas adjacent to roadways where trees have naturally generated and their density is disproportionately high compared to "typical" city settings. Although it cannot be confirmed with these data, it is likely that the stocking of planted street trees in maintained areas is considerably lower and could be substantially improved.

Species distribution and importance in Radford's street tree population is favorable. Having adequate species diversity and balanced species importance in a street tree population reduces vulnerability to taxon-specific disorders and ensures continuity in annual benefits. A common benchmark for taxon diversity is a street tree population comprising not more than 30% of a single Family, 20% of a single Genus, and 10% of a single Species. In Radford, there is minor concern for the abundance of eastern white pine, which accounts for 12% of street trees. Fortunately, white pine appears to thrive in Radford (relative performance index for the species is 1.00, which means that the species' average condition rating is equal to that of the entire street tree population) and there are few highly damaging disorders common to white pine in this region. At present, both ash (*Fraxinus* spp.) and maple (*Acer* spp.) are relatively minor components of the street tree population.

This is fortunate because both taxa are vulnerable to noxious introduced pests that are causing problems for other municipalities in the U.S. Despite their relatively low stem count, maples still account for about one-fourth of street tree leaf area and canopy cover in the city. Furthermore, anecdotal observation suggests that maples are particularly common in Radford's maintained areas. This could be problematic if an issue with maples arises in the future.

Radford has a suitable mix of small, medium, and large stature species in the street tree population. Having an abundance of large stature species (> 40 ft. tall at maturity) – where site conditions allow – helps maximizes canopy cover and net annual benefits (Geiger et al. 2004). Although large stature species are common in Radford, their numbers are relatively low in the younger age classes. Only 20% of large-maturing trees are 6 in. diameter or less, suggesting that planting and natural regeneration of these species has been low over the last decade. This notion is reinforced by the observation that only 12% of street trees are classified as young. To ensure long-term stability of the street tree population, it is important that young trees account for a substantial portion of the population. As trees are removed due to old age, poor health, and site conflicts, young trees are needed to fill the population gap and help minimize disruptions in canopy cover and benefits.

Radford's street trees are generally in good condition. Healthy, structurally sound trees are better able to provide environmental services and create fewer liabilities for the community. They are also better able to tolerate the stress of pests and adverse weather, helping to reduce their maintenance costs. Trees in good condition are also more attractive, which enhances their desirability and contributions to real estate value. By removing unhealthy and structurally unsound trees, the city can reduce hazards and enhance street tree value. Maintenance pruning to remove defective, unhealthy, and obstructive branches is the most cost-effective measure for improving street tree condition.

Stewardship Recommendations

A street tree stewardship plan provides a pathway to a sustainable, high-value urban forest. By following a stewardship plan, the city can benefit from a street tree population that is stable, resilient, safe, functional, and cost-effective. To achieve this vision for street trees, the stewardship plan must address three areas: (1) outreach and policy, (2) tree selection and planting, and (3) tree protection and maintenance.

Outreach and Policy

A citizenry informed about the benefits and needs of street trees is fundamental to creating a valuable urban forest. Without citizen support of ordinances, policies, tax appropriations, and service projects, the urban forest cannot reach its full potential. The first step in public outreach is to publicize the findings of the assessment reported here. Let citizens and politicians of Radford know that they have a highly valuable natural resource in their street trees that merits care and protection.

This message can be shared through numerous outlets such as local newspaper editorials, inserts in water bills, postings on the city website, and local bill boards. Hosting an Arbor Day or Earth Day celebration in a public space with coverage by local media can be highly effective. Civic groups and corporate sponsors can help spread the message within the community.

Another high priority for Radford is to obtain Tree City USA accreditation with the National Arbor Day Foundation. Municipalities are granted this designation by achieving several criteria that demonstrate their ongoing commitment to urban forest stewardship. The accreditation is a powerful cue to the community that the city cares about trees and can be used to leverage investments in the urban forest by donors and corporate sponsors. The credential also distinguishes the city as a nice place to work and live, potentially attracting new businesses and residents. Information about the Tree City USA program can be found at http://www.arborday.org/programs/treeCityUSA.

