Inventory and Analysis of Landscape Trees and Urban Forests on the Main Campus of Virginia Tech

Department of Forest Resources & Environmental Conservation

Virginia Tech

November 28, 2018

Photo from mytimeatvt2@wordpress.com

ACKNOWLEDGEMENTS

Many thanks to Jack Rosenberger, Virginia Tech's Campus Landscape Architect, for promoting the importance of the campus urban forest and initiating a comprehensive campus tree inventory. We are grateful to the Virginia Tech Office of University Planning for funding this project as a graduate assistantship for Peter Stewart and for a strongly supportive work environment. Also, thanks to the many students who have worked with Dr. Eric Wiseman in previous years collecting tree inventory data – without these earlier datasets, starting a complete campus tree inventory would have been much more difficult. A big thanks to Sarah Gugercin, Project Associate, for her work in the layout, design, and copy editing of this document's text, tables and figures. Thanks also to Dave Arnold, former Facilities GIS Manager, for taking on the roles of software architect, system administrator, and IT support, and taking the time to respond in detail to all GIS-related questions. Both he and Emma Powers, Facilities Geospatial Technician, deserve a great deal of credit for keeping this project running smoothly. We also thank Michael Justice in GIS for taking over mapping responsibilities in the GIS department. Finally, we thank John Peterson (Research Associate) and Dr. John Seiler (Professor of Forest Biology), all in the Virginia Tech Department of Forest Resources and Environmental Conservation, for making time to help with tree identification, and Bob Massengale, Landscape Architect with Office of University Planning, for additional helpful input in this report.

ABOUT THE AUTHORS

Peter Stewart is a graduate student in the Virginia Tech Department of Forest Resources and Environmental Conservation pursuing an M.S. degree in Forestry with a focus on urban forest management. He completed a BA in Environmental Studies at Wheaton College and has worked in residential and utility arboriculture for more than 10 years. He has been a Certified Arborist by the International Society of Arboriculture since 2012. Mr. Stewart carried out field data collection, data analyses, and preliminary reporting. In collaboration with Dr. Eric Wiseman, he assisted in writing this final report.

Dr. Eric Wiseman is an associate professor of urban forestry in the Virginia Tech Department of Forest Resources and Environmental Conservation. He holds B.S. and M.S. degrees from Virginia Tech and received his Ph.D. in Forest Resources from Clemson University. Dr. Wiseman has been a Certified Arborist by the International Society of Arboriculture for twenty years and holds the Society's Tree Risk Assessment Qualification. He has conducted urban forest inventories for numerous municipalities in Virginia and has performed extension education and technical assistance on tree inventories and urban forest management throughout the eastern United States. Dr. Wiseman oversaw final reporting, in addition to providing input during the planning of this campus tree inventory project, assisting with field data collection training, and providing guidance on data analysis.

ABOUT THIS REPORT

The contents of this report are based upon the inventory data contained herein and anecdotal field observations. The authors have made a good-faith effort to accurately collect, report, and interpret the inventory data in the context of general urban forest management. All field data were collected from a limited perspective at ground level, predominantly during the dormant season. Therefore, not all conditions affecting tree health and structural stability could necessarily be observed. Condition ratings and maintenance needs of trees are not definitive and should be interpreted with caution. Estimates of ecosystem services and economic value for the urban forest are provided, but should not be construed as a comprehensive assessment of forest benefits and values. There are numerous ways to assess resource value, and not all resource values can be readily quantified or described. This information is provided merely to demonstrate one facet of the tangible contributions that the campus urban forest makes to the university.

QUESTIONS ABOUT THIS REPORT

Questions about the specific contents of this report should be directed to:

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HOW TO CITE THIS REPORT

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EXECUTIVE SUMMARY

During the 2017-2018 academic year, a complete field inventory was conducted of landscape trees and select urban forests on approximately 900 acres of the Virginia Tech main campus in Blacksburg, Virginia. The inventory was performed predominantly on maintained grounds near buildings, parking lots, streets, and other improved facilities. Trees in the immediate vicinity of Smithfield Plantation, along with a few notable trees in the outlying agriculture fields were included in the inventory. The bulk of these trees had been previously inventoried by undergraduate students at Virginia Tech during the period 2006-2011; therefore, the current inventory was predominantly an update of existing data. The inventory was expanded to include trees (that exceeded 12 inches in trunk diameter) in natural areas around the Grove and the Duck Pond. Large trees in the old-growth forest on the eastern boundary of campus near Lane Stadium (from here on, "Old-Growth Forest"), were previously inventoried by local volunteers in 2012. Those inventory data were not updated during this inventory, but the data are included in certain aspects of the analysis in this report. Not enumerated during the field inventory were trees residing at outlying facilities south of Southgate Drive and the various agricultural and unmaintained lands within main campus. Field data collection comprised geo-locating the trees, taking digital photos of the trees, and collecting data on 15 attributes that described the identity, size, condition, maintenance needs, and growing environment of the trees. All data were stored in a university GIS system and subsequently analyzed with an urban forest assessment software called i-Tree Eco. Contained in this report is an analysis of the composition and condition of this tree population using criteria and indicators commonly employed in urban forest assessment. The analysis is reported in two ways: (i) collectively for the main campus and (ii) broken down into campus master plan districts. Also reported are the outputs from the i-Tree Eco analysis, which describe the ecosystem services and economic value of the campus urban forest. Presented below are key findings of the inventory and analysis.

KEY FINDINGS

- As of April 2018, the campus tree inventory database included 10,625 trees, of which 10,077 trees had current and complete inventory records. The data for the remaining 548 trees, located in the Old-Growth Forest, were not updated and, unless specifically noted, are not included in analyses here.
- Of the 10,077 current tree records, 8,352 are living trees, 214 are standing dead trees, and 1,511 are trees removed since the previous inventory.
- The replacement value of all inventoried trees, including those in the Old-Growth Forest, is estimated to be $30.6 million. This is an appraisal of the urban forest as a capital asset and reflects the cost of replacing the biomass of the trees through procurement and planting of the largest commonly available nursery stock.
- There are 225 tree species present in the inventoried portions of campus; 69% of the campus trees are species native to Virginia. The five most common species (as a percentage of the total tree population) are: sugar maple (*Acer saccharum*), 6%; eastern white pine (*Pinus strobus*), 5%; red maple (*Acer rubrum*), 4%; northern red oak (*Quercus rubra*), 4%; and serviceberry (*Amelanchier* spp.), 3%.
- About 57% of all trees are large stature species (eventually maturing at height greater than 50 feet).
- About 85% of all trees are classified as young or immature.
- About 69% of all live trees are classified as being in good or excellent condition.
- A maintenance need was identified for about 22% of the trees; the most common maintenance needs were cleaning prune (825 trees), disease or insect treatment (231 trees), and structural prune (210 trees).
- There were 187 trees identified as needing removal due to health, safety, or conflict concerns. VT Facilities began responding to concern trees identified in the Inventory in the spring and fall of 2018, and such work will be on going in the future.
- The greatest existing pest threats to campus trees are hemlock woolly adelgid, emerald ash borer, and Dutch elm disease. The greatest potential pest threats are winter moth, gypsy moth, and Asian longhorned beetle, each potentially impacting more than 1,500 campus trees.
- Annual ecosystem services of all inventoried trees, including those in the Old-Growth Forest, are valued at $36,444, and comprise:
    - $7,751 from 59.75 tons of gross carbon sequestration
    - $6,459 from 2.70 tons of air pollution removal
    - $17,184 from 257,072 cubic feet of avoided stormwater runoff
    - $5,050 in building energy savings from summer shade and winter windbreak effects

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List of Abbreviations

CAMPUS MASTER PLAN DISTRICTS

21st Century Living & Learning	21C
Agricultural Lands	AGL
Athletics & Recreation	ATR
Creativity & Innovation	CID
Central Spine	CSD
Gateway	GTW
Life Sciences & Technology	LST
North Academic	NOA
Northeast Academic	NEA
Oak Lane	OKL
Student Life	STL

OTHER ABBREVIATIONS

Office of University Planning	OUP
Forest Resources and Environmental Conservation	FREC
Forest Inventory and Analysis	FIA
Diameter at breast height	DBH
i-Tree Eco	ECO

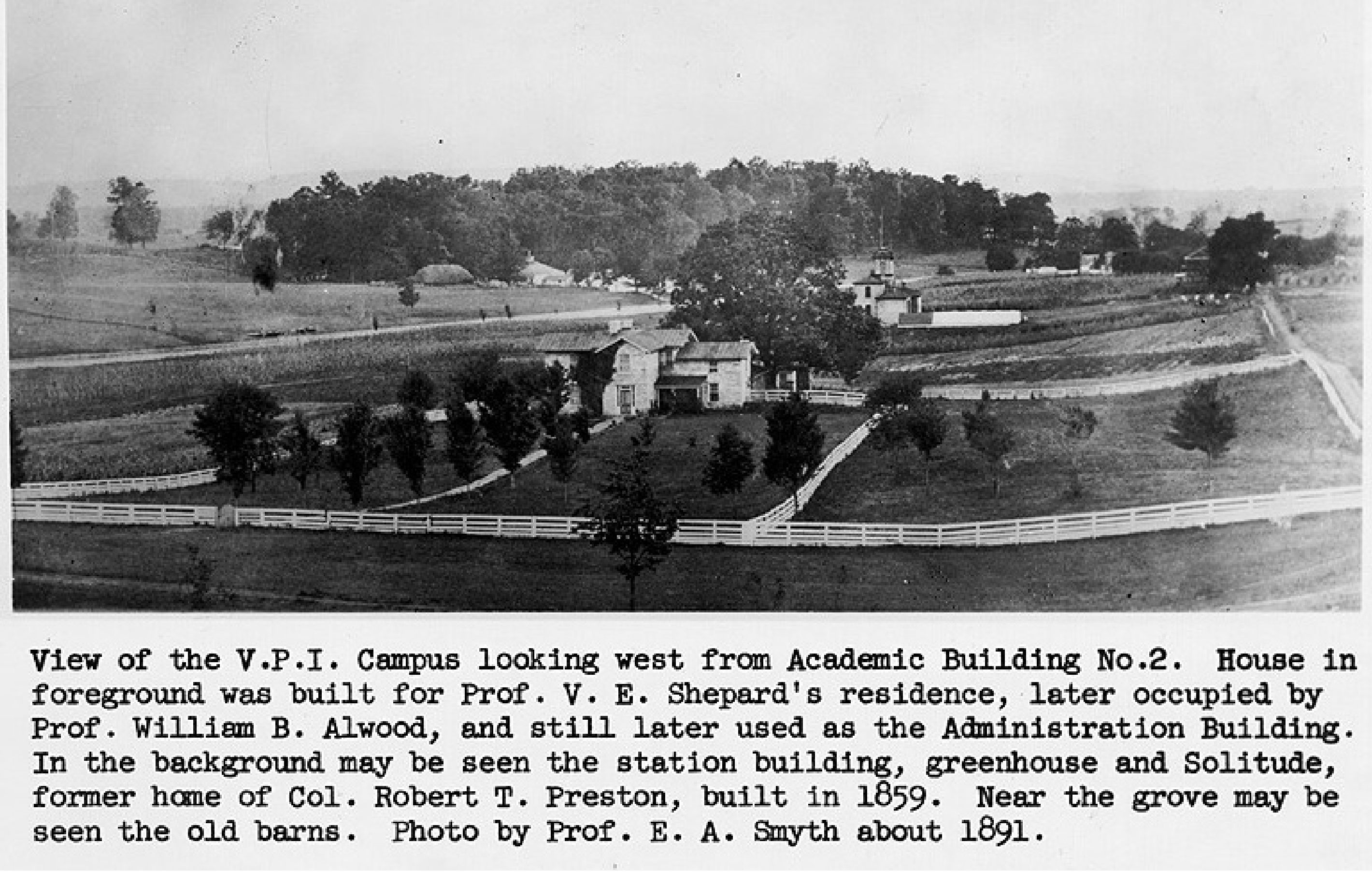
1. Introduction

BACKGROUND AND RATIONALE

The core of the Virginia Tech campus in Blacksburg, Virginia occupies about 900 acres, comprises about 200 buildings (Virginia Tech, 2018a), and is occupied daily by about 32,000 students and 7,700 faculty and support staff (Virginia Tech, 2018b). The campus resides in the Southern Limestone/Dolomite Valleys and Low Rolling Hills Level IV Ecoregion within the Ridge and Valley Level III Ecoregion (EPA, 2015). The natural forest cover type in this area is Oak-Hickory (Eyre, 1980). Since the beginning of European settlement in the mid-18th century, the campus area has been under continuous agricultural and increasingly urban land use. Smithfield Plantation (circa 1774) and Solitude (circa 1801) were the major land holdings that pre-dated the university's establishment in 1872 (Historic Smithfield, 2018; Virginia Tech, 2018c). Early photos of campus suggest that almost all existing native forest was cleared for agricultural purposes (**Figure 1, Figure 2**). Remnant forests and naturally occurring trees are largely restricted today to the Old-Growth Forest near Lane Stadium, the Grove, the lower drainage of Stroubles Creek, and derelict areas of the western agricultural fields. Otherwise, almost every landscape tree on campus has been purposely planted during the past 146 years. Campus photos from the early and mid-20th century suggest that landscape trees were aggressively planted as buildings and streets were constructed around the perimeter of the Drillfield (**Figure 3, Figure 4, Figure 5**). A close look at period photos suggests that deciduous shade trees such as maples, oaks, and elms, and conifers such as spruces and pines were predominantly planted.

As the university continues to grow and in-fill development urbanizes the main campus, there is need to understand the urban forest assets that reside there. Trees provide numerous benefits to the character, sustainability, and livability of campus. The bucolic character of campus has long been a key selling point of the university and figures prominently into its branding. The university has made multiple commitments in response to contemporary concerns over quality of life and campus sustainability that better reflect current values

Figure 1. View of the Virginia Polytechnic Institute campus in 1887, taken from unknown vantage point (Virginia Tech ImageBase, 2018a).



View of the V.P.I. Campus looking west from Academic Building No.2. House in foreground was built for Prof. V. E. Shepard's residence, later occupied by Prof. William B. Alwood, and still later used as the Administration Building. In the background may be seen the station building, greenhouse and Solitude, former home of Col. Robert T. Preston, built in 1859. Near the grove may be seen the old barns. Photo by Prof. E. A. Smyth about 1891.

Figure 2. View of the Virginia Polytechnic Institute campus in 1891. Inset caption describes photo details. Note that the Grove is visible on the high ridge in the background (Virginia Tech ImageBase, 2018b).

Figure 3. View of the Virginia Polytechnic Institute and State University campus in 1916, taken from unknown vantage point (Virginia Tech ImageBase, 2018c).

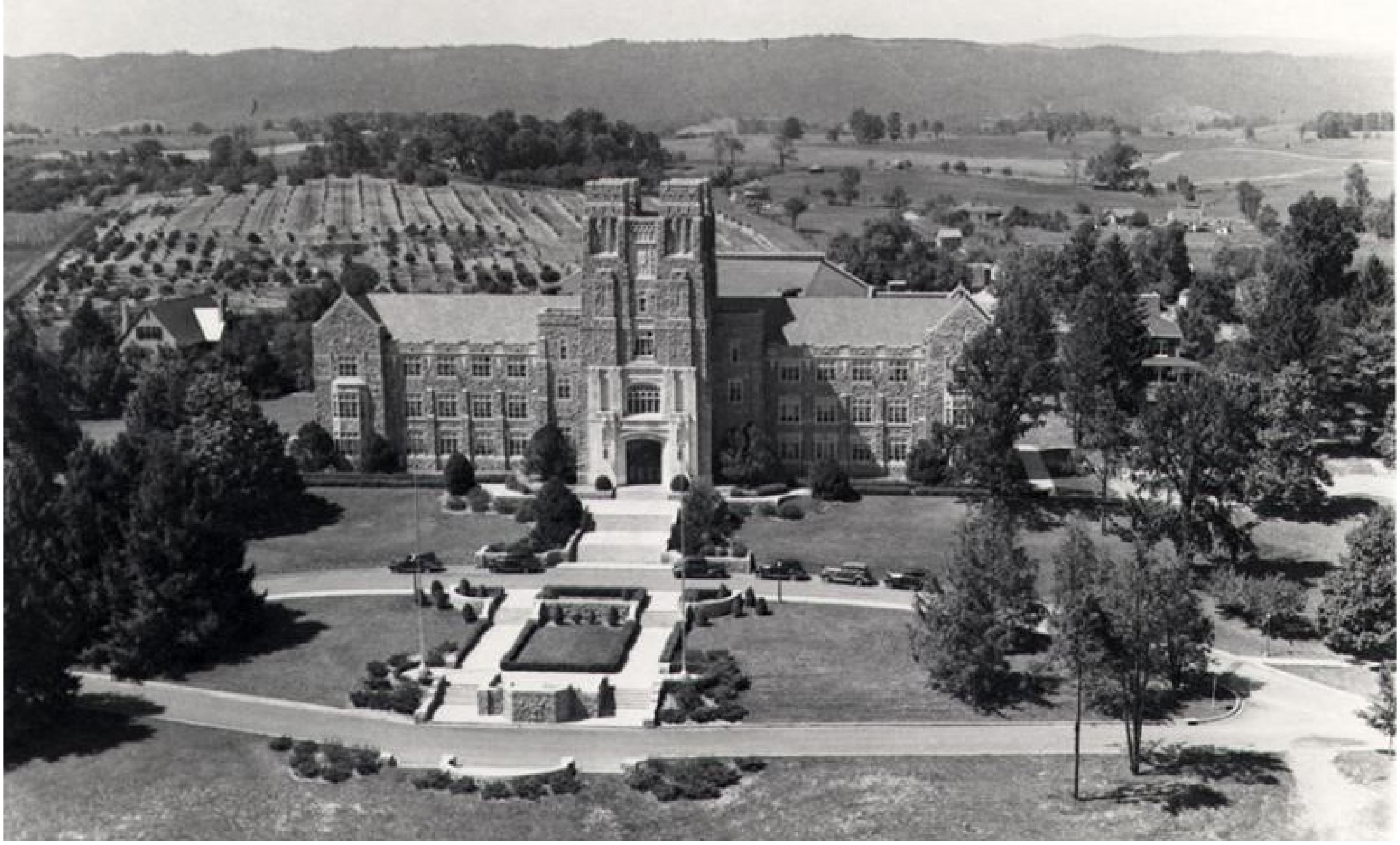


Figure 4. View of Burruss Hall on the Virginia Polytechnic Institute and State University campus in 1939. Orchards are visible in the background (Virginia Tech ImageBase, 2018d).

of the student body, faculty, and staff. Through ecosystem services such as carbon sequestration, air pollution abatement, stormwater runoff mitigation, and building energy conservation, campus trees help both the economic and environmental bottom-line of the university. As the campus becomes more urbanized, trees will play an important role in offsetting the negative social and psychological impacts of extensive hardscape, noise, glare, and heat islands. For Virginia Tech to create an environment where talented people want to work, study, and live, it needs to carefully plan, manage, and protect its urban forest assets. Conducting a comprehensive tree inventory is the first step in that process in understanding the existent opportunities and constraints in these forest assets.

There are historical anecdotes and scattered archival documents suggesting that piece-meal tree inventories have been performed on campus throughout the university's history. Dr. William Bradford Alwood—professor of horticulture, entomology, and mycology at Virginia Agricultural and Mechanical College (now Virginia Tech) from 1891 to 1904—perhaps carried out one of the first campus tree inventories around 1902. It was during that inventory that he documented an iconic campus tree—the bur oak (*Quercus macrocarpa*) that stands today on the north side of the Drillfield and was ceremoniously named the Alwood Oak in 2011 to recognize the multiple contributions that Dr. Alwood made to the university during his time there (Virginia Tech,

Figure 5. View of Seitz Hall on the Virginia Polytechnic Institute and State University campus in 1951 Northern red oaks in foreground and Sawara-cedar in background still exist today (Virginia Tech ImageBase, 2018e).

Figure 6. Photo of a bur oak (*Quercus macrocarpa*) on the Virginia Tech campus taken in September 1902 by Dr. William Alwood as part of his campus tree inventory. This is believed to be the large bur oak (now known as the Alwood oak) that stands today on the north side of the Drillfield (Photo from University Archives).

2011). The tree was inventoried by Dr. Alwood on September 11, 1902 (**Figure 6**). The seven-year-old bur oak was documented as tree number 66 and noted as being located next to the (now gone) Horticulture Hall. In 1932, Dr. Alwood donated his collection of inventory documents to the university and they reside in the University Libraries Special Collections today. More recently, a comprehensive existing vegetation map was created in 1979 **(Figure 7)**; a large-format copy of the map is in possession of the Massey Herbarium at Virginia Tech (J. Metzgar, personal communication, August 1, 2018). The map, which enumerates 156 distinct species, symbolizes trees as broad-leaved trees, coniferous trees, and wooded areas. Because there is no documentation of authorship on the map, the source, scope, and aim of the inventory is unknown.

In early 2006, Dr. Eric Wiseman, associate professor of urban forestry in the Department of Forest Resources and Environmental Conservation (FREC), undertook a comprehensive campus tree inventory aimed at creating a publicly-accessible web map of campus trees. Dr. Wiseman wrote a proposal for a teaching-learning grant from the Virginia Tech Center for Excellence in Undergraduate Teaching entitled 'A Web-based Geographic Information System (GIS) for Virginia Tech Campus Trees'. He was awarded a $2,000 grant to hire student interns and carry out the field inventory. Over a five-year period, Dr. Wiseman directed several cohorts of students in conducting the comprehensive inventory of landscape trees in maintained areas on main campus. These data comprised species, trunk diameter, condition, and spatial location for close to 6,000 trees. This information was stored in a geodatabase by the department, with an associated map viewable on a departmental website (**Figure 8**).

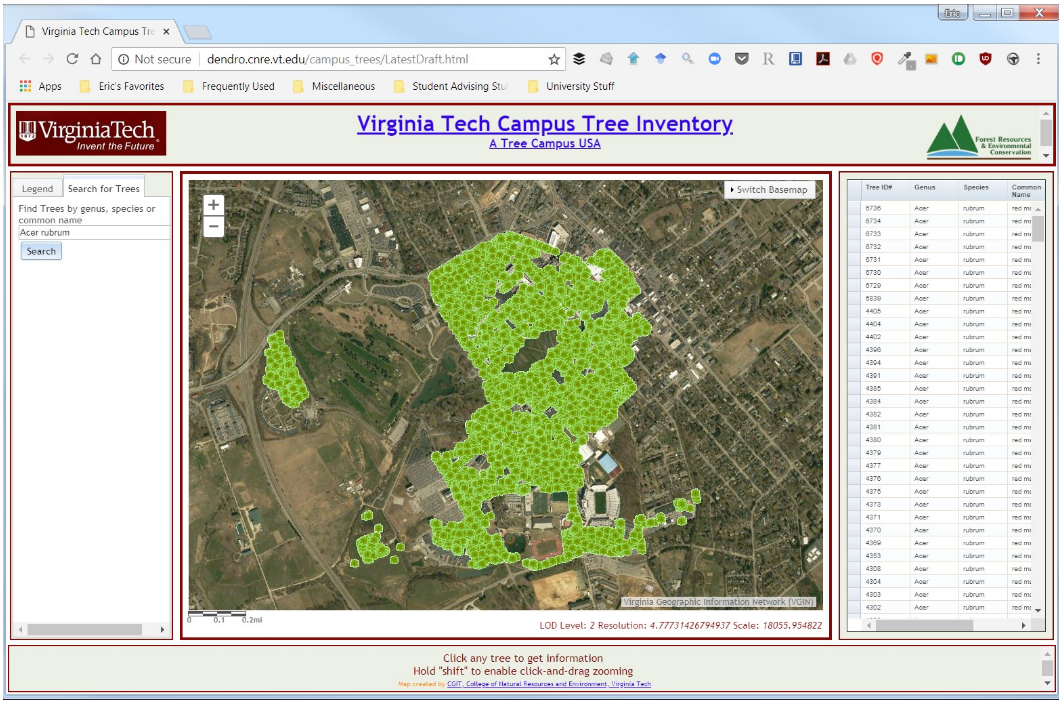
When a proposition was made by the university in 2012 to construct an indoor athletic practice facility on the eastern border of main campus, an inventory project was undertaken to document trees in the 11-acre forest known as Stadium Woods (Old-Growth Forest). The inventory, undertaken as a service project by the New River Master Naturalists and affiliated volunteers, documented the species and location of over 260 late-successional white and black oaks over 20 inches in trunk diameter (Walters, 2016).

