THE YALE TREE MANAGEMENT PLAN

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ABBREVIATIONS

ALARP	as low as reasonably possible
ANSI	American National Standards Institute
ANSI A300	United States, industry-developed, national consensus standards of practice for tree care.
ANSI Z133.1	United States Safety standards for arborists
BCMA	Board Certified Master Arborist
BMP	best management practice
B&B	balled & burlapped
CAES	Connecticut Agricultural Extension Service
CODIT	compartmentalization of decay in trees
CTLA	Council of Tree and Landscape Appraiser
DBH	diameter at breast height
D-tape	diameter tape
ET	evapotranspiration
GIS	geographic information system

IPCC	Intergovernmental Panel Climate Change
IPM	integrated pest management
ISA	International Society of Arboriculture
ISA LEVEL 1	International Society of Arboriculture Level 1 (limited visual assessment, see glossary)
ISA LEVEL 2	International Society of Arboriculture Level 2 (basic assessment, see glossary)
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
PHC	plant health care
RCA	Registered Consulting Arborist
TMP	Tree Management Plan
TPZ	tree protection zone
TRAQ	tree risk assessment qualification
VTA	visual tree assessment
YR	Yale Representative

FORESTRY SPECIES CODE KEY

Ar	Red Maple—*Acer rubrum*
As	Sugar Maple—*Acer saccharum*
Ap	Norway Maple—*Acer platanoides*
Aa	Tree-of-Heaven—*Ailanthus altissima*
Ba	Yellow Birch—*Betula alleghaniensis*
Bl	Black Birch—*Betula lenta*
Cc	Ironwood—*Carpinus caroliniana*
Cg	Pignut Hickory—*Carya glabra*
Co	Shagbark Hickory—*Carya ovata*
Ea	Russian Olive—*Elaeagnus angustifolia*
Fa	White Ash—*Fraxinus americana*
Fg	American Beech- *Fagus grandifolia*
Lt	Tulip Tree—*Liriodendron tulipifera*
Ms	Crabapple—*Malus* spp.
Ov	American Hophornbeam—*Ostrya virginiana*
Pd	Eastern Cottonwood—*Populus deltoides*
Ps	Black Cherry—*Prunus serotina*
Qr	Red Oak—*Quercus rubra*
Qa	White Oak—*Quercus alba*
Qv	Black Oak—*Quercus velutina*
Qb	Swamp Oak—*Quercus bicolor*
Pi s	Pine—*Pinus strobus*
Sa	Sassafras—*Sassafras albidum*

EXECUTIVE SUMMARY

A sound approach to management of the Yale Urban Forest is to quantify and interpret existing forest conditions by establishing a direction and pace with which to achieve the desired goals. A tree inventory provides the base information to create a tree management plan that aims to target goals and evaluate progress over a set time frame. The tree management plan is a tool for communicating with other stakeholders to proactively plan, prioritize, schedule, and scope areas of work, with an end goal of reducing unanticipated costs that are typically incurred when in a reactive setting.

Plan Development Team

This plan was developed for the Yale Office of Facilities and Planning by consulting arborists Treefoil LLC, to focus on current and future tree canopy maintenance and planning needs. Treefoil LLC staff involved with the project include Bradley Painter, principal, Isabelle Zaffetti, licensed arborist technician; and Georgia Hann, arborist technician; in collaboration with Mark Duntemann, senior consultant, Duntemann Urban Forestry LLC.

The Yale Office of Facilities team included Dev Hawley, Director, University Planning and Facilities Operations, Kristina Chmelar, Major Projects Planner and Michael West, Manager of Planning and Standards. An accompanying ArcGIS tree map was developed by Michael Slattery, Web Developer for the School of Forestry and Environmental Sciences and liaison with URI (Urban Resources Initiative) for coordination with previous inventory efforts.

Yale area supervisor representatives from the Office of Facilities Landscape, Grounds, and Maintenance—Walter Debboli, James Reid, Joseph Signore, Paul Catalano, and Edward Mockus—provided insight and support for their campus areas.

Inventory Scope

Treefoil LLC completed a tree inventory from October 2019 through March 2020 to achieve insight into the needs of the Yale Urban Forest and to forecast budgets for tree care and planting. The consultants were able to develop this tree management plan after analysis of the collected tree inventory data, with additional input from the various Yale team members.

The tree inventory included collection of data from existing trees and stumps in managed, woodland, and forested areas of the Yale campuses: Central North, Central South, School of Medicine, West, and Athletics, as well as from City of New Haven street trees immediately bordering these areas. The acreage inventoried is approximately 462 out of a total of 565 acres. Construction areas at the time of the inventory were not included in the inventory acreage though it is anticipated

Figure 1 Yale Campuses

they will be done at a future date. City of New Haven trees that border university property were also inventoried and are considered a separate designation.