To ensure that trees are reasonably protected from unnecessary harm and removal, the city should review, revise, and create administrative policies and ordinances pertaining to street trees. One of the greatest threats to street tree health is injury caused during the construction, maintenance, and repair of nearby infrastructure such as streets, sidewalks, water lines, utility lines, signs, and lampposts. Lawn mowing equipment is also a common cause of injury to young street trees. If not currently in existence, a policy should be adopted that requires city personnel and their contractors to follow protective procedures when working near street trees. A model policy from the City of Boulder, Colorado can be found here (http://www.bouldercolorado.gov/files/PDS/codes/dcs/ch03.pdf). Similarly, ordinances should be in place to protect street trees from activities on nearby private properties. To learn more about tree ordinances, visit http://www.cnr.vt.edu/vtod.

Tree Selection and Planting

Selecting appropriate trees for the roadside helps ensure that street trees remain healthy, safe, and functional. Selecting species that are of appropriate stature and form for the planting site is particularly important. Species that grow too tall or broad should not be planted under power lines or near sidewalks where branches will cause conflicts. Likewise, to prevent sidewalk damage, large maturing trees should not be planted in narrow planting strips (< 3 ft. wide) between curbs and sidewalks. In confined above- and below-ground spaces, small to medium stature species are most appropriate. However, large maturing trees (> 40 ft. tall at maturity) should always be advocated for unconfined spaces because they most effectively produce canopy cover and provide the greatest long-term return on planting investment.

Planting a diverse assemblage of species that are well-adapted to local conditions helps minimize the risk of species-specific problems as well as reduces tree maintenance costs. Radford already possesses a rich assortment of street trees and future tree planting plans should reflect this composition. Selection should favor those species that have proven track records of positive

performance. The Relative Performance Index provided by this assessment shows which species tend to outperform the average tree in terms of condition rating. Those with an index > 1.00 are above-average performers and vice versa. However, this index is not a perfect indicator because it can be biased by tree age (those that are relatively young tend to be in better condition) and tree placement (those in amicable environments tend to be healthier). Introducing new species into the street tree population has merit for addressing specific planting challenges, but should be approached with caution, particularly with non-native species that could become invasive. To learn more about selecting street tree species, visit http://www.cnr.vt.edu/dendro/treeselector and http://www.pubs.ext.vt.edu/426/426-610/426-610.html.

When planting new street trees, it is important to use high-quality nursery stock and proper planting procedures. High-quality trees will have higher survivorship and present fewer problems in the long-term. Of particular importance is branch structure and root system quality. Seemingly minor issues with branches and roots in young trees can lead to major problems such as co-dominant leaders and girdling roots in mature trees. The most pervasive issue with street tree planting is placing the root ball too deeply in the soil – commonly referred to as "deep planting". While there is no quantifiable evidence from this assessment that Radford's street trees are either low-quality nursery stock or planted improperly, the city must be vigilant in preventing these problems because they commonly do not manifest themselves for years or even decades after tree planting. Radford should review, revise, and if necessary, create a specification for nursery stock quality and tree planting procedures to be followed by vendors awarded street tree planting contracts. The Virginia Nursery and Landscape Association has published a standardized landscaping specification (http://www.vnla.org/Landscape%20Specs/VNLAldsSpecs111101.pdf) that could be helpful in crafting street tree specifications. A good example of landscape guidelines with specific information about street trees is provided by the City of Alexandria, Virginia (http://alexandriava.gov/uploadedFiles/recreation/info/040907_land_guidelines.pdf). For further information on selecting and planting high-quality trees, see http://www.pubs.ext.vt.edu/430/430-295/430-295.html.

Radford should strive to increase its street tree population through planting, particularly in land use areas with relative low tree abundance such as multi-family residential and commercial areas. On average, Radford has about 1 tree for every 79 ft. of roadway on both sides of the street, which is about 35% below full stocking (1 tree for every 50 ft. of roadway). Although this is a general guideline and may not be fully applicable to Radford, it is not uncommon to see roadsides in the city that could clearly sustain additional street trees. Given that about 45% of Radford's street trees are mature or over-mature, the city needs to invest in new plantings if it hopes to sustain the current street tree population.