In early 2017, discussions among faculty and staff engaged with planning and management of the campus urban forest clarified the need for an updated and expanded tree inventory. Spurred in part by work on the 2017 update to the Campus Master Plan, the Office of University Planning (OUP), within the Facilities Department, partnered with FREC to outline a comprehensive update to the tree inventory. The chosen approach was to employ a graduate assistant enrolled in the FREC graduate degree program to collect, archive, map, and analyze the inventory data in collaboration with key faculty and staff. The vision was that the inventory data would prove instrumental to facilities management, grounds management, capital project planning, sustainability planning, and community outreach. The inventory also helps fulfill standards of the Tree Campus USA designation granted to the university by the Arbor Day Foundation—a designation the university has held since 2008. From an urban forest management standpoint, the inventory data are critical to decision-making on tree planting, maintenance, protection, risk assessment, and succession planning. The inventory data enable systematic management, ensuring data-driven decisions and prioritized, efficient deployment of human and capital resources to manage the urban forest.

SCOPE AND LIMITATIONS OF THIS INVENTORY REPORT

While the tree inventory data have a range of possible uses, the primary objective of this report is to provide an assessment of the campus urban forest for the purpose of landscape planning – specifically to aid strategic tree planting and preservation based on a range of urban forest analyses. Additionally, supplemental analyses of ecosystem services and economic value have been included to demonstrate the social and environmental rationale for maintaining and growing the campus urban forest.

Figure 7. Photo of large-scale map of existing vegetation on main campus of Virginia Polytechnic Institute and State University, dated November 19, 1979 (Courtesy of Massey Herbarium).



Virginia Tech Campus Tree Inventory

A Tree Campus USA

Find Trees by genus, species or common name: Acer rubrum

Search

	Tree ID#	Genus	Species	Common Name
	6736	Acer	rubrum	red ma
	6734	Acer	rubrum	red ma
	6733	Acer	rubrum	red ma
	6732	Acer	rubrum	red ma
	6731	Acer	rubrum	red ma
	6730	Acer	rubrum	red ma
	6729	Acer	rubrum	red ma
	6839	Acer	rubrum	red ma
	4405	Acer	rubrum	red ma
	4404	Acer	rubrum	red ma
	4402	Acer	rubrum	red ma
	4396	Acer	rubrum	red ma
	4394	Acer	rubrum	red ma
	4391	Acer	rubrum	red ma
	4385	Acer	rubrum	red ma
	4384	Acer	rubrum	red ma
	4382	Acer	rubrum	red ma
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	4380	Acer	rubrum	red ma
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	4376	Acer	rubrum	red ma
	4375	Acer	rubrum	red ma
	4373	Acer	rubrum	red ma
	4371	Acer	rubrum	red ma
	4370	Acer	rubrum	red ma
	4369	Acer	rubrum	red ma
	4353	Acer	rubrum	red ma
	4308	Acer	rubrum	red ma
	4304	Acer	rubrum	red ma
	4303	Acer	rubrum	red ma
	4302	Acer	rubrum	red ma

LOD Level: 2 Resolution: 4.77731426794937 Scale: 18055.954822

Click any tree to get information
Hold "shift" to enable click-and-drag zooming
Map created by CGIT, College of Natural Resources and Environment, Virginia Tech

Figure 8. Website created to display campus tree inventory data that was collected during the 2006–2011 timeframe by students in the Virginia Tech Department of Forest Resources and Environmental Conservation.

As a result of this inventory, 10,625 records have been created for campus trees. This report focuses on the analysis of the subset of standing live and dead trees (8,566) at the time of the 2017–2018 inventory. At least 15 attributes and a photo were recorded for each tree. Of these attributes, the ones most relevant to this report are species identification, dimensional measurements, site variables, health and structure ratings, and maintenance recommendations. Using these measurements and ratings, this report provides an analysis of species composition, diversity, and age structure of the entire campus urban forest, along with a summary of tree health and structure ratings, growing conditions, and susceptibility to pests. Many of the same analyses are repeated at the smaller scale for campus master plan districts—which range in size from 30 to 190 acres—to allow comparisons between different parts of campus. Additionally, this report summarizes environmental benefits provided by the campus urban forest, including building energy savings, avoided runoff, air pollution removal, and carbon sequestration. Finally, this report makes some basic recommendations to enhance campus urban forest health, maintenance, and succession planning.

It is important to point out that this report is not a campus urban forest management plan. The inventory data and analysis are a source of information that—when interpreted in the broader context of campus challenges, opportunities, priorities, and capabilities—provide a foundation for crafting a management plan replete with goals, objectives, strategies, and actionable tasks. There are also limitations inherent to the tree inventory data. Because the bulk of the field inventory work was performed during the dormant season of 2017–2018, it was not possible to unequivocally evaluate the health and identify the species of all deciduous trees due to the absence of foliage. Likewise, observations of trees were made at ground level from a limited visual perspective, so not all possible conditions of concern with tree health and structural integrity could be observed.

In this report, qualitative ratings of tree structure are given. These ratings alone do not indicate overall risk associated with a tree. Instead, the ratings give an indication of the stability of the tree and therefore provide some insight into the likelihood of a tree failure. Judgment of the overall risk associated with a given tree would require further information about the site conditions and the potential consequences of a tree failure. Further, in identifying maintenance needs of trees, a parsimonious approach was taken whereby needs were only documented if they fell within the scope and capabilities of typical grounds maintenance on campus. In some cases, maintenance needs may have been observed that could be addressed for sake of tree health, but would fall outside the bounds of typical grounds maintenance, and therefore were not recorded.

2. Methods

INVENTORY PLANNING AND DESIGN

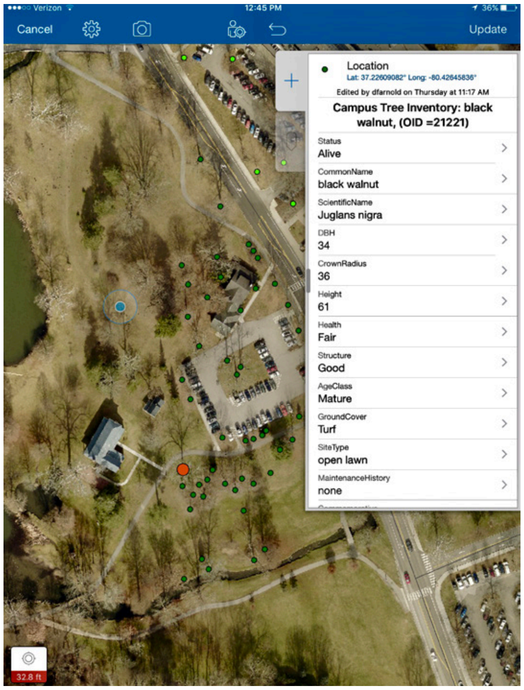
Collaborators on the inventory project convened in August 2017 to discuss project objectives, data model design, and data collection strategy. Virginia Tech Facilities GIS initially created a point feature class with a data model specific to the project objectives, in consultation with FREC and OUP. This data model included 19 tree attributes and linked photo storage for each point feature (tree), with values tied to digital drop-down lists for 14 of these attributes, thereby simplifying data collection and reducing the possibility for errors in data recording. Along with high-resolution leaf-off pictometry and other campus infrastructure layers, this point feature class was published as a hosted map service in ArcGIS Online (ESRI, Redlands, CA). The approximately 6,000 existing tree records from previous inventories were used to populate this new point feature class, in which the display color of each point would automatically change during data collection, once records had been updated. This online inventory map was accessible and editable in desktop ArcMap software, as an in-browser web map, or on a mobile device using the ESRI Collector App. A more detailed description of the GIS environment is included in **Appendix A**. Once the inventory protocol was finalized and the data model was installed on the field computer, the collaborators held a field training session during which the work flow procedures were simulated, including aspects of tree measurements, attribute classification, data entry, and data storage.

Figure 9. Urban forestry graduate student Peter Stewart collecting field inventory data in September 2017 on the main campus of Virginia Tech in Blacksburg, VA (Virginia Tech, 2017).

FIELD DATA COLLECTION

Field data were collected from August 2017 to March 2018 by graduate assistant Peter Stewart (**Figure 9**). Shown in **Figure 11** the geographic extent of the area where trees were inventoried. For analysis and reporting purposes, the inventory area was subdivided into campus master plan districts (**Figure 12**). All landscape trees greater than 1" DBH were inventoried in maintained areas of main campus, including the grounds of Smithfield Plantation, Oak Lane, and the Golf Course. In natural areas around the Grove and the Duck Pond, only trees greater than 12" DBH were inventoried. Previously inventoried trees in the Old-Growth Forest were not inventoried again, but their prior data are included in certain analyses presented here. Not enumerated during the field inventory were trees residing at outlying facilities south of Southgate Drive and the various agricultural and unmaintained lands within main campus. Also, one of the campus master plan districts – Autonomous Study Park – fell within the geographic scope of the tree inventory, but no trees there met the criteria for inclusion in the inventory. As a result, graphs of tree attributes by district shown later in the report omit the Autonomous Study Park district.

All field data were recorded using the ESRI Collector App installed on an iPad Pro tablet (Apple, Cupertino, CA). Shown in **Figure 10** is a screenshot of the iPad field data collection interface, with inventoried trees represented as green dots, and displaying the first 12 of the collected attributes for a processed tree (red dot). Tree photos were taken with the iPad's internal camera and associated with individual tree records in the database. Tree height and canopy radius were measured with a Forestry Pro laser hypsometer (Nikon, Tokyo, Japan) and a DLR130 laser distance measurer (Bosch, Farmington Hills, MI), respectively. Tree diameter was measured with a Biltmore stick and verified with a diameter tape for stems greater than 40" DBH. Descriptions of all other attributes and criteria for specific values are included in **Appendix B**.



Location
Lat: 37.22609082° Long: -80.42645836°
Edited by dfarnold on Thursday at 11:17 AM

Campus Tree Inventory: black walnut, (OID =21221)

Status	Alive
CommonName	black walnut
ScientificName	Juglans nigra
DBH	34
CrownRadius	36
Height	61
Health	Fair
Structure	Good
AgeClass	Mature
GroundCover	Turf
SiteType	open lawn
MaintenanceHistory	none

Figure 10. A screenshot of data collection using ESRI's Collector App. Inventoried trees are represented as green dots, overlaid on leaf-off campus pictometry. Twelve of 19 attributes recorded for each tree are visible in the box to the right of the screen.

INVENTORY DATA ANALYSIS

Upon completion of field data collection, the entire data set was carefully screened for missing, erroneous, illogical, and out-of-range values and then corrected accordingly. Descriptive statistics for tree attributes were calculated using Microsoft Excel. Distance and direction from each tree to a nearby (<60 feet) building were calculated in ArcMap. Data visualizations were created using Tableau software (Tableau Software, Seattle, WA). Ecosystem services and economic value of campus trees were analyzed using i-Tree Eco version 6 software. This urban forest assessment software was created by the USDA Forest Service and Davey Resource Group to enable users to quantify and monetize certain benefits provided by trees in urban areas (i-Tree Tools, 2018). The software employs mathematical models that integrate user-provided tree inventory data with local preprocessed weather data, local air pollution concentration data, and ecosystem service valuation data. Relevant output records from i-Tree Eco are provided in four files archived along with this report in a digital repository of Virginia Tech's University Libraries (VTechworks, 2018).

Figure 11. Aerial photo of the main campus of Virginia Tech in Blacksburg, VA showing the geographic extent of the tree inventory.

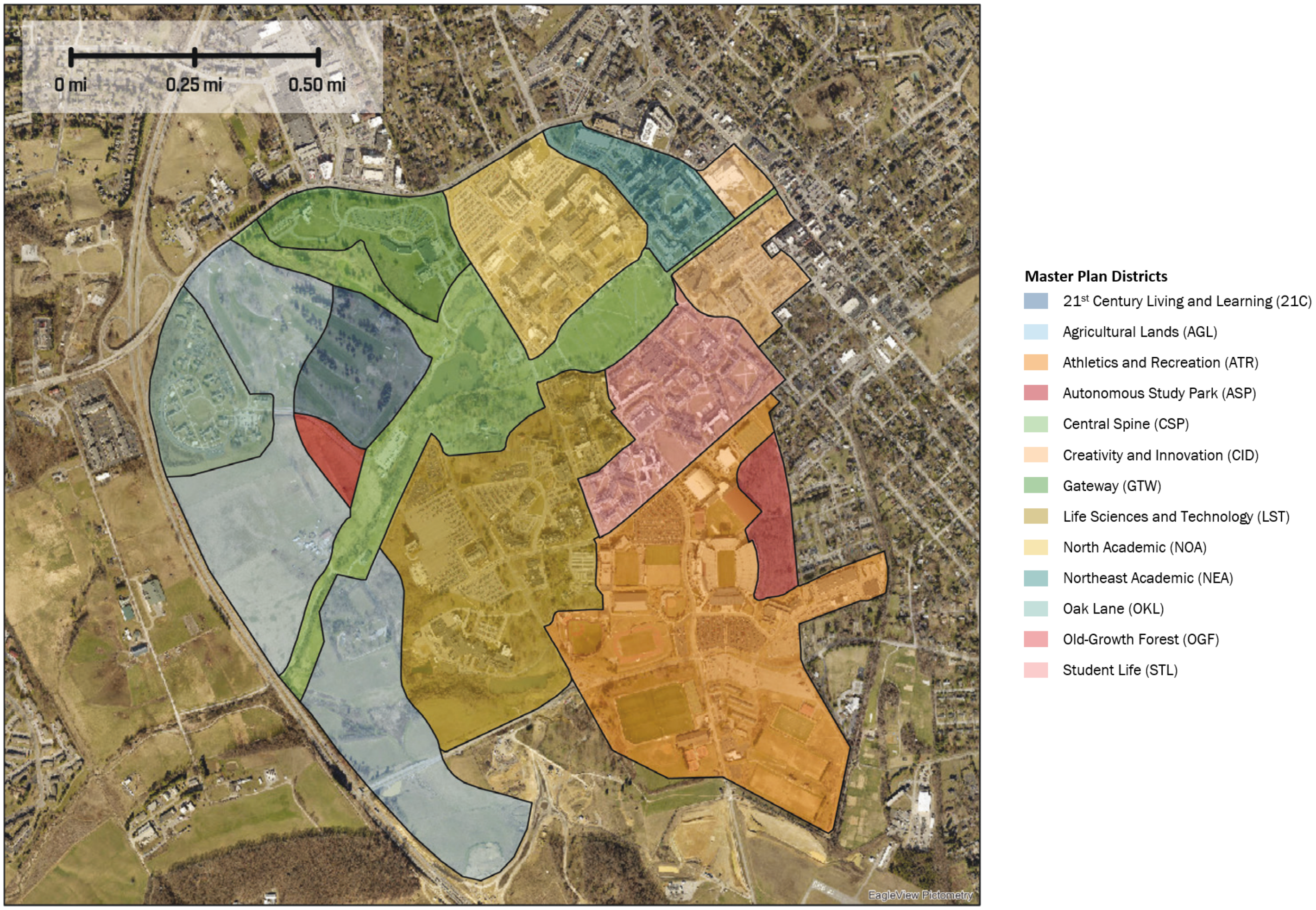


Figure 12. Aerial photo of the main campus of Virginia Tech in Blacksburg, VA showing the geographic extent of the tree inventory overlaid by campus master plan districts. Trees were inventoried in all but two districts. No trees met the criteria for inventory inclusion in the Autonomous Study Park and trees in the Old-Growth Forest had been previously inventoried in 2012.

Figure 13. Aerial photo of the main campus of Virginia Tech in Blacksburg, VA showing the location of 10,625 tree records that were curated in the tree inventory. Light green points are 548 trees in the Old-Growth Forest that were not updated in the current inventory. Dark green points comprise 8,352 living trees, 214 standing dead trees, and 1,511 trees removed since the previous inventory in 2006–2011.

3. Inventory Findings

CAMPUS TREE ABUNDANCE AND SPECIES COMPOSITION

A total of 10,625 tree records are now curated in the inventory for the main campus of Virginia Tech **(Figure 13)**. These tree records comprise the following:

- 548 trees in the Old-Growth Forest that were not updated in the current inventory
- 10,077 trees elsewhere on campus that were updated in the current inventory, including:
  - 1,511 trees removed since the previous inventory in 2006–2011
  - 8,352 living trees
  - 214 standing dead trees

Unless otherwise noted, the statistics reported in the remainder of this report pertain to the 8,566 living trees and standing dead trees that were updated during the current inventory. **Figure 14** shows the total number of trees inventoried in each campus master plan district. The greatest number of trees are in the Life Sciences and Technology District and the Central Spine District—together they account for about 40% of the tree population. In the Autonomous Study Park District, no trees there met the criteria for inclusion in the inventory. As a result, this district is omitted from **Figure 14** and several subsequent graphs of tree attributes by district.

Species identification was possible for 8,542 of the living trees and standing dead trees. The campus urban forest comprises 221 species from 89 genera. About 79% are broadleaf trees and 21% are conifers. Of all trees identified at the species level, 69% are native to Virginia, and an additional 3% are native to

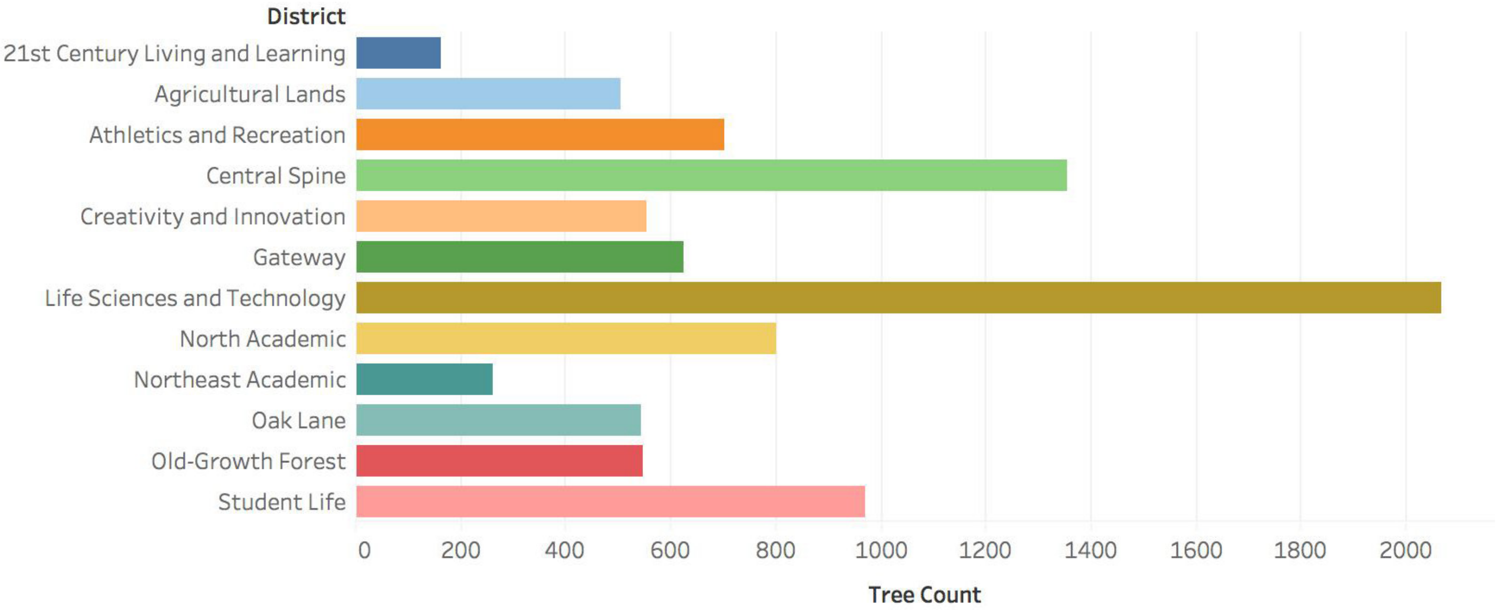


Figure 14. Count of total standing trees (alive and dead) by campus master plan district on the main campus of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees. Note that the 548 trees in the Old-Growth Forest district comprises only trees greater than 20" trunk diameter whereas other districts include trees greater than 1" trunk diameter (maintained areas) or 12" trunk diameter (natural areas).

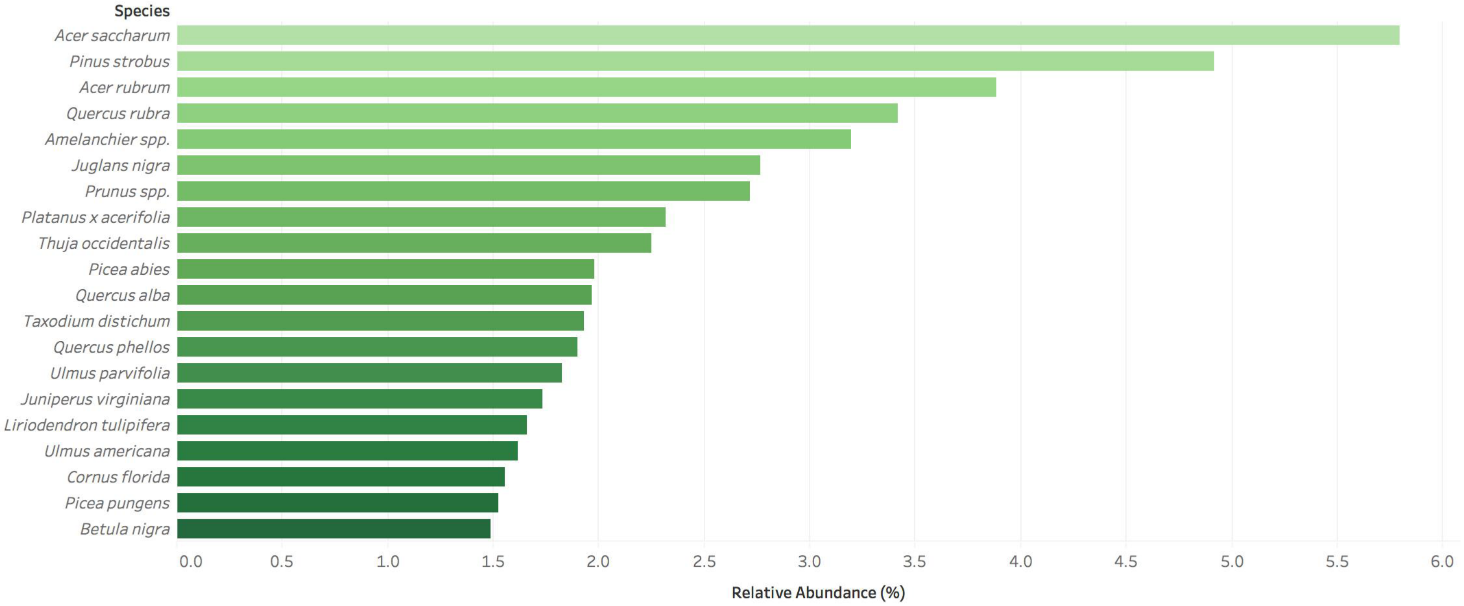


Figure 15. Relative abundance (percent of total tree population) of the 20 most common tree species on the main campus of Virginia Tech in Blacksburg, VA. These species account for about 50% of the total tree population of 8,542 living trees and standing dead trees.

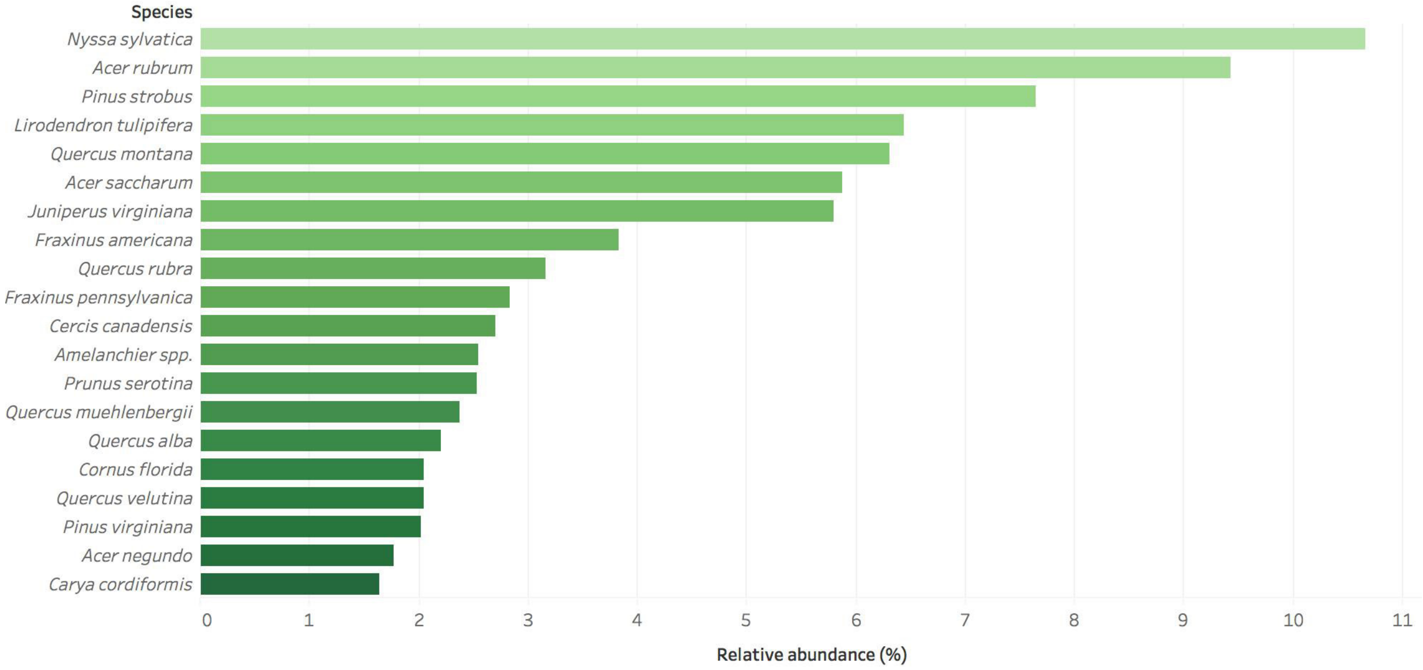


Figure 16. Relative abundance (percent of total tree population) of the 20 most common tree species found in rural forests of Montgomery County, VA. Data are taken from USDA Forest Service, Forest Inventory and Analysis (FIA) Program.

other U.S. states. Non-native species that have naturalized to the U.S. comprise 25% of campus trees, while the remaining 3% are exotic species. A comparison of the campus urban forest to surrounding rural forests using data from a 2016 USDA Forest Service Forest Inventory and Analysis (FIA) report reveals similarities in species composition. **Figure 15** shows the 20 most common species on campus and **Figure 16** shows the 20 most common species in nearby forests. Some of the most common species in nearby forests are much less prevalent on campus. For instance, the 1st and 4th most abundant species in rural forests of surrounding Montgomery County—*Nyssa sylvatica* and *Liriodendron tulipifera*—rank as only the 39th and 16th most abundant species on campus. Species richness (the number of species in the tree population) is much higher on campus than in nearby forests, as is species diversity as measured by the Shannon Index. On the other hand, species evenness (how balanced the number of trees are in each species) is higher in nearby forests. These statistics are given in **Table 1**. Urban forest composition is influenced by nearby rural forest composition because forest fragments and remnant trees often get incorporated into the urban forest as development occurs. So it is common to find similarities in species composition between the two. However, urban forest composition is altered by people who choose to eliminate certain native trees (because they are undesirable or fail to thrive) and choose to plant non-native trees with desired cultural or aesthetic characteristics. This has particularly been the case on the Virginia Tech campus because the vast majority of trees have been planted, rather than naturally regenerated, as the campus transitioned from agricultural to urban land use.

Understanding species composition is relevant to both the ecology and the functionality of the urban forest. Species vary considerably in their adaptability to urban environments—those that adapt poorly will experience both poor health and shortened lifespans, and frequent maintenance may be required to keep them healthy, safe, and attractive. Likewise, the physical characteristics of a species dictate the types of ecosystem services that it can provide as well as the potential hazards, nuisances, and conflicts that it may pose. Species composition also influences the vulnerability of a tree population to diseases and pests. Because harsh growing conditions and scarce maintenance dollars can shrink the palette of adaptable species in an urban forest, low species diversity is often encountered in urban areas. This diminishes the resiliency of the urban forest and can lead to considerable tree losses and mitigation expenses when a disease or pest is introduced to an area.

A common criterion for evaluating species diversity of an urban tree population is called Santamour's 10-20-30 rule (Santamour, 2004), which stipulates that no single species should exceed 10% of all trees, no single genus more than 20%, and no single family more that 30%. Virginia Tech's campus urban forest stays easily within these limits. Shown

Table 1. Diversity statistics for the campus urban forest of Virginia Tech and the surrounding rural forest of Montgomery County.

Forest type	Species Richness (Number of species)	Shannon's Diversity Index (H')	Pielou's Evenness Index (J')
Virginia Tech Campus Urban Forest	221	4.41	0.488
Montgomery County Rural Forest	47	3.26	0.858

in **Figure 17** is the breakdown of the five most common taxa at the family, genus, and species level for all trees campus-wide. The most abundant species, *Acer saccharum* (sugar maple), makes up about 6% of all trees; the most abundant genus, *Quercus*, includes about 15% of all trees, and the most abundant family, *Fagaceae*, includes about 17% of all trees.

A more stringent criterion offered by (Leff, 2016) judges an urban forest to have 'optimal' species diversity only when *each* neighborhood's tree population meets the 10-20-30% standard and its *overall* tree population meets a stricter standard of 5%, 10%, and 15% for species, genus, and family abundance, respectively. If campus master plan districts are substituted for neighborhoods in this evaluation, Virginia Tech's tree diversity does not meet either of these more stringent standards. At the district level, there are issues with over-abundance of pines in the 21st Century Living and Learning District, maples in the Athletics and Recreation District, and oaks in the Oak Lane District **(Figure 18)**. However, within 4 of 11 districts, relative abundance of taxa meet the 10-20-30% standard. The more stringent 5-10-15% standard campus-wide indicates issues with over-abundance of *Pinus strobus* and *Acer saccharum* at the species level, *Acer* and *Quercus* at the genus level, and *Fagaceae* at the family level.

An expanded look at species diversity by district is shown in **Figure 19**, displaying the five most abundant species in each district. Notably, *Pinus strobus* shows over-abundance in the 21st Century Living and Learning District, Agricultural Lands District, and Gateway District. Similarly, *Acer saccharum* is over-abundant in Athletics and Recreation District and Northeast Academic District, and *Quercus acutissima* is over-abundant in Oak Lane District. Overall, these are minor infractions of the diversity standards and pose no significant vulnerability to the tree population. The over-abundance of *Pinus strobus* is most problematic in the 21st Century Living and Learning District, but this is a consequence of their planting along fairways on the Golf Course, and many of them will likely not be retained as those lands are redeveloped in the future.

Assessing diversity based solely on relative abundance (stem count) provides an incomplete picture of diversity in terms of the contributions that individual species make to the biomass and ecosystem services of the urban forest. This is because species vary considerably in their size. For example, flowering dogwood (*Cornus florida*) and white oak (*Quercus alba*) are vastly different in their typical sizes. Hypothetically, a tree population comprising just these two species could be stocked predominantly with dogwoods, yet have almost all of the biomass in the larger white oaks. Therefore, an additional measure commonly employed is called the Relative Importance Value. **Figure 20** shows the top 20 species on Virginia Tech's campus, as ranked by importance value. It is called importance because it conveys the contribution that a species makes to the structure and function of a forest. This metric is calculated by adding the relative abundance (percentage of total stem count) of a species to its relative leaf area (the percentage of all leaf area in the forest belonging to that species). Leaf area is a sum total of the surface area of all foliage in the tree canopy and is calculated by i-Tree Eco using allometric equations that incorporate tree measurements obtained during the inventory. Because the most abundant species on campus tend to also be large trees, there is not much difference in the upper rankings of the most abundant and most important species. The notable difference is that *Amelanchier* spp. (serviceberry) is very common, but is not very important, because it is a small ornamental species. It is displaced by *Juglans nigra* (black walnut) in the top-five importance ratings.

SIZE AND AGE CHARACTERISTICS OF CAMPUS TREES

Trunk diameter, crown spread, and height were measured for each tree that was updated during the inventory. The distribution of these data are shown with histograms in **Figure 21**. Each histogram shows a right-skewed, asymmetric distribution that is typical of a relatively young, uneven-aged urban forest comprising numerous species. The mean trunk diam-

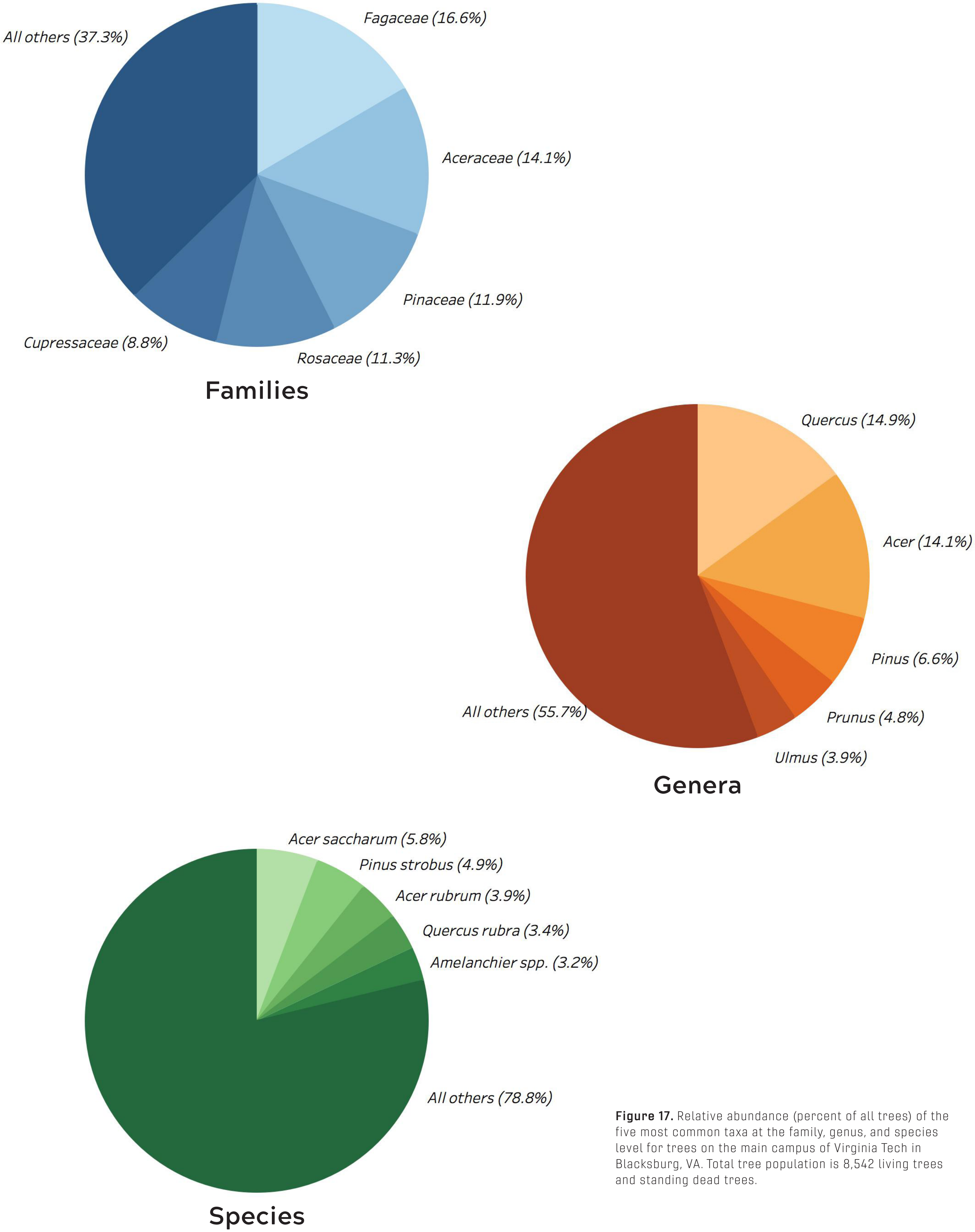


Figure 17. Relative abundance (percent of all trees) of the five most common taxa at the family, genus, and species level for trees on the main campus of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees.

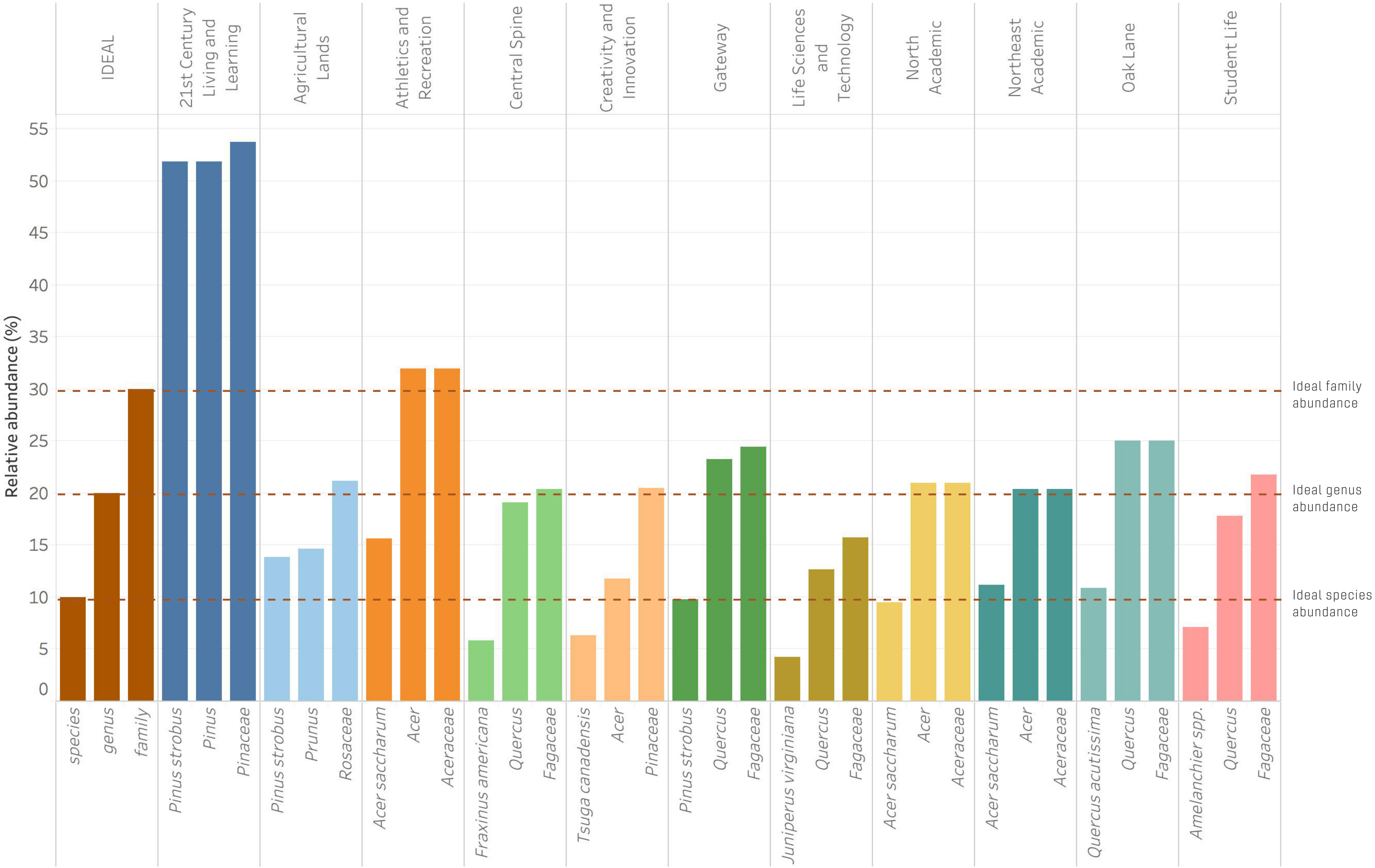


Figure 18. Relative abundance (percent of total tree population) of the most common taxa (species, genus, family) in each campus master plan district of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees. The left panel shows the ideal maximum abundance for each taxonomic level in a tree population.

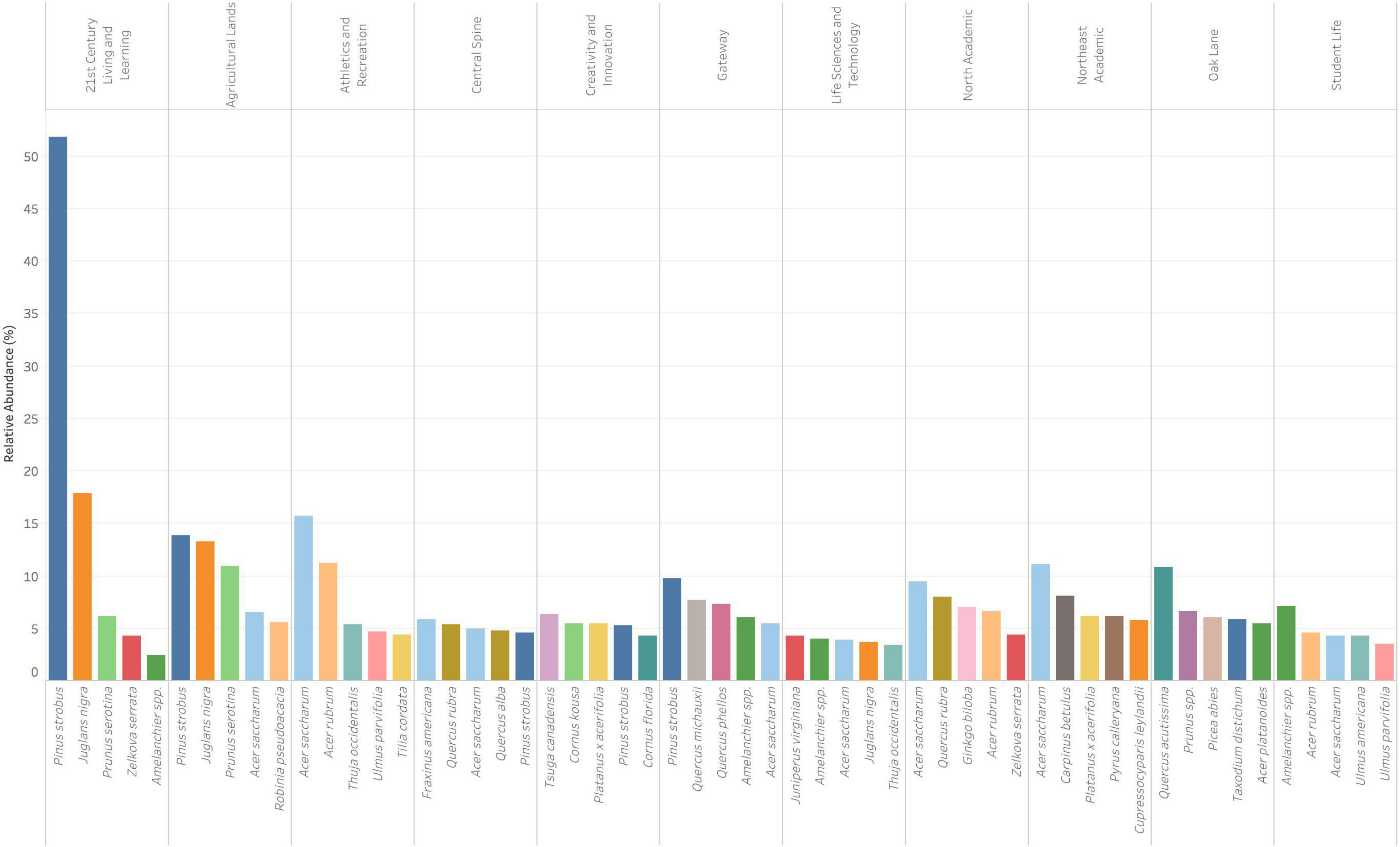


Figure 19. Relative abundance (percent of total tree population) of the five most common tree species in each campus master plan district of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees.

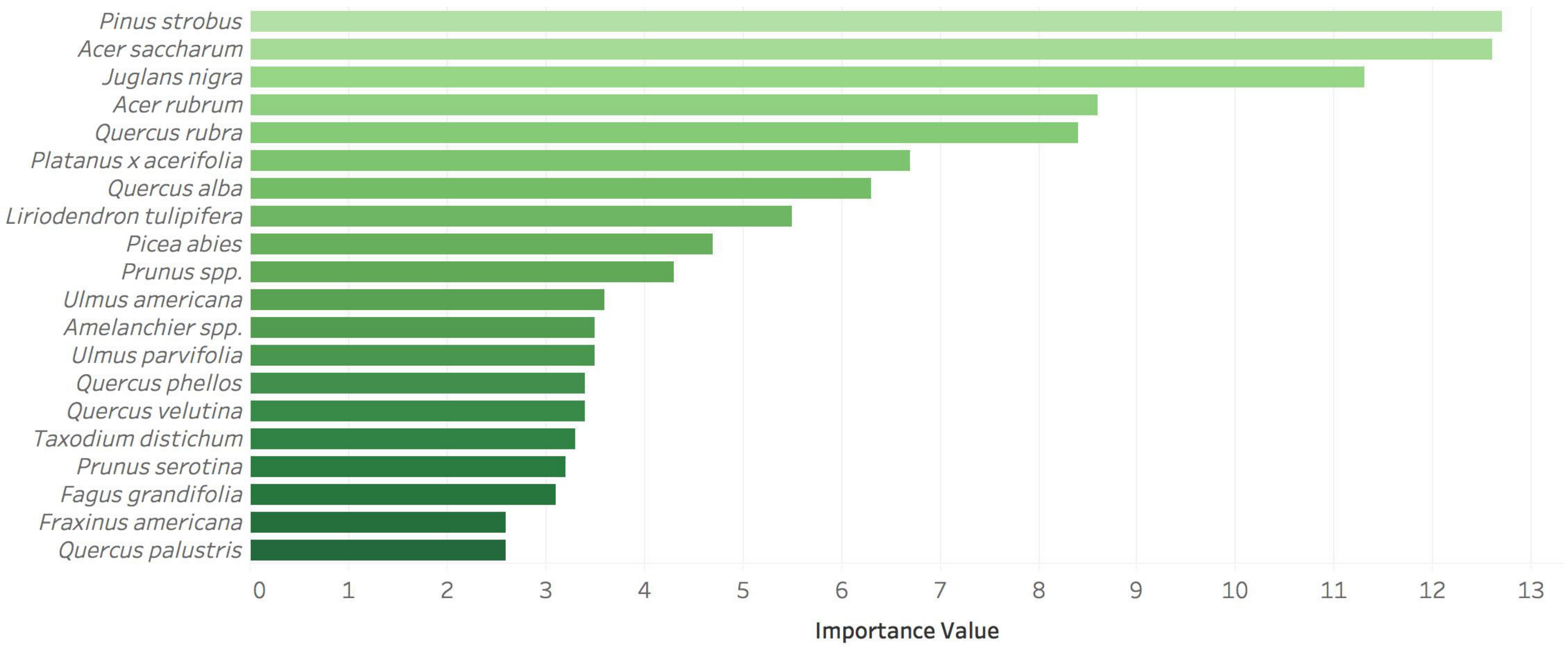


Figure 20. Top twenty species as ranked by relative importance (sum of relative abundance and relative leaf area) on the main campus of Virginia Tech in Blacksburg, VA. Compare to Figure 16 for relative abundance of tree species. Total tree population is 8,542 living trees and standing dead trees.