A realistic street tree planting goal for Radford over the next five years is to increase street tree stocking by net 10%. This will require planting about 300 trees per year in excess of typical tree removal rates along existing roadways. Undoubtedly, the city is not in an economic position to fully fund this level of planting, so creative approaches and partnerships will have to be taken. Because

street trees have documented benefits for air and water quality, the city should investigate state and federal grants that target environmental improvement. Corporate sponsors and private donors should also be developed as sources of funds to purchase trees. The Radford Beautification Commission should take the lead on developing partnerships with local civic groups and volunteers to help plant street trees. Before planting, though, a street survey should be undertaken to identify high-priority tree planting locations throughout the city. The guiding principle should be to plant trees in the easiest places first and the harder places later. That is, focus initial efforts on planting spaces with the fewest limitations (either environmental or social), and then work towards the more challenging spaces. Radford should seek guidance from the Virginia Department of Forestry's Urban and Community Forestry Program (http://www.dof.virginia.gov/urban/index.shtml) and the Virginia Urban Forest Council (http://treesvirginia.org) on how to develop a cost-effective street tree planting plan.

Tree Protection and Maintenance

Street trees require protection from injury and improper maintenance in order to live long, healthy, problem-free lives. Protecting trees also minimizes liability for the city due to hazardous conditions that come about from neglect and mistreatment. Recommendations to protect street trees from harm during construction and lawn maintenance were discussed earlier. Another priority for Radford is to ensure that proper tree maintenance practices, particularly pruning methods, are employed by city personnel and contractors working on street trees. Improper pruning diminishes the health, structure, and appearance of trees. All personnel tasked with tree pruning should receive basic training in tools and techniques. One to three hours of hands-on training is sufficient to prepare an individual for routine tasks such as pruning for street and sidewalk clearance. Advanced pruning techniques such as structural pruning of young trees may require a half to whole-day workshop. Training workshops are regularly held throughout the state in affiliation with the Virginia Urban Forest Council and Mid-Atlantic Chapter of the International Society of Arboriculture. A consulting arborist can also be hired to provide on-site training of personnel. Basic information on tree pruning can be found at http://www.pubs.ext.vt.edu/430/430-456/430-456.html and http://www.treesaregood.com/treecare/treecareinfo.aspx.

Radford should adopt a policy of only hiring tree service contractors with an arborist certified by the International Society of Arboriculture on staff. This credential indicates that the individual has demonstrated his or her competency in and commitment to proper tree care practices. Likewise, Radford should strive to have at least one employee who deals with street trees on credentialed as a Certified Arborist. To learn more about arborist certification, visit http://www.isa-arbor.com/certification. In addition, Radford should specify in all tree service contracts that services be performed in compliance with American National Standards Institute (ANSI) A300 standards for tree care operations. These standards represent professional consensus on proper practices of tree planting, pruning, cabling/bracing, fertilization, and lightning protection. By following these standards, Radford can ensure that its street trees are receiving proper care and can minimize

liabilities for improper practices such as topping. To learn more about A300 standards, visit http://www.treecareindustry.org/public/gov_standards_a300.htm.

Radford's first priority for tree maintenance is the removal of dead, hazardous, and obstructive trees. The assessment indicates that about 1,000 trees reside in the right-of-way that should be removed for these reasons. To minimize liabilities, the city should systematically remove these undesirable trees. This entails first identifying undesirable trees and then removing them in a timely manner. Windshield surveys should be conducted along major roadways to locate undesirable trees and prioritize their removal. Trees receiving the highest priority are those located in high traffic areas and that are large enough to cause substantial harm should they fail. Dead trees are the first priority followed by defective trees and obstructive trees. The city may need to hire an arborist to assist in identifying and prioritizing undesirable trees.