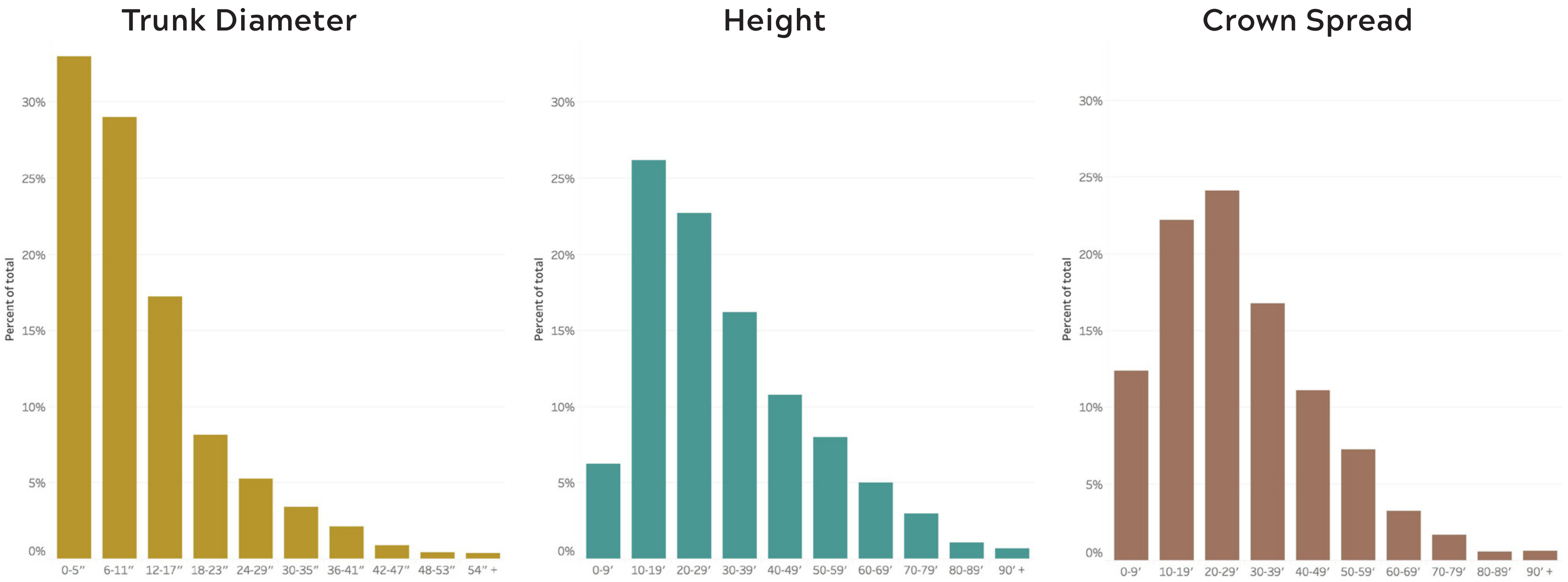


Figure 21. Distribution of the tree population by trunk diameter, crown spread, and height on the main campus of Virginia Tech in Blacksburg, VA. Shown in the x-axis is the lower limit of the measurement for each bin. Total tree population is 8,542 living trees and standing dead trees.

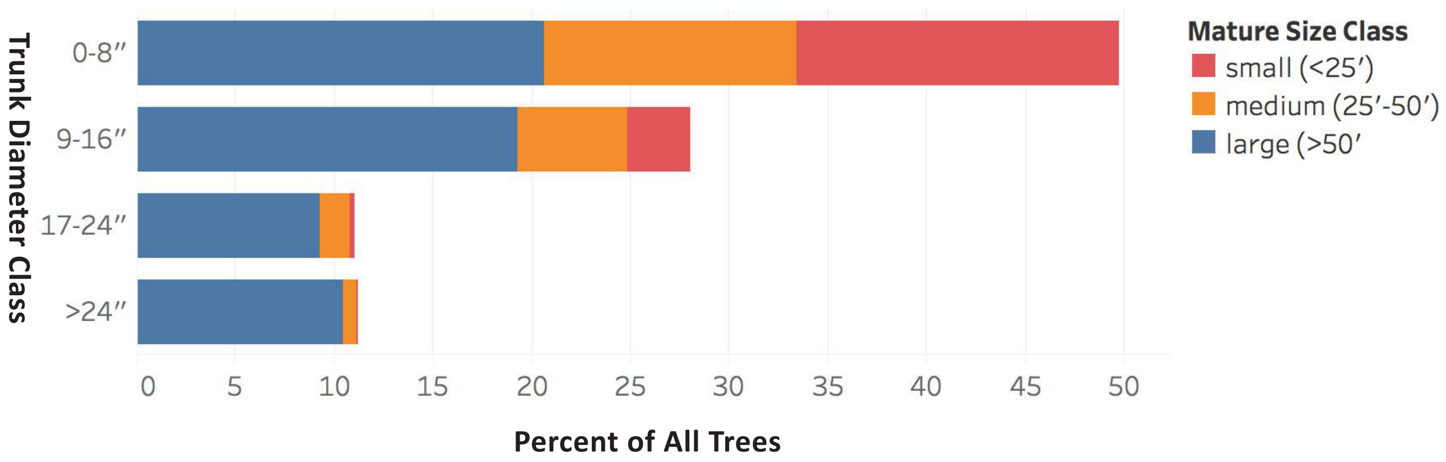


Figure 22. Distribution of the tree population across four trunk diameter classes on the main campus of Virginia Tech in Blacksburg, VA. Data are further classified by the mature height class (what height the species typically attains at maturity). Total tree population is 8,542 living trees and standing dead trees.

eter of all trees inventoried falls below six inches, the mean crown spread between 20 and 30 feet, and the mean height between 10 and 20 feet. Size characteristics of trees in the campus forest are relevant to numerous aspects of planning and management. For example, inferences can be made about the future growth potential of existing trees based on the differential between current tree size and typical mature tree size. This information can be important for predicting increases in biomass as well as maintenance needs. When combined with locational information, tree size can also predict future space needs for tree growth and how this might impact building encroachment, visibility, and solar access. Combined with other data collected during the field inventory, these measurements also provide insight into the age structure of the campus forest, both as a whole and by campus master plan districts.

The relative age of trees in an urban forest is helpful for understanding the future growth potential (i.e., how much canopy cover expansion might be expected from tree growth alone) and the long-term stability of the tree population (i.e., what might be expected for population attrition due to age-related mortality). Age distribution also gives insight into resiliency and expected maintenance needs of the urban forest because susceptibility to diseases and pests, inhospitable growing conditions, root disturbance, and storm damage tends to increase as trees age. Foresters commonly use trunk DBH distribution as an indicator of the age structure of a tree population. While this works well for merchantable timber species (which tend to be large-maturing species), it is an imperfect indicator in urban forests because the species diversity is much greater and there tends to be an abundance of small-maturing ornamental species. An 8” DBH flowering dogwood may be approaching old age whereas an 8” DBH white oak in still quite youthful. For this reason, each tree in this inventory was assigned an age class as well as having trunk DBH measured. The four age classes were young (recently transplanted), immature (beyond transplant establishment, but not having reach maturity), mature (reached typical expected size for the species in urban conditions), and over-mature (characteristics and symptoms of age-related senescence are evident). To provide further insight into the age and size characteristics, trees were also classified into mature height classes (what height the species typically attains at maturity): small (<25’), medium (25’-50’), and large (>50’).

Figure 22 shows the trunk DBH distribution of the campus tree population with a further breakdown by mature height class. A rule of thumb to judge population stability based on DBH distribution (Richards, 1983) stipulates that the tree population should be 40% trees of ≤8” DBH, 30% trees of 9”-16” DBH, 20% trees of 17”-24” DBH, and 10% trees of >24” DBH. This results in what foresters term an uneven-aged forest in which there is substantial stocking in the younger cohorts to ensure there are adequate mature trees in the future following natural attrition as the old trees die off. In this way, the population stays stable through time and there is continuity in ecosystem services and amenity benefits.

The DBH distribution of the campus urban forest follows the desired pattern of high stocking in the smaller DBH classes. Similar trends are seen when the data are broken down for each campus master plan district (**Figure 23**). While diameter distributions of many districts approach the Richards’ ideal, age distributions of trees in districts which have seen much development in recent years are clearly skewed towards younger trees, as seen in the Gateway District, the North

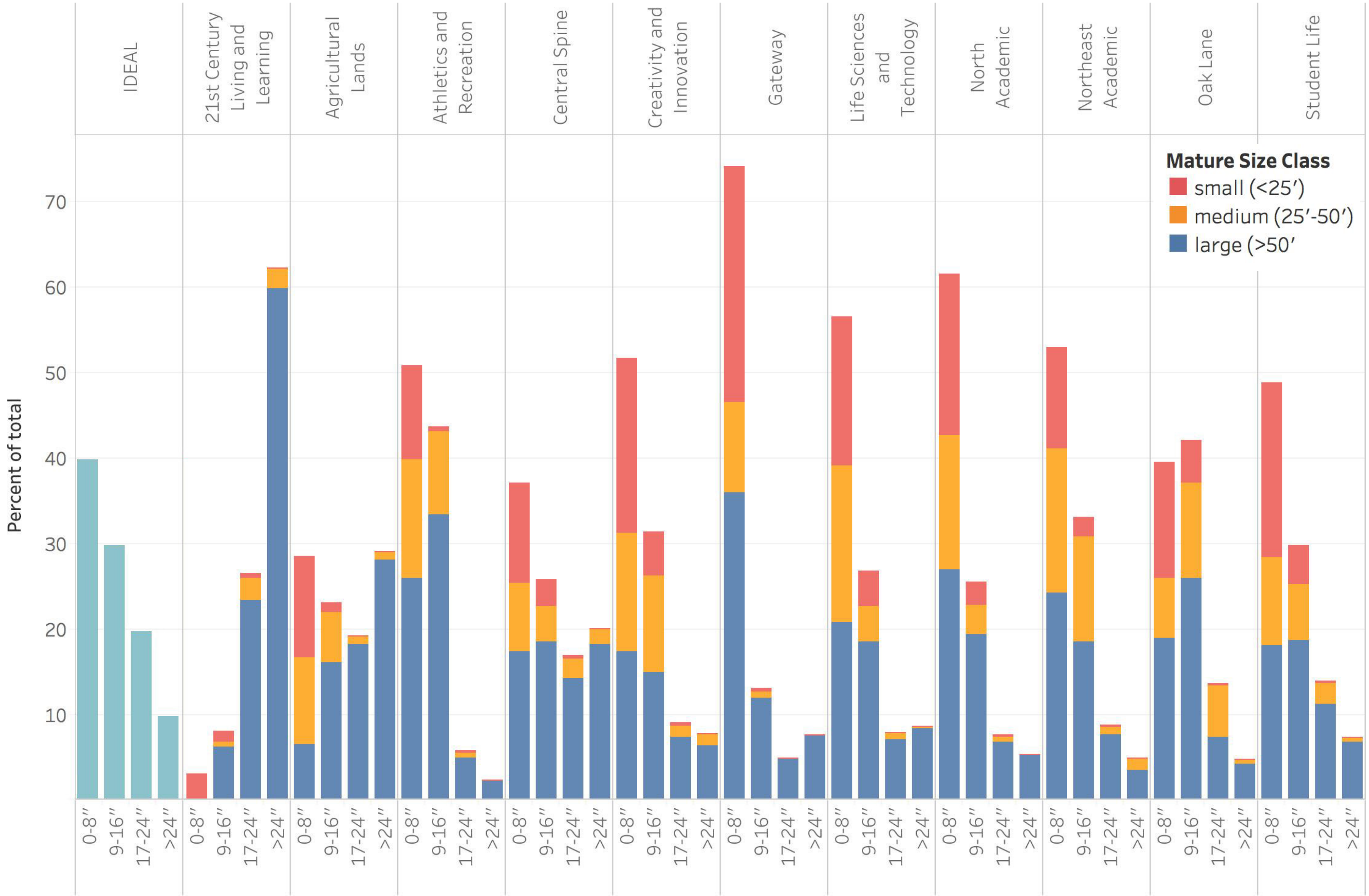


Figure 23. Distribution of the tree population across four trunk diameter classes in the campus master plan districts of Virginia Tech in Blacksburg, VA. Data are further classified by the mature height class (what height the species typically attains at maturity). Total tree population is 8,542 living trees and standing dead trees. The left panel shows the ideal maximum abundance for each diameter class in a tree population. Full names of the district abbreviations are provided at the front of the report.

Academic District, and the Life Sciences and Technology District. At the other extreme, tree age distributions in the 21st Century Living and Learning District and the Agricultural Lands District are heavily skewed towards older age classes. Returning to the overall campus distribution, there is a dip in the 17”-24” DBH class that suggests a lull in tree planting perhaps 25–35 years ago. This is indicative that the university must remain vigilant and committed to tree planting in perpetuity because there is practically no natural regeneration of trees on campus; almost all of them have to be planted.

The university must also stay committed to planting a diversity of mature height classes of trees. Large-maturing trees have more leaf area, canopy cover, and shade projection and tend to live longer than small-maturing species. As a result, they tend to provide greater ecosystem services and provide greater return-on-investment over their service life (USDA Forest Service, 2006). Large-maturing trees comprise about 60% of the campus tree population, which lends itself well to having long-lived trees with large and expansive canopies. Large-maturing trees are not suitable in all planting conditions such as where the soil volume is inadequate or aboveground growth may conflict with buildings, signs, or traffic flow. In those cases, smaller species would be more suitable.

Figure 24 shows the distribution of the campus tree population across four age classes. This is an admittedly subjective classification and provides no definitive indication of the potential longevity of trees. However, it does provide some additional insight into campus tree planting efforts and perhaps upcoming tree attrition due to old age. Over 80% of the trees are immature, suggesting a relatively youthful urban forest, which bodes well for the stability of the tree population. The young age class is very small, but it is important to understand that trees are in this age class for just the first few years following transplant; therefore, trees quickly ‘age out’ of this category. However, it does give some indication that relatively few trees have been planted on campus over the past two to four years. Anecdotal observations suggest that very few trees get planted on campus annually. There is considerable tree planting associated with each capital improvement, but sometimes those projects do not result in a net gain of trees because some existing trees are usually lost during construction. Typically, the only net gain occurs during the annual community tree planting events staged around Sustainability Week in the fall and Earth Week in the spring. And these are probably not truly net tree plantings given the number of trees removed annually due to natural attrition. The inventory revealed that about 1,500 trees had been removed since the prior inventory, which averages to about 135 trees removed annually. Tree plantings outside capital projects probably do not exceed this number. To maintain stability of the tree population over the next several decades, the university needs to make a greater commitment to increasing replacement tree plantings annually. Replacements need to exceed removals by at least a factor of 10% to 15% to account for early mortality from transplant shock, vandalism, and trafficking that often kill young trees.

The low percentage of campus trees classified as mature is concerning. Although there is no criterion for the optimal composition of mature trees, and myriad factors can contribute to trees not reaching maturity, there are some plausible explanations that merit the attention of the university. One factor is the infill development that has been occurring on campus over the past two decades. Inevitably, some trees will have to be removed when development occurs. However, the manner in which development is carried out can minimize losses of mature trees. For example, careful consideration should be given to existing tree assets early in the design process and reasonable adjustments in design should be made to incorporate, rather than displace, high-value trees. Moreover, appropriate tree preservation specifications must be written and enforced to protect trees on construction sites. Mature trees are particularly sensitive to construction disturbance due to their expansive root systems and low-vitality response to stress.

Beyond construction projects, Virginia Tech’s campus trees often reside in difficult growing conditions. Soil compaction and alkaline soil pH are the most common abiotic stresses experienced by campus trees that contribute to chronic decline and shortened lifespan. As a result, many trees do not reach maturity on campus. Compaction results from trafficking of soil within root zones by pedestrians and vehicles. As the campus has become denser and the community has grown larger, the incidence of soil compaction has undoubtedly increased. Few measures are taken on campus to prevent and alleviate soil compaction around high-value trees in high-traffic areas. Although used in some areas, mulching, groundcover vegetation, and fencing should be employed more widely around campus, and vehicular trafficking policies near trees should be more strongly enforced. Soil alkalinity can be equally problematic, but is difficult to prevent or remedy given the limestone bedrock underlying much of campus and the ubiquitous Hokie stone and concrete that leach calcium to the soil. Anecdotally, soil pH testing around campus trees in the course of teaching and outreach exercises by University faculty in Forestry and Horticulture has revealed pH levels ranging 7.2 to 8.5 in the highly developed landscapes. For this reason, species selection for alkalinity tolerance is important to ensure that planted trees will adapt to the soil conditions and thrive into maturity.

HEALTH AND STRUCTURE RATINGS OF CAMPUS TREES

Each tree’s health and structure were visually assessed from ground level during the inventory and given individual qualitative ratings of Poor, Fair, Good, or Excellent. Standing dead trees were designated as Dead within the health category and then given one of the above ratings for structure. Full definitions and indicators for each rating are provided in **Appendix B**. Health and structure were rated separately to draw distinctions between tree vitality and tree stability. The health rating is an indication of a tree’s ability to stay alive whereas

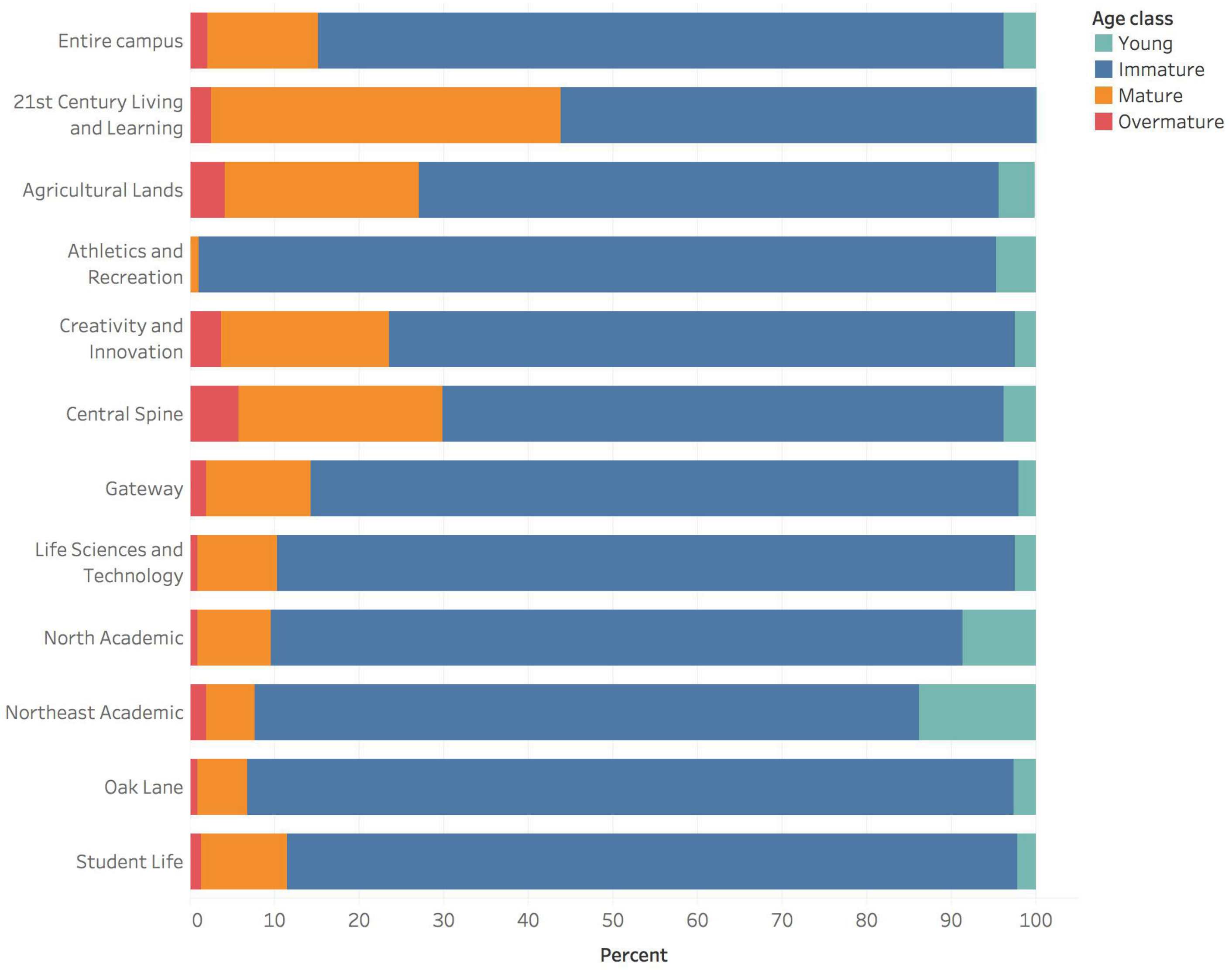


Figure 24. Distribution of the tree population across four age classes on the main campus of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees.

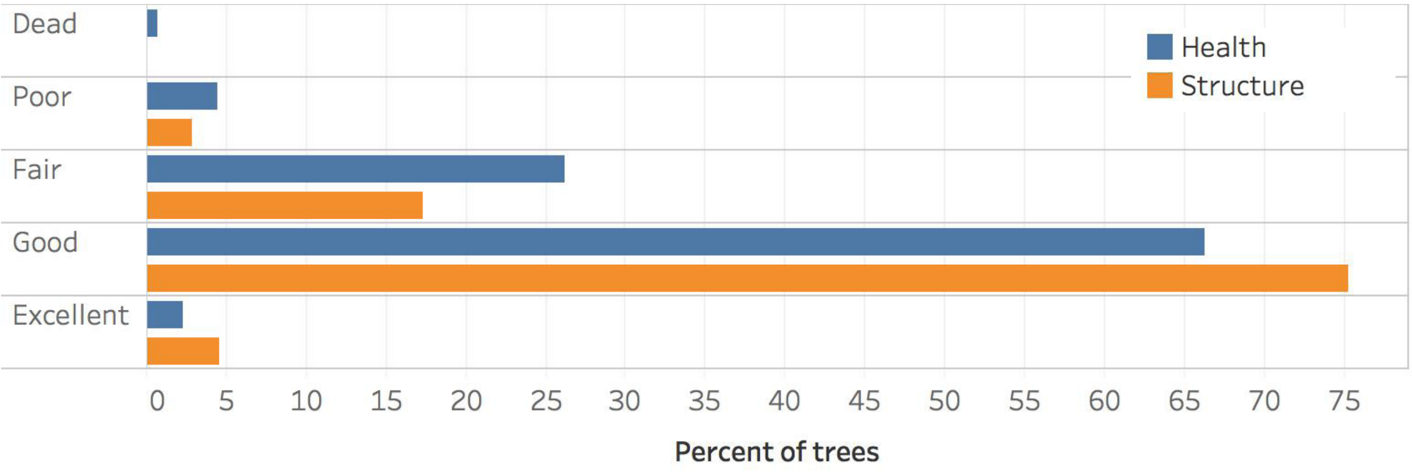


Figure 25. Health and structure ratings of trees inventoried on the main campus of Virginia Tech in Blacksburg, VA. Standing dead trees were denoted as dead in the health category. Total tree population is 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix B.

the structure rating is an indication of a tree's ability to stay intact and upright. There is often a correlation between the two, but it is possible to have a healthy, unstable tree, and vice versa. These ratings have different management implications too. An unhealthy tree may be one suffering from a disease or soil disorder that merits treatment with a pesticide or fertilizer to restore its health, whereas an unstable tree may require pruning, cabling, or removal to mitigate a hazard. Further, a low health rating may be an indication of a poorly adapted species to site conditions or inadequate protection from stress factors, whereas a low structure rating may be an indication of a weak-wooded species or inadequate maintenance.

Figure 25 shows the health and structure ratings of all trees on campus. Overall, the campus urban forest is very healthy and structurally sound. There are about 69% of the trees rated in good to excellent health and about 78% of the trees rated in good to excellent structure. There were 214 standing dead trees at the time of the inventory. Depending on the size and location of these trees, some may have been recommended for removal. A notable statistic is that 25% of the trees were rated as fair health. These are trees with moderate health issues that may need treatments to alleviate stress and ward off irreversible decline. Trees in poor health are usually not good candidates for treatments because prolonged stress has often reached a state of irreversible decline; usually, the most prudent action is to cull the tree and replant at the location when suitable. Likewise, trees with poor structure may pose an unreasonable risk of failure and may necessitate removal should there be high potential for personal injury or property damage. More details on maintenance recommendations are reported later.

Health ratings by campus master plan district (**Figure 26**) show few pronounced differences from overall ratings except for the relatively lower ratings for trees in the Creativity & Innovation District (CID) and the Central Spine District (CSD). In comparing these ratings with the trunk DBH class distributions, it appears that trees in the CID skew toward small trees, which might imply that the trees are relatively young (vulnerable to stress) or experience high mortality turnover due to difficult growing conditions. Likewise, trees in CSD show a more balanced DBH distribution, which suggests that these trees may be growing in naturalized landscapes where not as much preventive maintenance is performed. A similar pattern holds for ratings of tree structure across master plan districts (**Figure 26**), where again trees in the CID (and to a lesser extent CSD) were rated lower than others. Ratings of tree structure appeared more homogenous across districts than health ratings, presumably because much of the campus maintenance is geared toward hazard mitigation.

A different parsing of the same records allows a comparison of the relative condition of the most abundant species on campus. **Figure 27** shows a side-by-side comparison of health and structure ratings for the ten most abundant species. It appears that *Acer rubrum* (red maple), the third most common tree, has greater issues with health and structure than other common species. Possible reasons for this include the sensitivity of the species to alkaline soil (leading to nutrient deficiency and chlorosis) and the propensity of the species to develop codominant leaders and weak branch unions (particularly in the common cultivars). The numerous unspecified species of ornamental cherries and plums (*Prunus* spp.) have a broad range of disease and pest vulnerabilities that contribute to poor health and there is a large contingent of these trees

Figure 26. Health (left pane) and structure (right pane) ratings of trees inventoried in the campus master plan districts of Virginia Tech in Blacksburg, VA. Standing dead trees were denoted as dead in the health category. Total tree population is 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix B. Full names of the district abbreviations are provided at the front of the report. Trees identified as dead were only tallied in the Health rating.

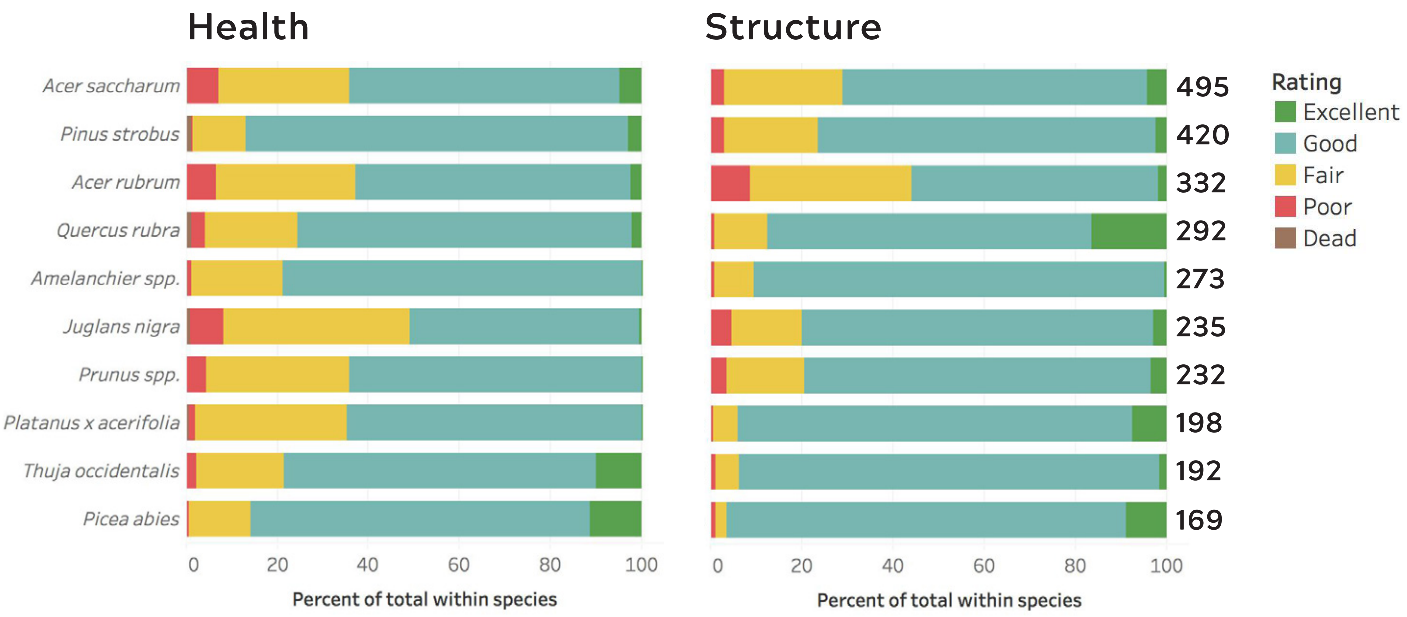


Figure 27. Health (left pane) and structure (right pane) ratings for the ten most abundant tree species on the main campus of Virginia Tech in Blacksburg, VA. Standing dead trees were denoted as dead in the health category. Total numbers of trees within each species are recorded to the right of the figure. Total tree population is 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix B.

Table 2. Best-performing and worst-performing tree species on campus based on average rating of health and structure for individual trees inventoried on the main campus of Virginia Tech in Blacksburg, VA. Each tree was assigned a numeric value of 0 to 4 corresponding with the ratings of 'Dead' through 'Excellent'. Only those species having 10 or more individual trees in the inventory are shown.

Best-Performing Tree Species					
Health			Structure		
Species	Avg. Rating	# Trees	Species	Avg. Rating	# Trees
Acer x freemanii	3.10	10	*Carya alba*	3.39	13
Acer buergerianum	3.00	22	*Quercus michauxii*	3.14	77
Carya alba	3.00	13	*Quercus bicolor*	3.09	113
Carya glabra	3.00	12	*Carya glabra*	3.08	12
Quercus texana	3.00	23	*Magnolia virginiana*	3.07	14
Taxodium distichum	2.98	165	*Acer campestre*	3.07	43
Lagerstroemia indica	2.98	85	*Picea abies*	3.04	169
Magnolia grandiflora	2.97	58	*Quercus rubra*	3.03	292
Picea abies	2.96	169	*Ulmus parvifolia*	3.03	156
Morus rubra	2.95	21	*Platanus x acerifolia*	3.01	198

Worst-Performing Tree Species					
Health			Structure		
Species	Avg. Rating	# Trees	Species	Avg. Rating	# Trees
Ulmus rubra	1.33	12	*Ulmus rubra*	1.83	12
Tsuga canadensis	1.68	76	*Betula lenta*	2.14	14
Fraxinus pennsylvanica	1.69	13	*Acer negundo*	2.15	27
Prunus avium	1.76	29	*Acer nigrum*	2.32	50
Pinus nigra	1.80	55	*Tsuga canadensis*	2.41	76
Fraxinus americana	1.95	110	*Prunus avium*	2.41	29
Acer nigrum	2.04	50	*Ulmus pumila*	2.42	12
Ulmus pumila	2.08	12	*Pinus nigra*	2.46	55
Robinia pseudoacacia	2.19	69	*Fraxinus pennsylvanica*	2.46	13
Chamaecyparis pisifera	2.21	19	*Fraxinus americana*	2.47	110

Figure 28. Locations of 47 commemorative trees on the main campus of Virginia Tech, Blacksburg, VA.

of advanced age, which exacerbates health problems. London plane tree (*Platanus × acerifolia*) has a spurious track record on campus despite its world-renowned reputation as a tough urban tree. Experts over the years have not been able to determine why this species fails to thrive in certain campus locations. Black walnut (*Juglans nigra*) seems relatively unhealthy compared to other common species, but this is probably an artifact due to most of the specimens residing in naturalized areas where limited tree maintenance is performed.

Finally, **Table 2** lists the best-performing and worst-performing tree species campus-wide, as assessed by their average health and structure ratings. Each tree was assigned a numeric value from 0 to 4 corresponding with the ratings of 'Dead' through 'Excellent'. To minimize bias from skewed species abundance, only those species having 10 or more individual trees on campus were considered in constructing the 'top-10' and 'bottom-10' lists shown in **Table 2**. The numerical ratings of the best-performing species tightly cluster around a value of '3', which corresponds with a 'Good' health or structure rating. Practically speaking, there is no substantive difference in the scores of the best-performing species, and the rankings are admittedly artificial. The key point is that each species should perform reasonably well when properly sited in the appropriate landscape setting on campus.

In looking at the worst-performing species, there is a bit more spread in the numerical rankings, particularly in the health category, where a few species rate just above 'Poor'. On the health side, it should be noted that several of these species are chronically plagued by diseases and pests: *Ulmus rubra* (Dutch elm disease), *Tsuga canadensis* (hemlock woolly adelgid), *Fraxinus pennsylvanica* (emerald ash borer), *Prunus avium* (tent caterpillar), and *Pinus nigra* (pitch mass borer). On the structure side, several of these species are prone to defects: *Ulmus rubra* (weak branch unions), *Betula lenta* (decay), and *Acer negundo* (weak wood). In some cases, poor performance may be attributable to advanced age of trees within a species rather than inherent vulnerabilities of the species. For example, *Acer nigrum* (black maple) on campus were planted during a brief timeframe 50 to 60 years ago and are reaching over-maturity that brings on health and structure issues. While these issues are all readily addressed through pest management and pruning, it is not sustainable or cost-effective to invest scarce maintenance dollars into species with chronic issues. Targeted preservation has been undertaken for certain hemlocks and ash trees on campus because these species have high intrinsic value, but the university should be more scrupulous in culling species with chronic problems and ceasing to plant them on campus.

COMMEMORATIVE TREES ON CAMPUS

Commemorative trees planted in honor of former members of the Virginia Tech community or ceremonial events are found throughout the main campus, as seen in **Figure 28**. A total of 47 commemorative trees were recorded during the 2017–2018 tree inventory. In each case, records stored in the tree inventory database include photos of the commemorative marker and a searchable record of the name of the person in whose memory the tree was planted. The most common species planted were *Acer saccharum*, *Amelanchier* spp., *Betula* spp., *Nyssa sylvatica*, and *Quercus bicolor*. Of these trees, the average diameter was 5.6 inches, the average crown spread was 19 feet, and the average height was 21.2 feet. This population of trees was consistently rated highly for health and structure, but not without exception: 33 of these trees, or 70.2%, were given a health rating of 'Good', yet four of these, or 8.5%, were given a 'Poor' health rating. Information recorded about these trees could be used both for maintenance purposes and as a part of a searchable database of commemorative markers on campus.

GROWING CONDITIONS OF CAMPUS TREES

Planting site type and groundcover type were recorded for each tree, allowing for a classification of typical growing conditions and a basic means for evaluating tree health outcomes between sites. Relative frequency of six site types and five common groundcovers are shown in **Figures 29** and **31**. Planting site type gives an indication of soil limitations potentially experienced by a tree, particularly constraints associated with inadequate soil volume. Site type can also be indicative of other potential sources of stress such reradiated heat from hardscape, contamination with deicing salt, and injury from vehicular and pedestrian traffic. Open lawn and landscape beds account for 85% of planting situations on campus. Generally speaking, these tend to be the least hostile growing environments because they usually afford unconstrained soil volume. In these settings, over 70% of trees are in good or excellent health (**Figure 30**). However, they can be difficult sites if vehicular and pedestrian traffic is heavy.

Parking lot islands, planting strips, and sidewalk pits are often difficult sites due to limited soil volume and expansive hardscape. Trees in parking lot islands on campus were found to be the least healthy. A typical scenario in these settings is that the islands have insufficient soil surface area to ensure adequate precipitation capture, and the soil volume is inadequate to store sufficient water to keep trees hydrated. This is compounded by the heat stress from the surrounding hardscape. Moreover, there is a history of planting large-maturing species in these islands (to ensure vertical clearance of vehicles), which then tend to outgrow the soil volumes and decline after a decade or so due to chronic drought stress. If the university desires expansive sustainable canopy cover in parking lots, then better technology needs to be incorporated into planting islands, such as structural soil and suspended pavement with soil vaults.

Trees situated in planting strips and sidewalk pits are intermediate in their health ratings, as would be expected because they are slightly less restrictive than parking lot islands, yet more difficult than lawns and landscape beds. Surprisingly, trees in sidewalk pits seem to be doing very well. The reasons may be two-fold. First, sidewalk pits are a relatively new design feature on campus; therefore the trees found in them are relatively young and have yet to encounter much stress associated with the constrained environment. Second, sidewalk pits on campus are often designed with expanded soil volumes and have surface grates that protect the soil from compaction by pedestrians. Natural areas actually have a smaller percentage of trees in excellent or good condition. This is not an indication of adverse growing conditions, but rather a lack of maintenance (due to low priority) and substantial competition amongst trees for space, light, and nutrients.

Given the predominance of open lawn and landscape bed site types, it is not surprising that turf and mulch account for the ground cover on over 80% of campus trees, as shown in **Figure 32**. It may be confusing that mulch is the predominant groundcover when open lawn prevails as the predominant site type. The reason for this is that there are numerous trees in open lawns that have a modest mulch ring installed, but would not be considered as situated in a landscape bed. This is particularly the case with young and immature trees where a mulch ring is maintained for several years to aid tree establishment into the landscape and helps deter injury from mowing equipment. Trees in parking lot islands, planting strips, and sidewalk pits also tend to have mulch installed. Mulch is generally considered a healthier groundcover for trees because it aids in moisture conservation, nutrient replenishment, and compaction abatement. Campus trees with mulch show a slightly better health rating than those in turf. The difference would probably be greater if mulched parking lot islands, where trees languish, were excluded. Whether the tree health benefits of mulch substantiate the additional cost of installing and maintaining mulch needs further consideration. As campus increases in density and population, it may be wise to utilize mulch more frequently in high traffic areas where there may be greater potential for soil erosion and compaction.

Bare soil indicates a lack of groundcover, and campus trees in bare soil conditions have the worst health ratings. Bare soil results from heavy vehicular and pedestrian traffic that kills turf and erodes mulch. As a result, the soil becomes compact and impervious to water and oxygen infiltration, which harms root health. Locations where bare soil is evidently impacting tree health should be identified and corrected with an appropriate ground cover to protect the soil and tree roots. Duff is a natural ground cover comprising organic detritus found in campus natural areas. While this should be the most beneficial groundcover for tree health, campus trees in this situation have intermediate health ratings. This is because campus trees in natural areas do not receive much preventive maintenance and declining trees are allowed to persist as part of the natural ecosystem rather than being removed like in

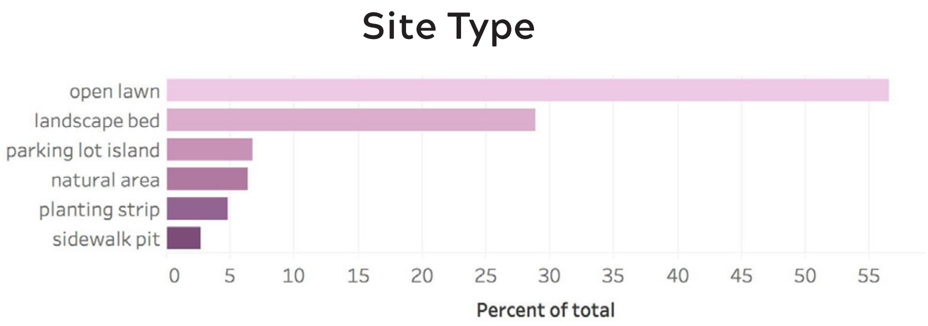


Figure 29. Site type classification for trees inventoried on the campus of Virginia Tech in Blacksburg, VA. Total tree population is 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix A.

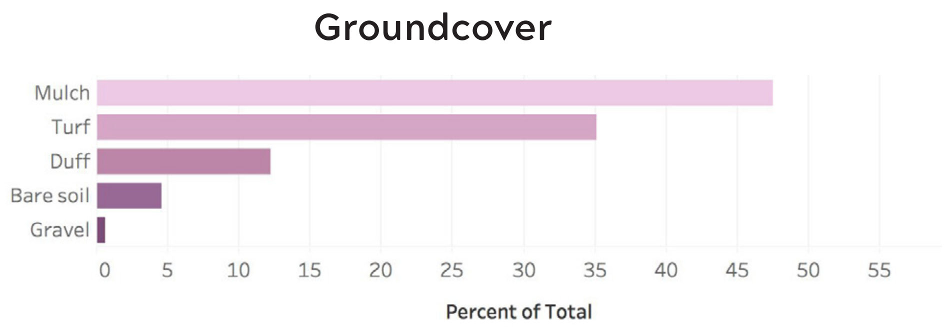


Figure 31. Groundcover type classification for trees inventoried on the campus of Virginia Tech in Blacksburg, Total tree population is 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix A.

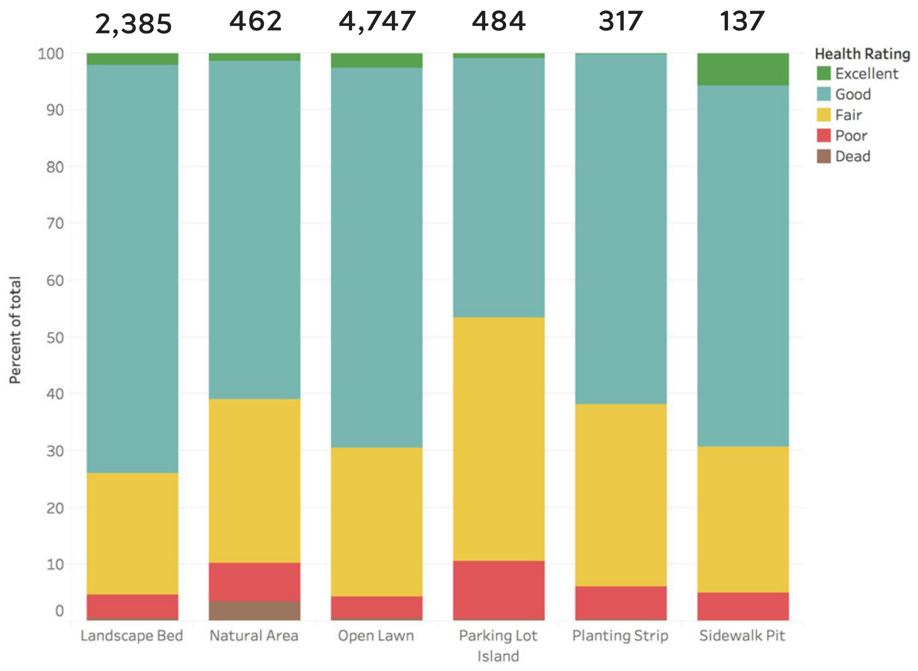


Figure 30. Site type classification, parsed by health rating, for living and standing dead trees inventoried on the campus of Virginia Tech in Blacksburg, VA. Shown above each bar is the total trees found in each site type. Data were missing for 10 trees. Full definitions and indicators for each rating are provided in Appendix A.

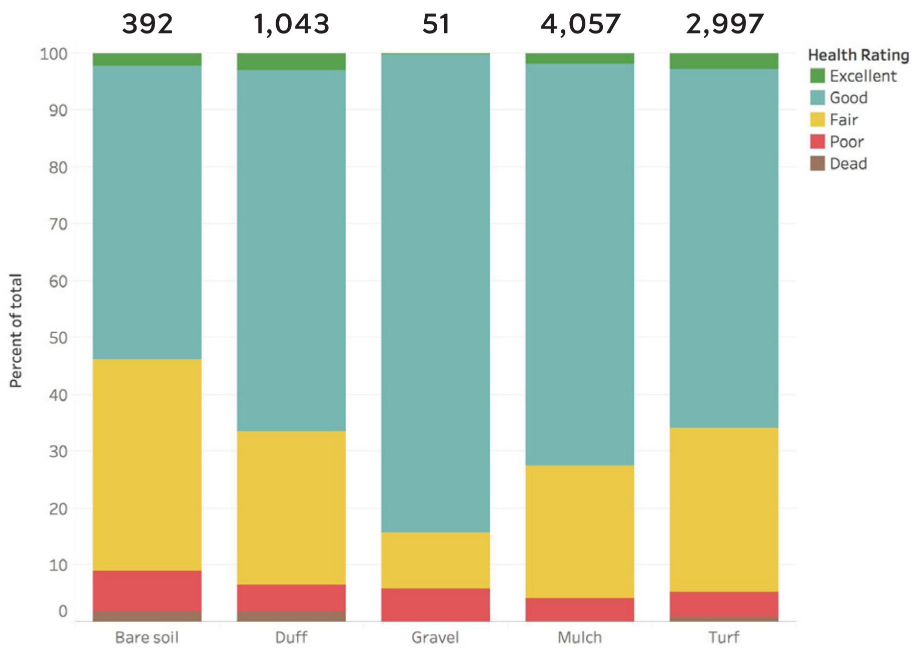


Figure 32. Groundcover type classification, parsed by health rating, for living and standing dead trees inventoried on the campus of Virginia Tech in Blacksburg, VA. Shown above each bar is the total trees found in each site type. Data were missing for 2 trees. Full definitions and indicators for each rating are provided in Appendix A.

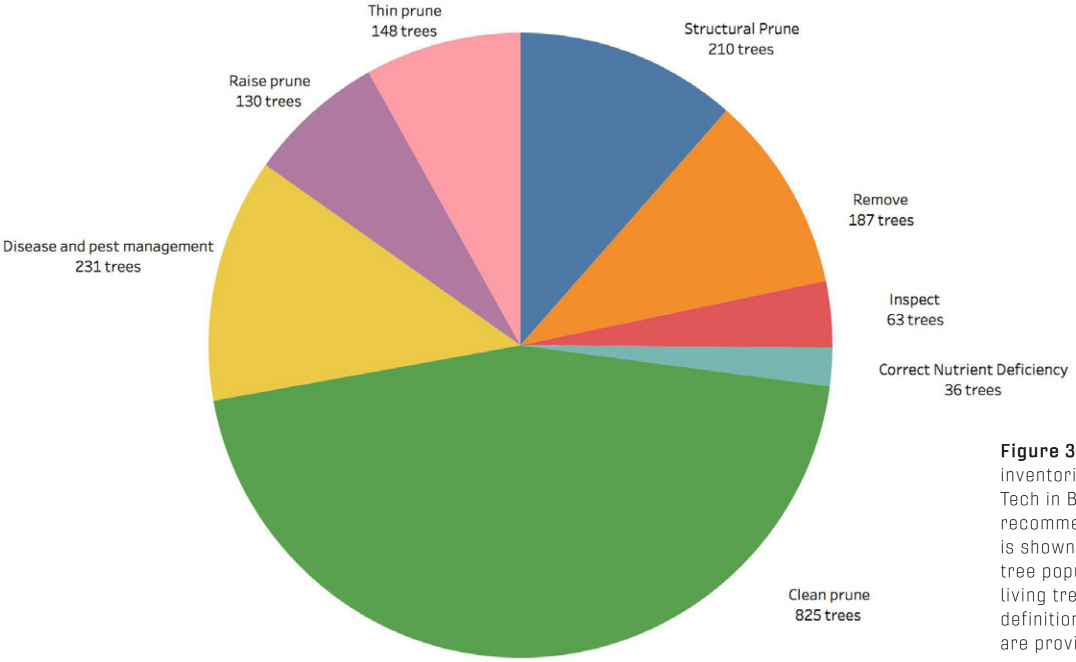


Figure 33 22% (1,830) of the trees inventoried on the campus of Virginia Tech in Blacksburg, VA had a maintenance recommendation. Each maintenance type is shown as a percentage of the total tree population, which comprises 8,542 living trees and standing dead trees. Full definitions and indicators for each rating are provided in Appendix B.

maintained portions of campus. The oddest finding was that trees growing in gravel are the healthiest. It is unclear why this might be the case. However, it seems to be an unusual groundcover (only 51 trees), and may represent signature landscapes that are carefully maintained around campus. Inert gravel can actually be a good groundcover because it allows good water infiltration, alleviates soil compaction, and can keep the soil cool; however, it does not offer any nutrient replenishment through organic matter breakdown.