Based on the assessment, pest and disease problems do not appear to be widespread in Radford's street trees, nor do the street trees appear to be particularly vulnerable to known invasive pests that have yet to enter the region. The most notable potential pest problem is hemlock woolly adelgid. It is estimated that nearly 600 eastern hemlocks reside along Radford's roadways. Although adelgid detection was outside the scope of this assessment, it is likely that many of these hemlocks are infested by adelgid because it is known to exist in the region and hemlocks show little resistance to infestation. Over time, the pest will kill trees unless they are controlled using pesticides. These trees can become hazardous once they die and should be removed promptly. To minimize losses of high-value hemlocks, the city should identify the most important trees in its street tree population and develop a preservation plan for them. It is recommended that the city not plant hemlock as a street tree in the future. To learn more about hemlock woolly adelgid, visit http://pubs.ext.vt.edu/3006/3006-1451/3006-1451.html.

Another potential pest threat for Radford's street trees is Asian longhorned beetle. This exotic pest has caused substantial harm to street trees in the northeastern United States. Although the pest feeds on a number of different tree species, losses have been most catastrophic for maples, which are popular street trees throughout the United States. Because Radford has a fairly high abundance of maples, the city should take caution in planting additional maples along roadways for the foreseeable future. By keeping maple abundance at a modest level in the street tree population, the city can minimize the risk of tree losses should Asian longhorned beetle invade Virginia. To learn more about this pest, visit http://www.uvm.edu/albeetle.

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Appendix A: Attributes and values used for street tree inventory in Radford, Virginia.

Attribute	Definition	Values
Tree ID number	Unique ID number assigned by the inventory software to each inventoried tree	1 to n
Street segment ID number	Unique ID number assigned by the inventory software to each sampled street segment	1 to n
Street name	Name of street on which inventoried tree resides	Chosen from name database
Street number	Address of building closest to the inventoried tree	1 to n
Land use	Prevailing land use in the vicinity of the inventoried tree.	Single family residential Multi-family residential Industrial/Large commercial Park/vacant/other Small commercial
Site type	Placement of inventoried tree in the landscape	Front yard Planting strip Cutout Median Other maintained locations Other unmaintained locations Backyard
Management responsibility	Notation of whether tree appears to be planted by city or adjacent property owner	City Private
Species	Botanical name of inventoried tree	Chosen from name database
Trunk diameter	Diameter of tree trunk measured 4.5 ft. above ground	1 to n
Structural condition	Rating of structural integrity of inventoried tree	Good Fair Poor Dead or dying
Health	Rating of health of inventoried tree	Good Fair Poor Dead or dying
Maintenance recommendation	Rating of maintenance need of inventoried tree	None Small tree (routine) Small tree (immediate) Large tree (routine) Large tree (immediate) Critical concern

Attribute	Definition	Values
Maintenance priority	Highest priority maintenance for the inventoried tree	None Stake/train Crown cleaning Crown raising Crown reduction/thinning Remove Treat pest/disease
Sidewalk heave	Rating of sidewalk damage caused by inventoried tree	None 0 – ¾ inches ¾ - 1 1/2 inches > 1 1/2 inches
Overhead utility lines	Rating of utility line presence/conflict with inventoried tree	No lines Present and no potential conflict Present and conflicting
Age Class	Qualitative rating of age of inventoried tree	Young Immature Mature Over-mature