MAINTENANCE NEEDS OF CAMPUS TREES

After observing the species, size, condition, and location of each tree, consideration was given to any maintenance needs. A parsimonious approach was taken here to ensure that maintenance was not over-prescribed, but rather judiciously recommended in accordance to the resources and capabilities of the university's facilities department. Therefore, the absence of a maintenance recommendation for any given tree does not imply that nothing could be done to improve tree condition or performance, but rather no practical maintenance option was observed. As such, only about 22% of the 8,542 living trees and standing dead trees received a maintenance recommendation. **Figure 33** shows a pie chart of the most commonly prescribed maintenance actions across the main campus.

Crown clean pruning was the most frequently identified maintenance need. This type of pruning removes dead, diseased, and defective branches from the tree crown for the purpose of safety, sanitation, and aesthetics. Crown cleaning was recommended for nearly 10% of the trees and outpaced all other maintenance needs by three-fold. When prioritizing crown cleaning, the university should first focus on large trees in high-use areas where a falling branch would be likely to strike a target and cause harm. Second priority should be given to crown cleaning of trees known to develop disease or pests as a result of dead branch accumulation. Examples would be native elms (dead branches may harbor elm bark beetles that vector Dutch elm disease) and flowering dogwoods (dogwood borers overwinter in dead branches).

Other forms of pruning were recommended at lower frequency. Crown thinning, aimed at reducing the density of branches to improve branch spacing and air and light penetration, was recommended for about 2% of trees, as was crown raising, aimed at increasing the height of branches above the ground to provide clearance and visibility. Structural pruning, recommend for about 3% of trees, is primarily targeted for young and immature trees to eliminate imperfections in branch arrangement that could lead to hazards or site conflicts in the long term. This type of pruning is critical to preventive maintenance of the urban forest. With a commitment by the university, structural pruning is a highly cost-effective approach to improving long-term safety and storm resilience of the urban forest. The fact that structural pruning was recommended for a relatively small number of trees is a testament to efforts by stakeholders to ensure that dependable species and high-quality nursery stock are procured for campus tree plantings.

About 2% of inventoried trees were recommended for removal. This roughly aligns with the trees identified as dead or poor condition; however, removal was not recommended for all of them because removal may not be necessary or desirable for all such trees. For example, dead and declining trees in natural areas have ecological value as wildlife habitat and sources of nutrient replenishment. In such cases, trees would only be permitted to remain if there was no unreasonable risk of the tree failing and causing harm to people or property. Most removals were recommended for trees in high-visibility or high-use areas where poor condition trees would be an eyesore or safety threat. These are usually trees that could not be reasonably rehabilitated in a cost-effective manner, and the prudent option is to minimize costs and risks by culling the trees.

A few trees warranted further inspection to properly diagnose a disorder or evaluate a structural concern. Those trees in high-use areas would be the highest priority for expediting inspection so that a determination can be quickly made for mitigating any unreasonable risks. Less than 1% of trees were identified as needing to correct a nutrient deficiency. On a campus where soils are notoriously alkaline and nutrient deficiencies are common amongst intolerant species, this finding seems low. However, the bulk of this inventory was carried out during the dormant season and nutrient deficiencies would not be evident in deciduous species. Poor choices have been made in the past by planting alkaline intolerant species such as willow oak and river birch; around campus however, better species choices in recent years for alkalinity tolerance have resulted in fewer nutrient deficiencies occurring in campus trees.

Looking at tree maintenance needs broken down by campus master plan districts, many of the trends seen in the overall population persist (**Figure 34**). Crown clean pruning is typically the greatest need, in some cases exceeding 15% of the local tree population, as seen in 21st Century Living & Learning District (21C), Agricultural Lands District (AGL), Creativity and Innovation District (CID), and the Central Spine District (CSD). These tend to be high-use districts where tree condition is diminished by site use impacts and there are numerous potential targets that could be harmed by falling branches. The CSD is a notable exception in that it lies outside primary maintenance areas and therefore may be overlooked for routine maintenance. The CID also had an unusually high frequency of crown raise pruning at nearly 10%, presumably due to the number of streets and sidewalks where vehicular and pedestrian conflicts with low branches might arise. Tree removal needs did not exceed more than 5% of the trees in any given district, but appeared in the greatest frequency in 21C, the CSD, and NOA. The 21C District has some of the oldest and largest trees on campus, and therefore may have a number of declining trees that could be hazardous. In contrast, the NOA District is a relatively new district that may be experiencing mortality of recently transplanted trees that are failing to thrive.

DISEASE AND PEST PROBLEMS OF CAMPUS TREES

Disease and pest treatment was recommended for less than 3% of the inventoried trees campus-wide. Treatment was recommended for all native hemlocks (hemlock woolly adelgid), native elms (Dutch elm disease), and native ash trees (emerald ash borer) because these diseases and pests are already exist on campus and are highly destructive to tree species that are valued by the campus community. Trees in these taxa account for 194 of 231 (82%) of all treatment recommendations campus-wide. Active control programs for these disease and pest problems are already carried out by grounds personnel. Another disease actively managed on campus is *Rhizosphaera* needle cast, a fungal disease affecting a wide variety of conifers. While Colorado blue spruce are typically the most heavily damaged, all spruce (*Picea*) and larch (*Larix*) species, as well as Douglas-fir (*Pseudotsuga*), are common hosts of this defoliating pathogen. Together, these three genera account for 348 trees, or 4% of all campus trees. Because control of needle cast is resource intensive and requires careful timing of repeated fungicide applications, the university has been moving away from planting these vulnerable conifers and opting for other conifer species that are resistant to the disease. Efforts should continue to diversify the conifer selections for resilient species that are suitable for the campus character and growing conditions.

It is important to note that the mere potential for a disease or pest does not necessitate treatment. Some diseases and pests cause minor or episodic damage to trees and may only warrant control under certain weather or seasonal conditions that must be evaluated through periodic monitoring to determine the potential for intolerable damage. Disease and pest control is expensive and potentially disruptive to the environment, so it should be undertaken only when intolerable damage to trees is anticipated. Looking at campus master plan districts, disease and pest treatment approached 10% of trees in the Creativity and Innovation District (CID) and the Central Spine District (CSD). This might be the consequence of a concentration of vulnerable tree species in those districts, but could also indicate stressful growing conditions that predispose trees to pests.

The assessment software i-Tree Eco was used to assess potential threats and consequences of noxious tree pests that might be introduced to campus. The assessment looked at 36 noxious pests and revealed that 5,473 (64%) of the campus trees are vulnerable to at least one of these pests (**Figure 35**). In terms of number of trees threatened, leaf area at risk of loss, and economic impact, the winter moth and gypsy moth are at the top of the list. Winter moth is a threat to 40% of the campus tree leaf area whereas gypsy moth threatens 25% of the leaf area. Their potential economic impact solely based on replacement cost of trees exceeds $20 million. This does not even account for potential pest control costs or lost value of ecosystem services due to dead trees. Both are

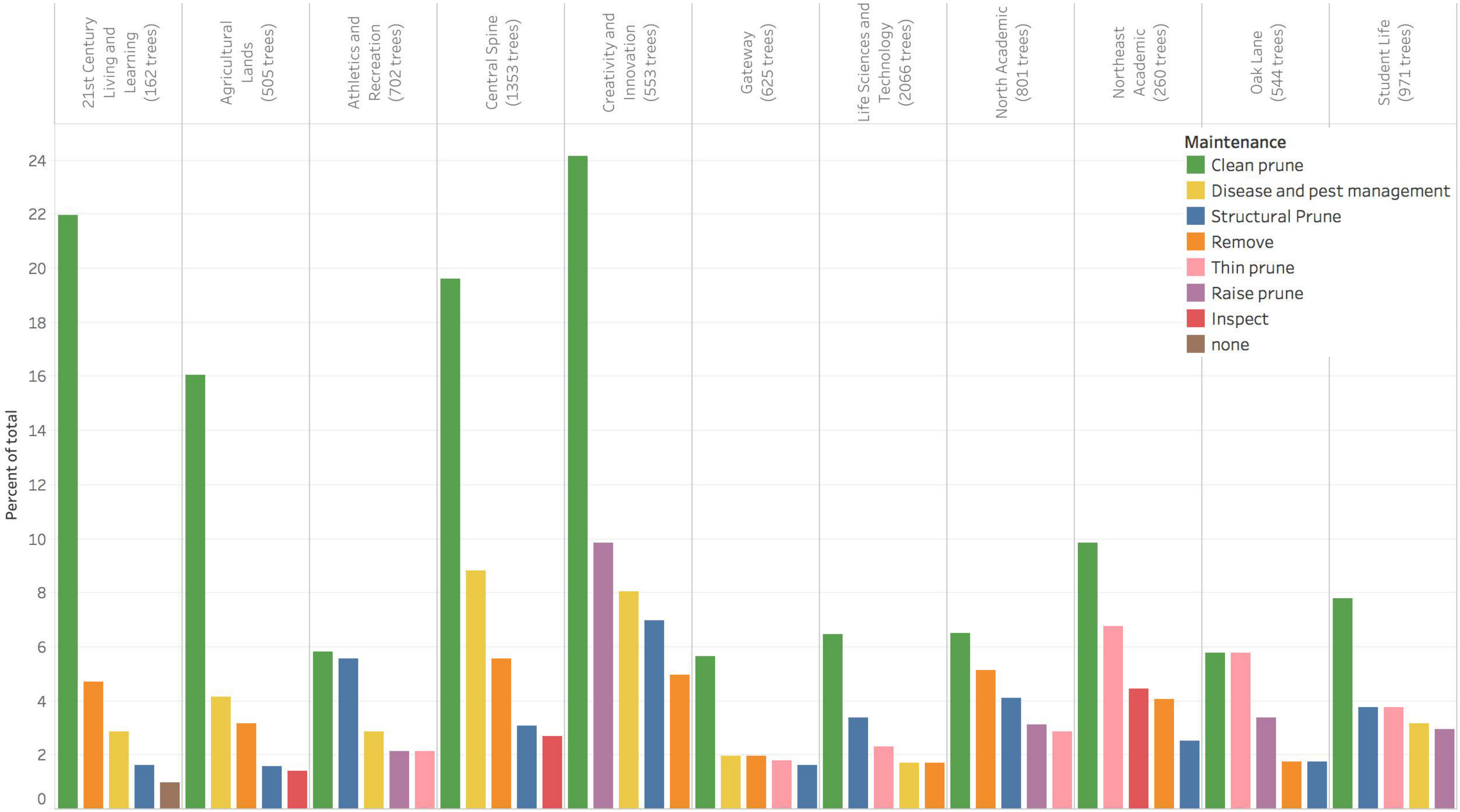


Figure 34. Most common maintenance needs of trees inventoried in the campus master plan districts of Virginia Tech in Blacksburg, VA. Each maintenance type is shown as a percentage of the total population of living trees and standing dead trees in the district (which is in parenthesis after the district name). Full definitions and indicators for each rating are provided in Appendix A.

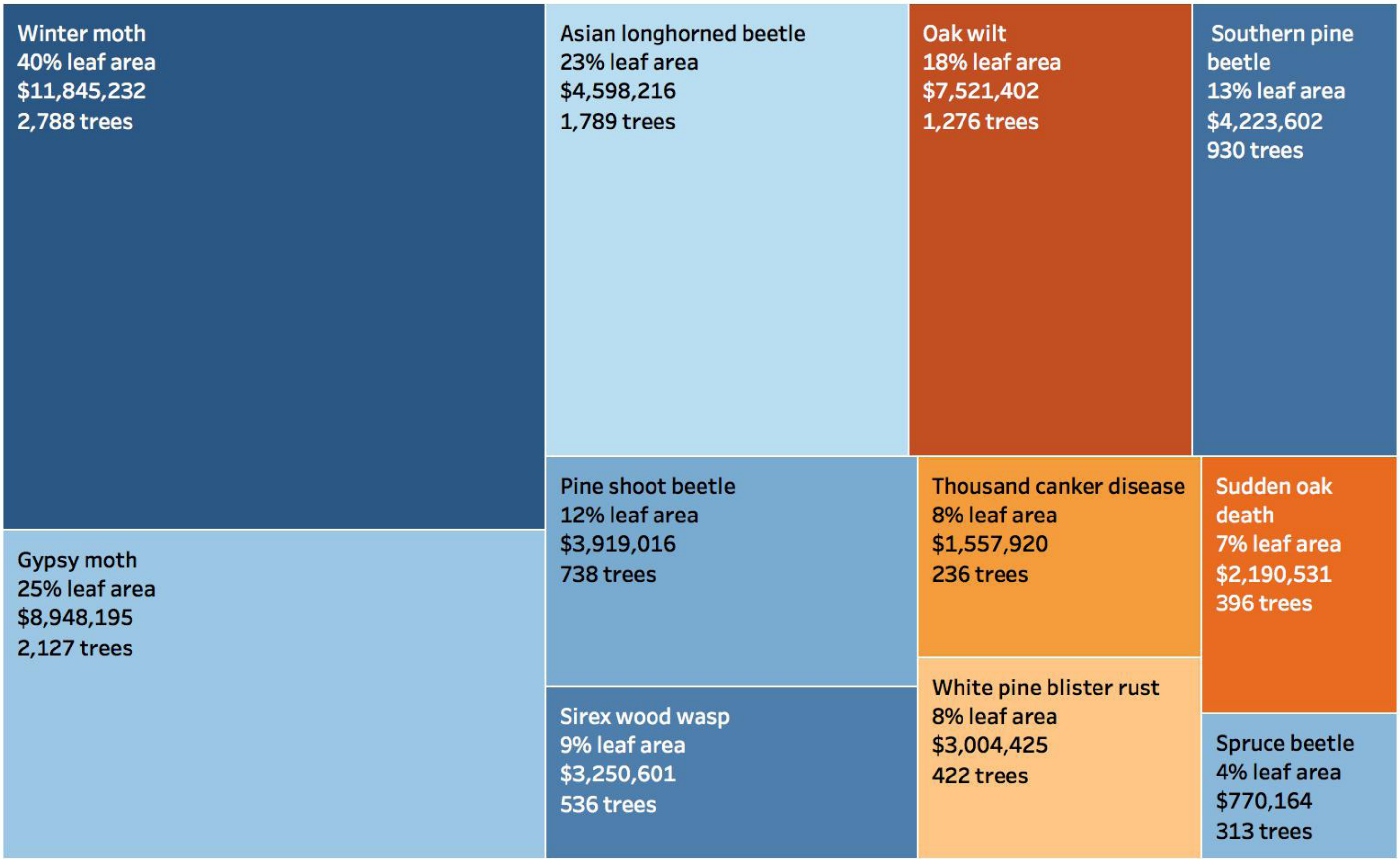


Figure 35. Pest vulnerability of trees inventoried on the campus of Virginia Tech in Blacksburg, VA. Shown is the percentage of leaf area and number of trees that are susceptible to loss due to tree mortality caused by noxious diseases and pests that could be introduced to the area. Susceptibility values are derived from an i-Tree Eco analysis of the inventory data, which considers the species and size distribution of tree species on campus along with host preferences of the noxious pests. Also shown is the replacement cost of trees that would be potentially lost to pest mortality. Only pests threatening 4% or more of campus leaf area are shown.

exotic pests introduced to the United States having caterpillar larvae that feed on foliage. Winter moth is a generalist feeder on a variety of hardwoods, many of which are found on campus (e.g., red oak, American elm, and red maple), but its activity in the United States has been successfully restricted to the Northeast thus far (Forestpests.org, 2018a; Center for Agriculture, Food and the Environment, 2015). Gypsy moth has long been established in southwestern Virginia, but has predominantly been a pest of forest stands of oaks. It is an episodic pest that is highly variable from year to year depending on weather conditions and counteracting effects of an entomopathogenic fungus that kills the larvae in wet springs (Forestpests.org, 2018b; USDA Forest Service, 2003).

Another serious potential pest of the campus urban forest is the Asian longhorned beetle, which threatens 23% of the campus tree leaf area, comprising 1,789 trees valued at over $4.5 million. This exotic pest kills trees by boring through the sapwood during its larval stage. It has been highly destructive in urban forests of the United States because of its preference for several species of maple (Forestpests.org, 2018c), which are abundantly planted in many cities and on campus as well. The epicenter of its destruction was Worcester, Massachusetts, where over 35,000 trees were removed over the past ten years in an effort to control the pest (Telegram.com, 2018). Asian longhorned beetle is a slow-moving pest and is unlikely to spread into new areas unless it is accidently transported on infested wood material. State and federal regulators are cognizant of its destructive potential and actively monitor for its spread. As with any noxious pest, local monitoring by university personnel will be important for early detection and rapid response, which was critical to the university's control of emerald ash borer in spring 2016.

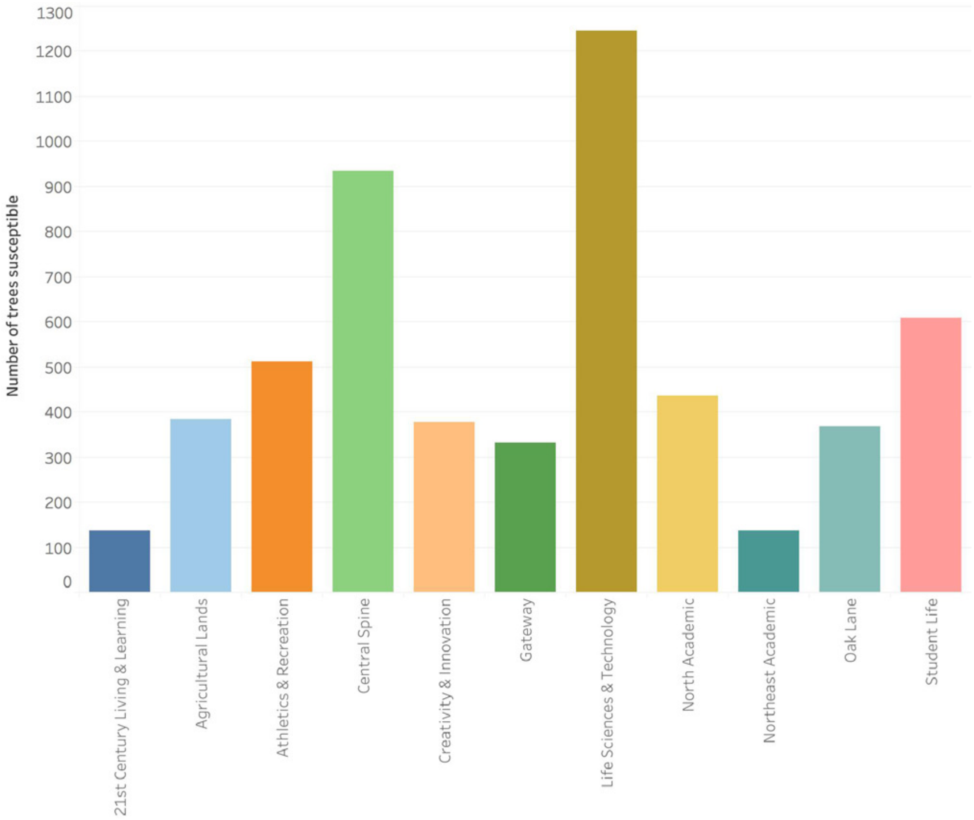


Figure 36. Pest vulnerability of trees inventoried in the campus master plan districts of Virginia Tech in Blacksburg, VA. Shown is the number of trees susceptible to loss due to tree mortality caused by 36 noxious diseases and pests that could be introduced to the area. Susceptibility values are derived from an i-Tree Eco analysis of the inventory data, which considers the species and size distribution of tree species on campus along with host preferences of the noxious pests.

The most threatening tree disease at this time is oak wilt, caused by the exotic fungal pathogen *Ceratocystis fagacearum*. Oak wilt threatens 18% of the campus tree leaf area, comprising 1,276 trees valued at over $7.5 million. Oak wilt affects all species of oaks, but species in the red oak group are more susceptible than those in the white oak group. This vascular disease is spread by sap beetles that feed upon infected trees and then carry fungal spores to healthy trees. The disease is also spread when the roots of infected and healthy trees intermix and transfer the fungus. Although oak wilt has been documented throughout most of western Virginia, it has not caused widespread oak mortality here as seen in Texas and parts of the Midwest (USDA Forest Service, 2017). At this time, the university should remain vigilant to the threat of oak wilt by closely monitoring oaks and taking prompt action to diagnose abnormal wilting observed in oaks. Should the disease be discovered, then fungicide injections and root graft pruning might be necessary. Oaks are abundant and important species on campus and should remain in the available plant palette; however, the oak composition should be monitored to ensure that abundance of oaks does not exceed the desired levels described earlier in this report.

The i-Tree Eco analysis revealed about a half-dozen other potential pest threats of significance, but none individually threaten more than 10% of the campus tree leaf area. This is an affirmation of the importance of tree species diversification as a first line of defense against pest threats. The potential pests described above are particularly noxious because they have a broad host range of tree species. In contrast, most tree pests are fairly specialized toward a few species (e.g., emerald ash borer). Therefore, ensuring that a handful of tree species do not dominate the campus urban forest is an important strategy in pest management.

Because tree species are not evenly dispersed across campus, there are some areas that have greater pest vulnerability than others. In **Figure 36**, the pest vulnerability by campus master plan district is shown. Most districts have low susceptibility to loss of leaf area from pests. The notable exceptions are the Central Spine District (CSD) and the Life Sciences & Technology District (LST), both of which have over 900 trees susceptible to pests. This is primarily a function of species composition and individual tree size. The CSD District has an abundance of large oaks and the LST District has an abundance of large maples. These species are vulnerable to four of the most noxious pests (winter moth, gypsy moth, oak wilt, and Asian longhorned beetle), and there is a lot of leaf area accounted for by the large trees that could be infested. With the exception of these two districts, the campus has a balanced, low-risk pest vulnerability profile and should be quite resilient in the event of an outbreak of an introduced pest.

4. Ecosystem Services and Economic Impacts of Campus Trees

The campus urban forest is an ecosystem that provides important services to the people who work, study, recreate, and visit there. Ecosystem services is a conceptual paradigm that spans both natural and manmade ecosystems. The campus urban forest has elements of both. Likewise, there are a broad range of potential services provided by this ecosystem. The United Nations categorizes these services asprovisioning services (e.g., wood fiber, clean water), regulating services (e.g., air cleansing, carbon sequestration, stormwater interception), supporting services (e.g., wildlife habitat, biological diversity), and cultural services (e.g., recreation, tourism, physical and mental health) (Food and Agriculture Organization of the United Nations, 2018). While all of these services can be rightfully attributed to the campus urban forest, they are not all easily observable or measurable. Thus any effort to enumerate all services is bound to be incomplete.

A comprehensive assessment of ecosystem services was not the intent of the campus tree inventory. However, the inventory data provide a basis to assess some aspects of ecosystem services and their economic impacts by employing i-Tree Eco urban forest assessment software. Fundamental to this assessment is an understanding that the campus urban forest is a type of infrastructure, akin to buildings and utilities, which has physical attributes that dictate the quality and quantity of services afforded to stakeholders and beneficiaries. Just like grey infrastructure, the green infrastructure of trees and associated vegetation must be purposefully designed, planned, created, and maintained to optimize its utility and value.