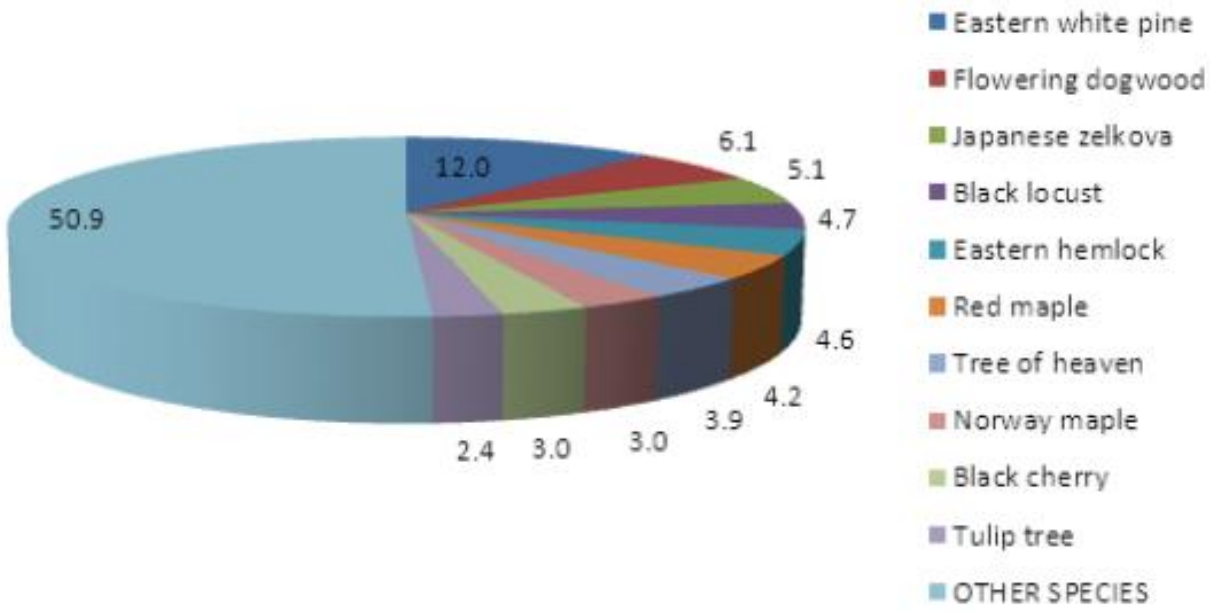
Appendix B: Radford, Virginia street tree population summary.

Species	DBH Class (in) 0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total Standard Error
Broadleaf Deciduous Large (BDL)										
Japanese zelkova	0	0	471	177	0	0	0	0	0	648 (±302)
Tree of heaven	17	160	261	25	0	8	8	8	8	496 (±201)
Norway maple	0	160	42	42	76	59	8	0	0	387 (±93)
Black cherry	59	126	118	59	17	0	0	0	8	387 (±85)
Tulip tree	0	17	93	84	84	17	8	8	0	311 (±115)
Siberian elm	8	8	76	67	25	59	8	8	25	286 (±113)
Sugar maple	0	8	109	59	34	17	25	0	0	252 (±70)
Silver maple	0	8	34	17	25	59	25	25	50	244 (±54)
Black walnut	0	34	101	34	17	17	8	0	0	210 (±74)
BDL OTHER	50	202	227	126	135	109	59	25	17	951 (±155)
Total	**135**	**724**	**1,532**	**690**	**412**	**345**	**151**	**76**	**109**	**4,174 (±524)**
Broadleaf Deciduous Medium (BDM)										
Black locust	118	185	185	76	8	17	0	0	8	597 (±196)
Red maple	25	210	93	84	42	42	34	0	8	539 (±111)
Boxelder	0	34	109	25	0	8	0	0	0	177 (±85)
BDM OTHER	17	118	93	93	42	17	0	8	0	387 (±72)
Total	**160**	**547**	**480**	**278**	**93**	**84**	**34**	**8**	**17**	**1,700 (±278)**
Broadleaf Deciduous Small (BDS)										
Flowering dogwood	101	337	320	17	0	0	0	0	0	774 (±146)
Rose-of-sharon	202	50	34	0	0	0	0	0	0	286 (±149)
Dogwood	34	151	76	0	0	0	0	0	0	261 (±100)
Callery pear	84	42	59	50	0	0	0	0	0	236 (±85)
Common crapemyrtle	101	42	25	8	8	0	0	0	0	185 (±94)
Eastern redbud	42	25	76	17	0	0	0	0	0	160 (±48)
Plum	8	42	109	0	0	0	0	0	0	160 (±67)
BDS OTHER	252	244	143	67	17	8	0	0	0	732 (±110)
Total	**825**	**934**	**842**	**160**	**25**	**8**	**0**	**0**	**0**	**2,794 (±315)**
Broadleaf Evergreen Large (BEL)										
BEL OTHER	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0 (±0)**
Broadleaf Evergreen Medium (BEM)										
BEM OTHER	0	0	8	0	0	0	0	0	0	8 (±8)
Total	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**8 (±8)**
Broadleaf Evergreen Small (BES)										
Holly	34	135	0	0	0	0	0	0	0	168 (±150)
American holly	0	76	42	8	8	0	0	0	0	135 (±52)
BES OTHER	50	42	50	17	0	0	0	0	0	160 (±44)
Total	**84**	**252**	**93**	**25**	**8**	**0**	**0**	**0**	**0**	**463 (±165)**
Conifer Evergreen Large (CEL)										
Eastern white pine	168	177	463	471	160	84	0	0	0	1,523 (±354)
Norway spruce	76	50	0	76	76	25	0	0	0	303 (±77)
Leyland cypress	118	34	25	0	0	0	0	0	0	177 (±93)
CEL OTHER	0	25	25	42	42	25	0	0	0	160 (±80)
Total	**362**	**286**	**513**	**589**	**278**	**135**	**0**	**0**	**0**	**2,163 (±404)**
Conifer Evergreen Medium (CEM)										
Eastern hemlock	0	84	295	135	42	8	17	0	0	581 (±241)
Virginia pine	8	168	50	25	0	0	0	0	0	252 (±142)
Northern white cedar	34	151	0	0	8	0	0	0	0	194 (±94)
Eastern red cedar	0	42	101	8	0	0	0	0	0	151 (±56)
CEM OTHER	50	34	84	25	8	8	0	0	0	210 (±50)
Total	**93**	**480**	**530**	**194**	**59**	**17**	**17**	**0**	**0**	**1,388 (±314)**