STRUCTURAL ASSET VALUE

As a structural asset, the campus urban forest can be economically valued like any other capital asset. With i-Tree Eco, it is possible to appraise the structural asset value of trees using a method called replacement cost valuation. The replacement cost of each tree is calculated by Eco based on a protocol developed by the Council of Tree and Landscape Appraisers (Nowak et al. 2008). The protocol looks at the species, size, condition, and location of a tree and combines that information with the prevailing cost to procure and plant a nursery-sized tree, culminating in an escalated value for a full-grown tree. The consequent appraisal describes the cost to replace a tree as a structural asset. Total structural value of campus trees using Eco was calculated to be nearly $31 million. Of note, trees inventoried within the Old-Growth Forest account for $4,575,000 (15%) of this value while only comprising 6% of all trees. This is due to the enormous size of trees populating the forest as well as the high intrinsic value of the species found there.

Structural value of campus trees may seem esoteric, but it has practical applications. For example, when construction must occur around campus trees, the structural value of individual trees could be used as a compliance tool to ensure proper protection is afforded to trees through issuance of performance bonds. Another application would be to use the total structural value of the urban forest for budgeting maintenance and capital renewal. One approach to this (Tradelineinc.com, 2010) is to allocate 2% of asset replacement value to annual maintenance and repair and another 2% to capital renewal (i.e., replanting of trees). Using this rule of thumb, about $600,000 would be allocated to annual tree maintenance and about $600,000 to annual tree planting and aftercare. This may be an imperfect application of a capital asset model, but it draws attention to the need for continual investment in maintenance and planting that is proportionate to the scale and value of the urban forest asset.

ECOSYSTEM SERVICES

The ecosystem services of the urban forest, in and of themselves, also have monetary value. In i-Tree Eco, a range of services can be modeled, quantified, and monetized on an annual basis. Again, these are not the only ecosystem services of the urban forest, just those that are readily quantified and monetized. Below is a summary of four modeled ecosystem services: (1) carbon sequestration and storage, (2) air pollution mitigation, (3) avoided stormwater runoff, and (4) building energy conservation. Statistics for the model outputs are shown in **Table 3**.

Carbon sequestration is the withdrawal of carbon dioxide from the atmosphere and synthesis of carbon-based compounds (i.e., wood) in the tree through photosynthesis. Annual gross carbon sequestration, the amount of carbon captured during one year of tree growth, is estimated at 59.75 tons for campus trees, an ecosystem service valued at $7,751 annually. This is a gross value because it does not account for carbon releases due to tree respiration, decomposition, or combustion of fossil fuels for tree maintenance. Once carbon is synthesized into wood, it remains stored in trees until death and decomposition of the tree. Because trees are long-lived, this storage may last decades. Total carbon storage by campus trees is estimated at 4,573 tons, with a value of $566,214. Using species-specific allometric equations, Eco calculates carbon content of trees as 50% of the dry weight of their above-ground biomass. This is converted to a monetary value using the most recent EPA estimate of the social cost of carbon (EPA 2016), currently $129.73 per ton. The carbon service of campus trees is an important consideration

Table 3. Outputs from i-Tree Eco modeling of ecosystem services provided by trees inventoried on the Virginia Tech campus in Blacksburg, VA. Results are parsed by trees in the Old-Growth Forest (548 living trees) and the rest of campus (8,352 living trees).

	Stadium Woods		Other Areas		Entire Campus	
	Amount	Value	Amount	Value	Amount	Value
Replacement (structural) value	—	$4,575,048	—	$26,047,769	—	$30,622,817
Total carbon storage	831 t	$107,741	3,742 t	$458,473	4,573 t	$566,214
Annual benefits						
Building energy savings	—	—	—	$5,050	—	$5,050
Gross carbon sequestration	9.37 t	$1,216	50.38 t	$6,535	59.75 t	$7,751
Air pollution removal	0.30 t	$655	2.40 t	$5,804	2.70 t	$6,459
Avoided stormwater runoff	25,743 ft^3	$1,721	231,329 ft^3	$15,463	257,072 ft^3	$17,184
Total annual benefits	—	$3,592	—	$32,852	—	$36,444

as it relates to the university's climate action commitment (Virginia Tech, 2018d), which pledges to improve energy efficiency and reduce carbon dioxide emissions. Increasing the number of trees, the extent of canopy cover, and the longevity of trees plays a role in this commitment.

Mitigation of four types of air pollution are modeled by i-Tree Eco: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and small particulate matter ($PM_{2.5}$). Campus trees mitigate these pollutants in a couple different ways. First, they can absorb gaseous pollutants into leaves or trap particulates on the surfaces of leaves and bark. Second, they can reduce production of pollutants by keeping urban areas cool, which both decreases the combustion of fossil fuels for air conditioning and slows the volatilization of precursor chemicals that create air pollution. Eco models air pollution mitigation using data about the leaf area and metabolic rates of campus trees, weather data, and historic levels of air pollution in the area. The monetary value is calculated by multiplying pollution mitigation quantities and median externality costs for each type of pollutant. Specifically, externality costs reflect the adverse effects on human health associated with these pollutants, as modeled by the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (Nowak et al., 2014). Total air pollution mitigation by campus trees is about 2.7 tons annually, valued at $6,459. The bulk of these benefits come from mitigation of O_3 ($4,250) and $PM_{2.5}$ ($2,110), both of which are serious respiratory irritants and can cause distress for individuals with disorders such as COPD and asthma. To maximize pollution mitigation benefits, it is important to leverage the cooling effects of the campus urban forest by incorporating shade trees into parking lots where hot pavement radiates heat and volatilizes compounds and fluids contained in vehicles.

Managing stormwater runoff and its impacts on the Stroubles Creek watershed is one of the biggest environmental challenges on campus. Stroubles Creek has been recognized as an impaired watershed, and much of its degradation is attributable to ongoing urbanization in the headwaters on and around campus (Virginia Department of Environmental Quality, 2015). Urbanization increases the volume and rate of runoff into natural bodies of water and also conveys sediment, chemical, and thermal pollution that is detrimental to water quality. Trees mitigate harmful effects of stormwater runoff in a number of ways. When precipitation falls from the sky, much of it lands upon impervious surfaces such as parking lots, roads, sidewalks, and buildings. This water moves across the impervious surfaces and is eventually conveyed into a stormwater system that drains to detention ponds and stream channels around campus. Tree canopy that projects over impervious surfaces captures much of the precipitation and either holds it in the canopy where it eventually evaporates or channels it down the stems and into the soil around the base of the tree. This is known as groundwater recharge. Tree roots also hold soil in place and prevent erosion of sediment, and the soil rhizosphere can cleanse a number of pollutants from runoff as it makes its way toward groundwater and surface water.

Avoided stormwater runoff is calculated by Eco as the sum of modeled rainfall interception, evaporation, and transpiration, based on Blacksburg's historical rainfall patterns, and allometric calculations of leaf area in campus trees. Monetary value is calculated by multiplying the total volume of runoff avoided by the avoidance cost of $0.067/ft^3 of stormwater (McPherson et al. 2007). Based on this method, campus trees prevent an estimated 257,072 ft^3 (1,923,032 gallons) of runoff annually, valued at $17,184.

Trees cool urban surroundings by shading out the sun's rays and absorbing heat through evapotranspiration. This has an appreciable effect on thermal comfort when people are outdoors, but also influences building energy consumption. When large trees are in close proximity to buildings, they cast shade that keeps buildings cool in summer and block cold winter winds that infiltrate doors, windows, and crevices. In this way, air conditioning can be ran less in summer and heat can be run less in winter. This equates to cost savings for energy consumption, but also helps the environment by avoiding air pollution and carbon emissions associated with energy generation and consumption. However, shade can also be a liability in winter, particularly from evergreen trees, when it deters passive solar heating of buildings that necessitates extra energy consumption for heating. For this reason, trees are optimally located on the west and east aspect of buildings to block the low-angled sun in early morning and late afternoon of summer, yet keep the south aspect open to allow passive solar heating when the sun reaches its zenith in winter.

Eco calculates total building energy effects of trees as the sum of savings in summer cooling costs from tree shading, savings in winter heating costs from wind blocking, and negative expenditures in winter for extra heating due to unwanted shade. Azimuthal direction and distance from each tree to the nearest buildings are necessary inputs, and only trees over 20 feet tall and within 60 feet of a building are included in calculations. Although the Eco models were designed for residential structures under three stories tall, and few buildings on campus meet this standard, results are shown here to give an indication of the building energy effects. Campus trees were estimated to provide a total reduction in cooling costs of $7,958 annually, and a total increase in heating costs of $2,908 annually, resulting in a net savings of $5,050 annually. Associated with this reduction in energy usage is an annual reduction in energy-associated carbon emissions estimated at 3,305 tons.

POTENTIAL TREE WASTE UTILIZATION

Not included in the i-Tree Eco assessment, but equally important to the sustainability profile of the campus urban forest is the utilization of debris from trees that are cut down. While often treated as waste, significant value and utility can be recovered from tree debris removed in urban forestry operations. Utilization spans a range of low-value to high-value products that vary in their environmental benefits. On the low end is recycling of leaves, twigs, and small branches as compost and mulch. These materials can be used for landscape soil enrichment and erosion control, but they eventually decompose and release their stored carbon back to the atmosphere. Better quality wood debris is best diverted to durable wood products that store carbon indefinitely and perhaps offset the costs of dimensional lumber used around campus. These wood products might range from utilitarian items such as rough-sawn decking, planking, railing, and benches used in rustic areas around the Duck Pond and the Old-Growth Forest, to artisanal items such as furniture, mantles, and keepsakes manufactured by professional artisans. The best example of a high-value recovery carried out on campus was the manufacture by students in the Wood Enterprise Institute of several live-edge tables from a white oak located in the Grove that succumbed to old age (Virginia Tech, 2016). There has been considerable growth in the reclaimed urban wood market in recent years, and numerous entrepreneurs are now involved in milling and crafting businesses. Given alumni interest in university mementos, crafting wood products from campus trees could be an opportunity to both generate revenue and contribute to the environmental bottom line of the university.

Michigan State University has capitalized on similar opportunities with its campus urban forest by creating its MSU Shadows Collection that retails collectibles crafted from salvaged campus trees (Michigan State University, 2018).

A rough estimation of sawtimber that might be salvageable from trees removed on campus is included here as an illustration of the potential for durable wood products. During the inventory, a total of 1,511 trees were identified as having been removed since the previous inventory began in 2006. Of these, trees with a diameter between 16 and 24 inches were identified as a conservative baseline for merchantable logs. From this list of trees, only species known to be used for sawtimber were selected, including hard maple, oak, yellow poplar, walnut, spruce and pine. Assuming a very low yield of only one 8 foot log per tree, and using the Doyle rule to calculate lumber content (Heiligmann and Bratkovich, 2016), the resulting 66 trees could produce 8,479 board-feet of lumber. Envisioning this lumber as wood products requires numerous assumptions about wood quality, accessibility, and feasibility, all of which could be potential stumbling blocks. However, a sustainability portfolio for an urban forest would not be complete without considering what to do with the remains of campus trees when their service life comes to an end. At worst, they end up as compost and mulch used to cultivate the next generation of trees. At best, they get repurposed into durable wood products that lock up carbon and generate revenue.

5. Synthesis of Findings and Recommendations

The urban forest on the campus of Virginia Tech was borne out of an agricultural legacy and a landscape design ethic aimed at creating pastoral spaces and vistas predominated with native broadleaf tree species. The campus urban forest comprises mostly planted trees in maintained landscapes, but several significant remnant forests occupy the Old-Growth Forest, the Grove, and the Duck Pond. The future of the campus envisions more people in an increasingly dense configuration of buildings and roadways that will eventually push out into the periphery where collections of relic pasture trees reside in the agricultural fields and the Golf Course. The university possesses an incredible natural resource in its campus urban forest and must pay careful attention to tree management and urban forest stewardship to sustain the character and contributions of the resource. Below are described and reiterated several management and stewardship considerations based on the findings of the tree inventory detailed in this report.

1. DETAILED TREE CANOPY COVER ASSESSMENT

A field inventory is just one way to assess the extent and structure of an urban forest. Over a large geographic area such as campus, an important complementary assessment is a tree canopy cover analysis. This entails delineating tree canopy (and other land cover types) on aerial or satellite imagery. The delineation is carried out by supervised computer algorithms on high-spatial-resolution imagery. The algorithm classifies each image pixel into one of several pre-determined land cover classes, resulting in a tree canopy and land cover map that shows the percentage of land area in each class. The value of this information is that changes in tree canopy over time can be precisely tracked to evaluate efforts to conserve and enhance canopy cover. The map can also be used to identify locations where trees can be planted and specify the number of trees necessary to achieve a long-range canopy cover goal. The Virginia Tech campus was included in a tree canopy cover assessment for the Town of Blacksburg carried out by Virginia Department of Forestry in 2008. Researchers in the Virginia Tech Department of Forest Resources and Environmental Conservation extracted from the town map a portion of main campus comparable in area to the current inventory. They found the following coverages on campus: tree canopy (16.1%), non-tree vegetation (45.6%), impervious surface and buildings (31.1%), and water (1.1%). This is unusually low tree canopy for an urbanized area in the eastern United States, but is heavily swayed by treeless agriculture areas over much of the western portion of campus. As development moves into those areas, there will be abundant opportunities for tree planting that should be aggressively pursued to bring up tree canopy to a more desirable level. A tree canopy cover assessment should be conducted on campus no less than once every five years to monitor and track the extent of the urban forest.

2. ENHANCED PLANTING TO INCREASE TREE STOCKING AND CANOPY COVER

This report detailed current tree stocking on campus and discussed rough trends in planting and attrition. Having an urban forest of over 8,000 living trees requires a strong, sustained effort of annual tree planting to outpace attrition and maintain adequate stocking and canopy cover. The long-term provision of ecosystem services depends on it. The inventory data should be more carefully analyzed to understand the nuances of planting and attrition so that a strategic plan for tree planting can be crafted that goes beyond the routine tree plantings associated with capital projects and community service projects. Information included in this report about ecosystem services and economic impacts of campus trees should be used to leverage resources and investments in tree planting.

3. STRATEGIC SPECIES SELECTION FOR DIVERSITY, RESILIENCY, AND FUNCTIONALITY

The composition of the campus urban forest meets or exceeds most metrics for diversity, resiliency, and functionality. This results from a good bit of purposeful planning and serendipity. Campus is located in a favorable physiographic province and climate zone to have high species diversity. Thoughtful attention to species selection over the last few decades has resulted in an urban forest that is reasonably diverse and well adapted to the local conditions and site use activities. Future planning for tree planting should give careful consideration to the species composition data found in this report along with the analyses of species relative importance values and relative performance values. The aim is to continue stocking the urban forest with a diverse mix of species that are proven performers on campus. Doing so will ensure that the urban forest is resilient to impacts by pests and weather and creates high value for the university by maximizing ecosystem services while minimizing maintenance costs. Efforts should also continue to ensure that new plantings include a reasonable mix of small-, medium-, and large-maturing species. Each tree type offers slightly different benefits in terms of aesthetics and ecosystem services.

4. IMPROVED PARKING LOT PLANTING CONDITIONS

Parking lots are difficult growing environments for trees given the small soil volumes, intense heat, and heavy site use. Trees in parking lots on campus tend to not thrive, particularly those in the interior of lots. These islands have traditionally been woefully undersized to sustain trees, though they have improved some in recent capital projects. Parking lots are one of the worst offenders for campus sustainability due to the heat and stormwater runoff. Trees can help mitigate these effects, but they must be able to grow reasonably large and have a lifespan of at least a couple decades. This is not possible unless adequate soil volumes are created. It is abundantly clear that the university is pressed for parking lot surface area and has lots of pressure to maximize space at the expense of squeezing out trees. There are proven technologies for increasing soil volume for trees without foregoing surface area for vehicles. These technologies are admittedly expensive compared to conventional tree islands, but the environmental impacts of unshaded parking lots are also expensive. Economic decisions about parking lot design should take into consideration the environmental costs of parking lots and recognize that properly designed tree spaces provide a considerable return-on-investment through shade and stormwater interception.

5. ENHANCED MAINTENANCE AND PROTECTION CAPABILITIES

Virginia Tech has a capable grounds staff that does well to maintain a healthy, safe, and attractive urban forest. But there are many competing interests for grounds maintenance efforts, and resources for tree care and protection are highly constrained, often resulting in a triage-oriented, reactive approach to tree management. The science and practice of arboriculture has advanced considerably over the past two decades. The current best management practices of arboriculture have elevated the standard of care to a level that requires professionals with specialized training to evaluate trees and write maintenance and protection specifications. Many aspects of campus tree care are well within the capabilities of the grounds staff, but certain aspects of pest management, risk management, and construction management require an advanced skill set. Personnel additions in recent years have increased capabilities in these areas, but the lack of a central role primarily focused on the urban forest leads to inefficiencies and lack of accountability. In short, the university needs a staff arborist with the necessary training and qualifications whose sole responsibility is to oversee comprehensive, systematic management of the campus urban forest. In addition, budgetary allocations should be made to the grounds division that are more in line with the asset value of the campus urban forest. Without adequate resources, sufficient maintenance cannot be performed on trees to keep them healthy, safe, and attractive. This can lead to greater long-term liabilities and costs as tree condition diminishes and service life shortens.

6. MONITORING AND LONG-RANGE PLANNING FOR DISEASES AND PESTS

There are several major diseases and pests that threaten the campus urban forest. There are ongoing programs to manage Dutch elm disease, needlecast disease, emerald ash borer, and hemlock woolly adelgid. But there are other noxious pests lurking outside the region that are high risk of introduction to campus and could impact a substantial number of campus trees. The key to minimizing impacts is early detection and rapid response. Early detection requires frequent monitoring of the urban forest and scouting for signs or symptoms of potential pests. This does not have to be incumbent on any single individual on the grounds staff. Rather, all grounds personnel should be trained and empowered to recognize tree problems during their routine field tasks and report them to supervisors. Likewise, personnel should maintain periodic contact with entomologists, pathologists, arborists, and foresters throughout their professional network to keep tabs on emerging threats in the area so that they know what to be expecting and looking for on campus. The rapid response aspect requires planning. This means studying the potential pests to understand their biology, ecology, and control options. With this understanding, personnel can ensure that appropriate pesticides and pesticide application equipment are readily available to rapidly deploy in the event of an outbreak. In some cases, preventive treatments may need to be undertaken before a pest arrives on campus to ensure adequate control. The arrival of emerald ash borer on campus in 2016 is a good case study of early detection and rapid response. In that case, an urban forestry student actually discovered the pest on campus and quickly notified grounds staff. They then quickly mobilized a response of culling and destroying low value, heavily infested trees and treating high value trees with pesticide. The response was largely successful, but could have operated more smoothly with additional planning for the inevitable arrival of that pest.

7. ENHANCED RISK ASSESSMENT AND MANAGEMENT

As campus expands, densifies, and increases in population, there will be greater potential for tree harm to people, property, and activities. In the campus tree inventory, a structural rating was given to each tree as an indication of its integrity and stability. While this information provides insight on the probability of tree failure, it does not address the probability of a tree part striking a target and causing harm. For this reason, the structural rating of trees cannot be used solely to determine the level of risk or the need for mitigation. The standard of care for managing tree risk in urban areas is steadily increasing as more practitioners and organizations voluntarily comply with the A300-Part 9 standard for tree risk assessment of the American National Standards Institute. Complementing this standard is a best management practices manual published by the International Society of Arboriculture (ISA). These documents lay out concepts and practices for identifying, analyzing, and evaluating tree risk and are now viewed as the prevailing standard of care. In addition, the ISA now has a specialized credential called the Tree Risk Assessment Qualification that is granted to Certified Arborists who complete a two-day course and pass a competency exam. The university should integrate these standards, BMPs, and credentials into policies and procedures for tree risk management. A common approach of organizations is to err on the side of caution and cut down any tree with an outward indication of structural instability. While this greatly reduces exposure to legal liability, it is not cost effective and is irresponsible as a steward of the urban forest. Unnecessarily cutting down trees is both a direct cost and an opportunity cost for grounds operations and forfeits a landscape asset. Instead, the university should direct qualified personnel to carry out a reasonable and proportionate approach to inspecting trees and mitigating risks using tools and techniques appropriate for the landscape context.

8. INCREASED FOCUS ON ECOSYSTEM SERVICES AND SUSTAINABILITY

A traditional viewpoint holds that urban forests are amenities largely imbued with esoteric or intangible benefits. However, research on urban ecosystems is revealing an ever-expanding portfolio of tangible benefits from landscape trees that have significant environmental and economic value. As a result, urban forests are increasingly managed from the standpoint of ecosystem services and trees are purposefully being designed into built environments with consideration for their ability to mitigate the negative effects of urbanization. In this report, a small glimpse of the ecosystem services, and economic impacts of campus trees was provided with an analysis of the inventory data using i-Tree Eco software. This analysis provides credible, tangible evidence that campus trees are improving the campus environment and helping to control the costs of operating the institution. Provision of ecosystem services and return-on-investment is not as simple as planting trees in vacant spaces. Trees vary considerably in their services and economic impact depending on what they are, where they are, and how big they are. These are important concepts that should be given consideration as capital projects are planned and decisions are made about which trees will be displaced and which trees will be replaced. Recognizing that trees play a vital function in the local ecosystem and that choices about landscape design and maintenance have an impact on those ecosystem functions will enhance decision-making and improve the university's sustainability profile.

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Appendix A: GIS Protocol

Campus trees were inventoried using ESRI's Collector for ArcGIS application (i.e., Collector app) installed on an Apple iPad Pro with built-in 4G wireless internet access. The Collector app was configured to a custom tree inventory data model developed and hosted by the Virginia Tech Facilities Department Office of Data Administration and Management, with guidance provided by the Virginia Tech Department of Forest Resources and Environmental Conservation Department (FREC), Virginia Tech Office of University Planning (OUP), and the International Society of Arboriculture's "Best Management Practices – Tree Inventories" publication (Bond, 2013). The data model used field domains where appropriate to expedite field data entry using pick lists. Attachments were also enabled in the underlying data source (i.e., PostgreSQL enterprise geodatabase) to allow tree photos to be related to each tree record. Additional data viewers using ArcGIS Online's Web Application Builder were developed to allow members of FREC and OUP read-only access to the campus tree inventory.

Appendix B: Inventory Data Model

A total of 19 attributes were assigned to each tree in the process of inventory data collection. Of these, 15 were required fields, two were optional fields (Maintenance Recommendations 2 and 3), and two were attributes added after completion of data collection (Tree Type, Native Status). These last two were joined to the dataset using tree species as a common field. Descriptions of all attributes are given here, including all permitted values for those with defined domains. Definitions and indicators of values are also given where appropriate.