Appendix B: continued.

Species	DBH Class (in) 0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total Standard Error
Conifer Evergreen Small (CES)										
CES OTHER	0	17	17	0	0	0	0	0	0	34 (±25)
Total	**0**	**17**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**34 (±25)**
Palm Evergreen Large (PEL)										
PEL OTHER	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0 (±0)**
Palm Evergreen Medium (PEM)										
PEM OTHER	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0 (±0)**
Palm Evergreen Small (PES)										
PES OTHER	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0 (±0)**
Grand Total	**1,658**	**3,240**	**4,014**	**1,935**	**875**	**589**	**202**	**84**	**126**	**12,724 (±1,157)**

Appendix C: Radford, Virginia street tree species distribution.



Appendix D: Radford, Virginia street tree importance values.

Species	Number of Trees	% of Total Trees	Leaf Area (ft^2)	% of Total Leaf Area	Canopy Cover (ft^2)	% of Total Canopy Cover	Importance Value
Eastern white pine	1,523	12.0	1,857,158	7.4	841,271	12.6	10.7
Flowering dogwood	774	6.1	154,035	0.6	167,427	2.5	3.1
Japanese zelkova	648	5.1	1,038,040	4.2	294,097	4.4	4.5
Black locust	597	4.7	692,013	2.8	280,030	4.2	3.9
Eastern hemlock	581	4.6	309,154	1.2	234,854	3.5	3.1
Red maple	539	4.2	2,056,287	8.2	403,805	6.0	6.2
Tree of heaven	496	3.9	1,072,045	4.3	220,619	3.3	3.8
Norway maple	387	3.0	1,543,509	6.2	296,373	4.4	4.5
Black cherry	387	3.0	690,313	2.8	153,010	2.3	2.7
Tulip tree	311	2.4	1,490,739	6.0	285,987	4.3	4.2
Norway spruce	303	2.4	488,317	2.0	204,430	3.1	2.5
Rose-of-sharon	286	2.2	20,861	0.1	32,511	0.5	0.9
Siberian elm	286	2.2	2,258,923	9.0	358,113	5.4	5.5
Dogwood	261	2.1	40,921	0.2	48,544	0.7	1.0
Sugar maple	252	2.0	1,103,543	4.4	298,485	4.5	3.6
Virginia pine	252	2.0	50,177	0.2	37,758	0.6	0.9
Silver maple	244	1.9	2,263,242	9.1	474,356	7.1	6.0
Callery pear	236	1.9	109,139	0.4	65,894	1.0	1.1
Black walnut	210	1.7	671,391	2.7	138,811	2.1	2.1
Northern white cedar	194	1.5	24,024	0.1	20,616	0.3	0.6
Common crapemyrtle	185	1.5	26,832	0.1	29,533	0.4	0.7
Boxelder	177	1.4	254,246	1.0	108,096	1.6	1.3
Leyland cypress	177	1.4	14,162	0.1	12,998	0.2	0.5
Holly	168	1.3	1,958	0.0	12,673	0.2	0.5
Eastern redbud	160	1.3	41,797	0.2	40,799	0.6	0.7
Plum	160	1.3	40,130	0.2	38,673	0.6	0.7
Eastern red cedar	151	1.2	42,440	0.2	30,094	0.4	0.6
American holly	135	1.1	30,329	0.1	29,034	0.4	0.5
OTHER TREES	2,642	20.8	6,597,217	26.4	1,533,453	22.9	23.4
Total	12,724	100.0	24,982,945	100.0	6,692,344	100.0	100.0

Appendix E: Radford, Virginia street tree age class distribution.

Age Class	Tree Count	Standard Error	% of Zone	% of All Trees
Young	1,590	(±358)	12.50	12.50
Immature	5,352	(±655)	42.06	42.06
Mature	5,445	(±582)	42.79	42.79
Over-mature	337	(±67)	2.65	2.65
Total	12,724	(±1157)	100.00	100.00

Appendix F: Radford, Virginia street tree trunk diameter (DBH) distribution.

	DBH class (in)								
Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42
Eastern white pine	11.05	11.60	30.39	30.94	10.50	5.52	0.00	0.00	0.00
Flowering dogwood	13.04	43.48	41.30	2.17	0.00	0.00	0.00	0.00	0.00
Japanese zelkova	0.00	0.00	72.73	27.27	0.00	0.00	0.00	0.00	0.00
Black locust	19.72	30.99	30.99	12.68	1.41	2.82	0.00	0.00	1.41
Eastern hemlock	0.00	14.49	50.72	23.19	7.25	1.45	2.90	0.00	0.00
Red maple	4.69	39.06	17.19	15.63	7.81	7.81	6.25	0.00	1.56
Tree of heaven	3.39	32.20	52.54	5.08	0.00	1.69	1.69	1.69	1.69
Norway maple	0.00	41.30	10.87	10.87	19.57	15.22	2.17	0.00	0.00
Black cherry	15.22	32.61	30.43	15.22	4.35	0.00	0.00	0.00	2.17
Tulip tree	0.00	5.41	29.73	27.03	27.03	5.41	2.70	2.70	0.00
Citywide total	13.03	25.46	31.55	15.21	6.88	4.63	1.59	0.66	0.99

Appendix G: Radford, Virginia street tree land use location.

Land Use	Tree Count	Standard Error	% of Zone	% of All Trees
Single family residential	8,659	(±951)	68.06	68.06
Multi-family residential	1,229	(±404)	9.66	9.66
Industrial/Large commercial	303	(±195)	2.38	2.38
Park/vacant/other	2,087	(±572)	16.40	16.40
Small commercial	446	(±159)	3.51	3.51
Total	12,724	(±1157)	100.00	100.00

Appendix H: Radford, Virginia street tree site type placement.

Site Type	Tree Count	Standard Error	% of Zone	% of All Trees
Front yard	6,067	(±719)	47.69	47.69
Planting strip	530	(±252)	4.17	4.17
Cutout	8	(±8)	0.07	0.07
Median	623	(±242)	4.89	4.89
Other maintained locations	1,725	(±446)	13.56	13.56
Other un-maintained locations	2,769	(±715)	21.76	21.76
Backyard	1,001	(±209)	7.87	7.87
Total	12,724	(±1157)	100.00	100.00

Appendix I: Radford, Virginia street tree condition ratings.

Structural Rating

Condition	Tree Count	Standard Error	% of Zone	% of All Trees
Dead or Dying	505	(±98)	3.97	3.97
Poor	2,188	(±281)	17.20	17.20
Fair	5,217	(±576)	41.01	41.01
Good	4,813	(±587)	37.83	37.83
Total	12,724	(±1157)	100.00	100.00

Health Rating

Condition	Tree Count	Standard Error	% of Zone	% of All Trees
Dead or Dying	438	(±96)	3.44	3.44
Poor	1,043	(±217)	8.20	8.20
Fair	4,376	(±481)	34.39	34.39
Good	6,867	(±725)	53.97	53.97
Total	12,724	(±1157)	100.00	100.00

Appendix J: Radford, Virginia street tree benefits summary. Monetary worth of each benefit type on an annual basis is shown in dollars.

Species	Energy	CO_2	Air Quality	Stormwater	Aesthetic/Other	Total ($)	Standard Error	% of Total $
Eastern white pine	10,302	3,143	4,895	28,487	43,795	90,621	(±21,060)	11.1
Flowering dogwood	1,911	624	919	3,053	5,856	12,363	(±2,332)	1.5
Japanese zelkova	3,772	1,450	-908	9,991	38,358	52,663	(±24,514)	6.4
Black locust	3,300	1,371	1,440	7,757	21,152	35,020	(±11,511)	4.3
Eastern hemlock	2,661	715	1,737	5,938	5,304	16,355	(±6,796)	2.0
Red maple	4,708	1,749	1,353	16,814	36,028	60,651	(±12,505)	7.4
Tree of heaven	2,629	907	-1,455	8,927	22,960	33,968	(±13,732)	4.2
Norway maple	3,498	1,209	-2,215	12,737	25,864	41,092	(±9,875)	5.0
Black cherry	1,872	651	-865	5,924	16,410	23,992	(±5,286)	2.9
Tulip tree	3,433	1,194	-2,125	12,296	25,711	40,510	(±14,948)	5.0
Norway spruce	2,427	741	1,123	7,278	9,045	20,614	(±5,221)	2.5
Rose-of-sharon	360	85	175	536	1,332	2,488	(±1,293)	0.3
Siberian elm	4,163	1,314	-3,659	17,307	25,727	44,851	(±17,752)	5.5
Dogwood	546	173	264	862	1,787	3,632	(±1,388)	0.4
Sugar maple	3,499	883	1,025	10,104	18,149	33,660	(±9,309)	4.1
Virginia pine	429	113	278	958	1,659	3,437	(±1,934)	0.4
Silver maple	5,336	2,130	1,623	19,603	23,905	52,597	(±11,704)	6.4
Callery pear	794	256	395	1,529	3,604	6,577	(±2,384)	0.8
Black walnut	1,670	595	-903	5,682	13,740	20,785	(±7,341)	2.5
Northern white cedar	221	57	151	491	964	1,883	(±913)	0.2
Common crapemyrtle	339	60	150	528	971	2,049	(±1,043)	0.3
Boxelder	1,278	556	557	2,918	7,752	13,062	(±6,274)	1.6
Leyland cypress	148	41	90	299	1,347	1,926	(±1,010)	0.2
Holly	141	36	104	176	174	632	(±564)	0.1
Eastern redbud	478	155	228	771	1,329	2,961	(±896)	0.4
Plum	444	79	196	734	2,519	3,971	(±1,661)	0.5
Eastern red cedar	330	92	217	787	1,229	2,654	(±986)	0.3
American holly	326	90	241	656	622	1,934	(±744)	0.2
OTHER STREET TREE	17,873	6,325	-3,125	59,531	109,808	190,412	(±334,783)	23.3
Citywide Total	78,888	26,792	1,905	242,674	467,102	817,360	(±74,319)	100.0