INVENTORY DATA FIELDS

Field Name	Field Type	Domain	Description	Comments
CommonName	Text	L_Tree_CmnNm		
ScientificName	Text	L_Tree_SciNm		
DBH	Integer		Diameter at breast height (in whole inches)	For multi-stem trees: use largest stem
CrownRadius	Integer		Tree's crown radius (in whole feet)	Rough average for asymmetrical crown
Height	Integer		Tree's height (in whole feet)	
Status	Text	L_Tree_Status	3 categories: alive, dead, or removed	
Health	Text	L_Tree_HealthStructure	4 level rating	
Structure	Text	L_Tree_HealthStructure	4 level rating	
GroundCover	Text	L_Tree_GroundCover	8 categories	
SiteType	Text	L_Tree_SiteType	6 categories	
AgeClass	Text	L_Tree_Age_Class	4 level rating	
CollectionDate	Date		Date tree was originally inventoried	Not changed for previously inventoried trees
Commemorative	Text	L_Tree_Commemorative	Whether the tree was planted as a memorial; 2 categories	
MaintenanceHistory	Text	L_Tree_MaintenanceHistory	Existing hardware in tree; 3 categories	
MaintenanceRecommendation1	Text	L_Tree_Maintenance	Highest priority maintenance recommendation; 15 categories	
MaintenanceRecommendation2	Text	L_Tree_Maintenance	2nd highest priority maintenance recommendation	

Field Name	**Field Type**	**Domain**	**Description**	**Comments**
MaintenanceRecommendation3	Text	L_Tree_Maintenance	3rd highest priority maintenance recommendation	
treetype	Text		leaf type, evergreen status and mature size class; 12 categories	Added to data model April 2018
nativestatus	Text		Origin/establishment of tree; 4 categories	Aadded to data model April 2018

SPECIES COMMON NAMES

DomainName	L_Tree_CmnNm							
DomainType	CodedValue							
FieldType	String							
MergePolicy	DefaultValue							
SplitPolicy	DefaultValue							
Description	L_CmnNm							
Owner	fis							
Name								
Aesculus x worlitzensis	Black spruce	Chinese Tupelo	English oak	Indian paper birch	Narrow-leafed ash	Red buckeye	Southern bayberry	White poplar
Alder	Black tupelo	Chinkapin oak	English walnut	Italian cypress	Narrow-leaved gimlet	Red cedar	Southern bayberry	White spruce
Alleghany chinkapin	Black walnut	Clammy locust	European alder	Ivyleaf maple	Northern catalpa	Red horsechestnut	Southern catalpa	White willow
Alternateleaf dogwood	Black willow	Coast redwood	European ash	Jack pine	Northern hackberry	Red maple	Southern crabapple	Willow
American basswood	Blackjack oak	Cockspur hawthorn	European beech	Japanese black pine	Northern pin oak	Red mulberry	Southern Japanese hemlock	Willow oak
American beech	Blue ash	Common chokecherry	European bird cherry	Japanese garden juniper	Northern red oak	Red pine	Southern magnolia	Winged elm
American chestnut	Blue Chinese fir	Common crapemyrtle	European hornbeam	Japanese hornbeam	Northern white cedar	Red spruce	Southern red oak	Wisconsin weeping willow
American elm	Blue spruce	Common fig	European larch	Japanese maple	Norway maple	Redbay	Spruce	Witch hazel
American hazlenut	Bluejack oak	Common hoptree	European mountain ash	Japanese pagoda tree	Norway spruce	River birch	Spruce pine	Yaupon
American holly	Bottlebrush buckeye	Common juniper	European white birch	Japanese red cedar	Nuttall oak	Rock elm	Staghorn sumac	Yellow birch
American hornbeam	Boxelder	Common pear	Fir	Japanese red pine	Oak	Rocky mountain juniper	Star magnolia	Yellow buckeye
American mountain ash	Boxwood	Common pearlbrush	Fire thorn	Japanese snowbell	Ohio buckeye	Rocky mountain maple	Striped maple	Yellow buckeye

American plum
American sycamore
Amur chokecherry
Amur corktree
Amur maackia
Amur maple
Apple
Apple serviceberry
Arizona cypress
Ash
Asian white birch
Atlantic white cedar
Atlas cedar
Australian pine
Austrian pine
Autumn olive
Baldcypress
Broadleaf Deciduous Large
Broadleaf Deciduous Medium
Broadleaf Deciduous Small
Broadleaf Evergreen Large
Broadleaf Evergreen Medium
Broadleaf Evergreen Small
Buckeye
Bur oak
Butternut
Callery pear
Camellia
Camperdown elm
Canada yew
Carolina ash
Carolina hemlock
Carolina laurelcherry
Carolina poplar
Common persimmon
Conifer Evergreen Large
Conifer Evergreen Medium
Conifer Evergreen Small
Corkscrew willow
Cornelian cherry
Cottonwood
Crabapple
Crack willow
Crapemyrtle
Crimean linden
Cucumber tree
Dahoon
Darlington oak
Dawn redwood
Deodar cedar
Devils walking stick
Flamegold
Flowering ash
Flowering dogwood
Flowering plum
Formosa firethorn
Forsythia
Franklin tree
Fraser fir
Fraser photinia
Freeman maple
Fremont cottonwood
Fringe tree
Ginkgo
Golden chain tree
Goldenrain tree
Gray birch
Gray dogwood
Japanese tree lilac
Japanese white pine
Japanese zelkova
Juniper
Katsura tree
Kentucky coffeetree
Korean Evodia
Korean mountain ash
Kousa dogwood
Kwanzan cherry
Lanceleaf cottonwood
Larch
Laurel oak
Leatherleaf mahonia
Leyland cypress
Ligustro
Lilac
One seed juniper
Orange eye butterflybush
Osage orange
Overcup oak
Pacific rhododendron
Paper birch
Paper mulberry
Paperbark maple
Paradise apple
Paradise apple
Paulownia
Pawpaw
Peach
Pear
Pecan
Pendent silver linden
Persian ironwood
Rosebay rhododendron
Rosegold pussy willow
Rosemallow
Rose-of-sharon
Royal paulownia
Russian olive
Sand pine
Sargent cherry
Sasanqua camellia
Sassafras
Saul's oak
Sawara false cypress
Sawtooth oak
Scarlet oak
Scotch pine
September elm
Serviceberry
Sugar maple
Sugarberry
Sumac
Swamp chestnut oak
Swamp white oak
Sweet cherry
Sweet mountain pine
Sweet olive
Sweetbay
Sweetgum
Sycamore
Sycamore maple
Taiwan cherry
Taiwanese photinia
Tatar maple
Topal holly
Tree of heaven
Yellowwood
Yew
Yew podocarpus
Yoshino flowering cherry

Balsam fir	Carriere hawthorn	Dixie rosemallow	Gray poplar	Limber pine	Photinia	Shagbark hickory	Trident maple	
Balsam poplar	Catalpa	Dogwood	Green ash	Littleleaf linden	Pignut hickory	Shellbark hickory	Tulip tree	
Basswood	Catawba rhododendron	Douglas fir	Green hawthorn	Live oak	Pin cherry	Shingle oak	Turkey oak	
Beech	Caucasian ash	Downy hawthorn	Hackberry	Loblolly pine	Pin oak	Shore juniper	Turkish hazelnut	
Bigleaf linden	Chaste tree	Downy serviceberry	Hardy rubber tree	London plane	Pine	Shortleaf pine	Two-wing silverbell	
Bigleaf maple	Cherry plum	Dutch elm	Harlequin glorybower	Longleaf pine	Pitch pine	Showy forsythia	Umbrella magnolia	
Bigtooth aspen	Chestnut oak	Eastern cottonwood	Hawthorn	Loquat tree	Plains cottonwood	Shumard oak	Unknown tree	
Birch	Chinaberry	Eastern hemlock	Hazelnut	Magnolia	Plum	Siberian elm	Unlisted tree	
Bitternut hickory	Chinese chestnut	Eastern hophornbeam	Hedge maple	Manchu cherry	Pond pine	Silver linden	Viburnum	
Black ash	Chinese elm	Eastern red cedar	Hickory	Maple	Ponderosa pine	Silver maple	Virginia pine	
Black birch	Chinese flame tree	Eastern redbud	Higan cherry	Mimosa	Port Orford cedar	Slash pine	Walnut	
Black cherry	Chinese fringe tree	Eastern serviceberry	Holly	Mockernut hickory	Post oak	Slippery elm	Washington hawthorn	
Black haw	Chinese holly	Eastern white pine	Honeylocust	Mockernut hickory	Privet	Smoke tree	Water oak	
Black hickory	Chinese magnolia	Elaeagnus	Honeysuckle	Mountain ash	Purple blow maple	Smooth hawthorn	Western red cedar	
Black locust	Chinese magnolia; Saucer magnolia	Elm	Hornbeam	Mountain silverbell	Purpleleaf sand cherry	Smooth serviceberry	White ash	
Black maple	Chinese parasoltree	Engelmann spruce	Horsechestnut	Mulberry	Pussy willow	Smooth sumac	White fir	
Black oak	Chinese pistache	English elm	Hybrid dogwood	Myrtle dahoon	Pyramid magnolia	Snowdrop tree	White mulberry	
Black poplar	Chinese privet	English holly	Incense cedar	Narrowleaf cottonwood	Quaking aspen	Sourwood	White oak	

SPECIES SCIENTIFIC NAMES

DomainName	L_Tree_SciNm							
DomainType	CodedValue							
FieldType	String							
MergePolicy	DefaultValue							
SplitPolicy	DefaultValue							
Description	L_Tree_SciNm							
Owner	fis							
Name								
Abies balsamea	Betula papyrifera	Chamaecyparis thyoides	Fraxinus angustifolia	Ligustrum sinense	Picea rubens	Prunus padus	Quercus virginiana	Ulmus glabra 'Camperdownii'
Abies concolor	Betula pendula	Chionanthus retusus	Fraxinus caroliniana	Ligustrum species	Picea species	Prunus pensylvanica	Quercus x saulii	Ulmus parvifolia
Abies fraseri	Betula platyphylla	Chionanthus virginicus	Fraxinus excelsior	Liquidambar styraciflua	Pinus banksiana	Prunus persica	Rhododendron catawbiense	Ulmus procera
Abies species	Betula populifolia	Cladrastis kentukea	Fraxinus nigra	Liriodendron tulipifera	Pinus clausa	Prunus sargentii	Rhododendron macrophyllum	Ulmus pumila
Acer buergerianum	Betula species	Clerodendrun trichotomum	Fraxinus ornus	Lonicera species	Pinus densiflora	Prunus serotina	Rhododendron maximum	Ulmus rubra
Acer campestre	Betula utilis	Conifer Evergreen Large	Fraxinus oxycarpa	Maackia amurensis	Pinus echinata	Prunus serrulata	Rhus glabra	Ulmus serotina
Acer cissifolium	Broadleaf Deciduous Large	Conifer Evergreen Medium	Fraxinus pennsylvanica	Maclura pomifera	Pinus elliottii	Prunus species	Rhus species	Ulmus species
Acer ginnala	Broadleaf Deciduous Medium	Conifer Evergreen Small	Fraxinus quadrangulata	Magnolia acuminata	Pinus flexilis	Prunus subhirtella	Rhus typhina	Ulmus thomasii
Acer glabrum	Broadleaf Deciduous Small	Cornus alternifolia	Fraxinus species	Magnolia denudata	Pinus glabra	Prunus tomentosa	Robinia pseudoacacia	Ulmus x hollandica
Acer griseum	Broadleaf Evergreen Large	Cornus florida	Ginkgo biloba	Magnolia grandiflora	Pinus mugo	Prunus triloba	Robinia viscosa	Unknown unknown
Acer macrophyllum	Broadleaf Evergreen Medium	Cornus kousa	Gleditsia triacanthos	Magnolia soulangiana	Pinus nigra	Prunus virginiana	Salix alba	Unlisted unlisted

Acer negundo
Acer nigrum
Acer palmatum
Acer pensylvanicum
Acer platanoides
Acer pseudoplatanus
Acer rubrum
Acer saccharinum
Acer saccharum
Acer species
Acer tataricum
Acer truncatum
Acer x freemanii
Aesculus flava
Aesculus glabra
Aesculus hippocastanum
Aesculus octandra
Aesculus parviflora
Aesculus pavia
Broadleaf Evergreen Small
Broussonetia papyrifera
Buddleja davidii
Buxus species
Calocedrus decurrens
Camellia japonica
Camellia sasanqua
Carpinus betulus
Carpinus caroliniana
Carpinus japonica
Carpinus species
Carya alba
Carya cordiformis
Carya glabra
Carya illinoinensis
Carya laciniosa
Carya ovata
Carya species
Carya texana
Cornus mas
Cornus racemosa
Cornus species
Cornus x rutgersensis
Corylus americana
Corylus colurna
Corylus species
Cotinus coggygria
Crataegus crus-galli
Crataegus laevigata
Crataegus mollis
Crataegus phaenopyrum
Crataegus species
Crataegus viridis
Crataegus x Lavallei
Cryptomeria japonica
Cunninghamia lanceolata
Cupressus arizonica
Cupressus sempervirens
Gymnocladus dioicus
Halesia carolina
Halesia diptera
Halesia tetraptera
Hamamelis virginiana
Hibiscus mutabilis
Hibiscus species
Hibiscus syriacus
Ilex aquifolium
Ilex cassine
Ilex cornuta
Ilex myrtifolia
Ilex opaca
Ilex species
Ilex vomitoria
Ilex x attenuata
Juglans cinerea
Juglans nigra
Juglans regia
Magnolia species
Magnolia stellata
Magnolia tripetala
Magnolia virginiana
Magnolia x soulangiana
Mahonia bealei
Malus angustifolia
Malus pumila
Malus species
Malus sylvestris
Malus tschonoskii
Melia azedarach
Metasequoia glyptostroboides
Morella cerifera
Morus alba
Morus rubra
Morus species
Myrica cerifera
Nyssa sinensis
Pinus palustris
Pinus parviflora
Pinus ponderosa
Pinus resinosa
Pinus rigida
Pinus serotina
Pinus species
Pinus strobus
Pinus sylvestris
Pinus taeda
Pinus thunbergii
Pinus virginiana
Pistacia chinensis
Platanus occidentalis
Platanus species
Platanus x acerifolia
Podocarpus macrophyllus
Populus alba
Populus angustifolia
Prunus x cistena
Prunus yedoensis
Pseudotsuga menziesii
Ptelea trifoliata
Pyracantha coccinea
Pyracantha koidzumii
Pyrus calleryana
Pyrus communis
Pyrus species
Quercus acutissima
Quercus alba
Quercus bicolor
Quercus coccinea
Quercus ellipsoidalis
Quercus falcata
Quercus hemisphaerica
Quercus imbricaria
Quercus incana
Quercus laevis
Salix babylonica
Salix discolor
Salix fragilis
Salix gracilistyla
Salix matsudana
Salix nigra
Salix species
Sassafras albidum
Sequoia sempervirens
Sophora japonicum
Sorbus alnifolia
Sorbus americana
Sorbus aucuparia
Sorbus species
Styrax japonicus
Syringa reticulata
Syringa species
Taxodium distichum
Taxus canadensis
Viburnum prunifolium
Viburnum species
Vitex agnus-castus
x Cupressocyparis leylandii
Zelkova serrata

- Aesculus species
- Aesculus x carnea
- Aesculus x worlitzensis
- Ailanthus altissima
- Albizia julibrissin
- Alnus glutinosa
- Alnus species
- Amelanchier arborea
- Amelanchier canadensis
- Amelanchier laevis
- Amelanchier species
- Amelanchier x grandiflora
- Aralia spinosa
- Asimina triloba
- Betula alleghaniensis
- Betula lenta
- Betula nigra
- Carya tomentosa
- Castanea dentata
- Castanea mollissima
- Castanea pumila
- Casuarina equisetifolia
- Catalpa bignonioides
- Catalpa species
- Catalpa speciosa
- Cedrus atlantica
- Cedrus deodara
- Celtis laevigata
- Celtis occidentalis
- Celtis species
- Cercidiphyllum japonicum
- Cercis canadensis
- Chamaecyparis lawsoniana
- Chamaecyparis pisifera
- Diospyros virginiana
- Elaeagnus angustifolia
- Elaeagnus species
- Elaeagnus umbellata
- Eriobotrya japonica
- Eucommia ulmoides
- Euonymus species
- Exochorda racemosa
- Fagus grandifolia
- Fagus species
- Fagus sylvatica
- Ficus carica
- Firmiana simplex
- Forsythia species
- Forsythia x intermedia
- Franklinia alatamaha
- Fraxinus americana
- Juglans species
- Juniperus communis
- Juniperus conferta
- Juniperus monosperma
- Juniperus procumbens
- Juniperus scopulorum
- Juniperus species
- Juniperus virginiana
- Koelreuteria bipinnata
- Koelreuteria elegans
- Koelreuteria paniculata
- Laburnum anagyroides
- Lagerstroemia indica
- Lagerstroemia species
- Larix decidua
- Larix species
- Ligustrum japonicum
- Nyssa sylvatica
- Osmanthus fragrans
- Ostrya virginiana
- Oxydendrum arboreum
- Parrotia persica
- Paulownia species
- Paulownia tomentosa
- Persea borbonia
- Phellodendron amurense
- Photinia serratifolia
- Photinia serrulata
- Photinia x fraseri
- Picea abies
- Picea engelmannii
- Picea glauca
- Picea mariana
- Picea pungens
- Populus balsamifera
- Populus deltoides
- Populus fremontii
- Populus grandidentata
- Populus nigra
- Populus sargentii
- Populus species
- Populus tremuloides
- Populus x acuminata
- Populus x canadensis
- Populus x canescens
- Prunus americana
- Prunus avium
- Prunus campanulata
- Prunus caroliniana
- Prunus cerasifera
- Prunus maackii
- Quercus laurifolia
- Quercus lyrata
- Quercus macrocarpa
- Quercus marilandica
- Quercus michauxii
- Quercus muehlenbergii
- Quercus nigra
- Quercus palustris
- Quercus phellos
- Quercus prinus
- Quercus robur
- Quercus rubra
- Quercus shumardii
- Quercus species
- Quercus stellata
- Quercus texana
- Quercus velutina
- Taxus species
- Tetradium daniellii
- Thuja occidentalis
- Thuja plicata
- Thuja species
- Tilia americana
- Tilia cordata
- Tilia petiolaris
- Tilia platyphyllos
- Tilia species
- Tilia tomentosa
- Tilia x euchlora
- Tsuga canadensis
- Tsuga caroliniana
- Tsuga sieboldii
- Ulmus alata
- Ulmus americana

TREE HEALTH AND STRUCTURE RATINGS

DomainName	L_Tree_HealthStructure		
DomainType	CodedValue		
FieldType	String		
MergePolicy	DefaultValue		
SplitPolicy	DefaultValue		
Description	L_Tree_Health_Structure		
Owner	fis		
Coded Values (Health)			
Code	**Name**	**Definition**	**Indicators**
Exc	Excellent	No observable indications of issues with pests, abiotic stress, or loss of vitality	<5% of canopy affected by: chorosis, necrosis, signs of insect or pathogen damage
Good	Good	Observable indications of minor issues with pests, abiotic stress, or loss of vitality	5-20% of canopy affected by above signs; dieback or decay present only on small limbs
Fair	Fair	Observable indications of moderate issues with pests, abiotic stress, or loss of vitality	20-50% of canopy affected by above signs; dieback or decay present on large limbs
Poor	Poor	Observable indications of major issues with pests, abiotic stress, or loss of vitality	>50% of canopy affected by above signs; large wounds, canker or decay present on bole
Coded Values (Structure)			
Code	**Name**	**Definition**	**Indicators**
Exc	Excellent	No observable indications of defects or abnormalities in its growth pattern	No wounds or signs of decay; no included bark,crossing or crowded branches
Good	Good	Observable indications of minor defects or abnormalities in its growth pattern	Indicators above visible on small limbs or in few locations in crown
Fair	Fair	Observable indications of moderate defects or abnormalities in its growth pattern	Indicators above visible on large limbs or throughout crown
Poor	Poor	Observable indications of major defects or abnormalities in its growth pattern	Main leaders, trunk or root collar weakened by wounding or decay

GROUNDCOVER CLASSIFICATION

DomainName	L_Tree_GroundCover	
DomainType	CodedValue	
FieldType	String	
MergePolicy	DefaultValue	
SplitPolicy	DefaultValue	
Description	L_Tree_GroundCover	
Owner	fis	
Coded Values		
Code	**Name**	**Definition**
Turf	Turf	
Mulch	Mulch	
Bare soil	Bare soil	
Gravel	Gravel	
Asphalt	Asphalt	
Concrete	Concrete	
Duff	Duff	An unmanaged natural ground cover, e.g., leaf litter or meadow

SITE TYPE CLASSIFICATION

DomainName	L_Tree_SiteType	
DomainType	CodedValue	
FieldType	String	
MergePolicy	DefaultValue	
SplitPolicy	DefaultValue	
Description	SiteType	
Owner	fis	
Coded Values		
Code	**Name**	**Definition**
natural area	natural area	Including both engineered natural areas and unmaintained meadows, woods, or wetlands
open lawn	open lawn	
parking lot island	parking lot island	
planter box	planter box	
planting strip	planting strip	<10' wide strip of planting area between impervious surfaces
sidewalk pit	sidewalk pit	

AGE CLASSIFICATION

DomainName	L_Tree_AgeClass		
DomainType	CodedValue		
FieldType	String		
MergePolicy	DefaultValue		
SplitPolicy	DefaultValue		
Description	L_Age_Class		
Owner	fis		
Coded Values			
Code	**Name**	**Definition**	**Indicators**
Young	Young	Tree transplanted or germinated in last 3 years	Often indicated by stakes or tree gators
Immature	Immature	Tree that is established but not reached the typical functional size for the species	This category covers about 80% of campus trees
Mature	Mature	Tree that has reached the typical functional size for the species	Rough criteria: shade trees > 30" , ornamentals > 10"
Overmature	Overmature	Tree that has begun showing characteristics of senesence or retrenchment	Both mature and declining

COMMEMORATIVE TREE STATUS

DomainName	L_Tree_Commemorative
DomainType	CodedValue
FieldType	String
MergePolicy	DefaultValue
SplitPolicy	DefaultValue
Description	L_Tree_Commemorative
Owner	fis
Coded Values	
Code	**Name**
no	No
yes	Yes
Each commemorative tree has a photo attached of the plaque or stone, and the person's name is included in the "Notes" field	

MAINTENANCE HISTORY

DomainName	L_Tree_MaintenanceHistory
DomainType	CodedValue
FieldType	String
MergePolicy	DefaultValue
SplitPolicy	DefaultValue
Description	L_Tree_MaintenanceHistory
Owner	fis
Coded Values	
Code	**Name**
cabled	cabled
lightning protection	lightning protection
none	none

MAINTENANCE RECOMMENDATIONS

DomainName	L_Tree_Maintenance	
DomainType	CodedValue	
FieldType	String	
MergePolicy	DefaultValue	
SplitPolicy	DefaultValue	
Description	L_Tree_Maintenance	
Owner	fis	
Coded Values		
Code	**Name**	**Definition**
Clean	Clean	Prune out major deadwood
Correct Nutrient Deficiency	Correct Nutrient Deficiency	With soil amendment or fertilization
Disease and insect treatment	Disease and insect treatment	Generally used for annual or regular treatments of persistent pests
Inspect	Inspect	Generally for potential hazards needing further evaluation, often needing aerial inspection
Mulch	Mulch	Add mulch
Mulch Correction	Mulch Correction	Fix mulch (uncover root collar)
None	None	
Raise	Raise	Raise for pedestrian or vehicular traffic; also used for clearance from a building
Reduce	Reduce	Reduce the height or spread of the crown -- generally for conflict with wires, lighting
Remove	Remove	
Restore	Restore	Pruning to improve poor structure due to topping cuts or storm damage
Structural Prune	Structural Prune	For Young and young Immature trees -- to select scaffold branches and improve form
Stump Grind	Stump Grind	
Thin	Thin	For immature trees: reduce branch crowding , improve form. Cuts are much smaller than for structural pruning
Transplant	Transplant	

TREE TYPE

Tree Type Values	Definition		Mature height (feet)	
BDL	Broadleaf Deciduous Large		Large	> 50
BDM	Broadleaf Deciduous Medium		Medium	25 - 50
BDS	Broadleaf Deciduous Small		Small	< 25
BEL	Broadleaf Evergreen Large			
BEM	Broadleaf Evergreen Medium			
BES	Broadleaf Evergreen Small			
CDL	Coniferous Deciduous Large			
CDM	Coniferous Deciduous Medium			
CDS	Coniferous Deciduous Small			
CEL	Coniferous Evergreen Large			
CEM	Coniferous Evergreen Medium			
CES	Coniferous Evergreen Small			

NATIVE STATUS OF TREE SPECIES

Native Status Values	Definition
VA_native	Native to VA
US_native	Native to US
Naturalized	Naturalized to US
Exotic	Non-native, non-naturalized
*For IDs at the genus level, (i.e. Acer species), Native_Status is left blank except for when	
whole genus falls in the same category	
*Trees of horticultural origin:	
cultivars coded by species,	
hybrids coded as native if all parents are	