METHODOLOGY

Pre-Inventory Phase

The pre-inventory phase served to review and finalize data and associated collection fields with management team members. Data structure was finalized for ArcGis compatible deliverables. Project liaisons were identified for all parties and protocols were established for communications, project updates, notifications of high and extreme risk trees and any additional data requests. Tree identification tag considerations were discussed as well as the retrieval of any pertinent past tree-related events.

Inventory Phase

Data collection occurred in all university campus areas (Central North, Central South, Yale School of Medicine, West Campus and Athletics) starting in Central North Campus in October 2019 and completing in Athletics in March 2020. All trees with trunks four inches and greater in diameter within managed areas were tagged, assessed, and digitally mapped; some smaller trees in newly landscaped areas were also tagged, assessed, and inventoried. Trees in woodland areas (wooded areas under approximately

1.3 acres) over 8" DBH were tagged and inventoried while forested areas (areas over approximately 1.3 acres) were forest surveyed.

Development of the Tree Management Plan

This tree management plan and associated recommendations were developed after a review of each campus GIS tree inventory data results. It provides specific recommendations for arborist contract management and anticipated budgeting purposes for facilities planning, maintenance, inspections, resilience, and planting based on tree location, size, species, condition, and priority level. The ArcGis platform can be manually updated to include future removals, maintenance actions, plantings, and more.

Data Collection

Bradley Painter from Treefoil LLC and subconsultant, Mark Duntemann were the primary collectors of data, using handheld Trimble GeoExplorer 6000Series GeoXT satellite receivers. Data collection occurred from October 2019 until March 2020.

The data were downloaded, post-processed, edited, and then provided to Yale University to test data integrity and system compatibility on Yale's existing ArcGis platform. The locations were recorded for data post-processing activities and made available to the Yale tree management team for upload onto the existing Yale ArcGIS map platform where the tree locations and collected information are plotted and reviewed.

Data Collection Fields

The following data fields are the final list of data the project team agreed to have collected during the initial design phase.

1. Inventory Date.
2. Assessor Name.
3. Tag Number. Number on tag attached to tree.
4. Organization. Identifies the owner of the subject tree. This consisted of either Yale University or the City of New Haven.
5. Campus. (Central North, Central South, School of Medicine, Athletics, or West).
6. Event 1. Assigned the event type of "Inventory" to the record by date collected.
7. Item Type. Identifies the item as a **T**ree, **P**lanting (identified planting site) or **R**emoved Tree (a previously inventoried tree that is now gone.)
8. Common Name. The common name assigned to the inventoried tree
9. Diameter. The diameter was measured to the nearest inch.
10. Condition. (Excellent, Good, Fair, Poor, Very Poor, and Dead See Appendix 1).
11. Defects. A defect is a visible flaw or an aberration that causes an item to be less than perfect.
12. Cavity/Decay. Cavity/decay is the deterioration of wood by a decay fungi.
13. Event 2. Recommended maintenance actions, other than "Inventory". The selections included: Prune, Removal, Cable, and Grind Stump.
14. Prune. If Prune was selected in Event 2, a specific type of pruning was noted in this field of all A300 recommended pruning: Cleaning, Clearance, Reduction and Structural.
15. Monitor. Tree had some structural aberration that requires a shorter inspection interval.

16. Priority. Choices included: Memorial, Milestone, Donated, and Specimen.

17. Utility. Recorded presence of overhead utility lines (transmission, distribution, or service).

18. Latitude. 1984 State Plane Coordinates—Connecticut

19. Longitude. 1984 State Plane Coordinates—Connecticut

20. Comments. Field for additional details to be recorded.

21. Value. A calculated value for each tree based on the diameter, condition, functional depreciation, and external depreciation of each tree.

SOIL SAMPLING

Managed Area Soil Sampling

Soil samples were taken from sample plots in managed areas (mowed areas and planting beds). The plots were selected as representative of the general physical condition. The samples were tested using a standard nutrient analysis (see Appendix 3).

Forested Area Soil Sampling

Forested areas were determined by Yale University. The forested areas were in West Campus and Athletics Campus. The areas and plot points were selected after initial onsite review and selection as determined by the character of the plot.

Three evenly spaced soil samples were taken and were delivered to the UConn Soil Nutrient Analysis Laboratory for analysis to test for percent soil organic matter (see Soil Test Results, Appendix 3B).

FORESTRY AREA SURVEY

Based on a site review of the forest area assigned to the project, the consultants inventoried all trees with trunks eight inches or greater in parcels that are 1.2 acres or less in size. Areas of 1.3 or larger were plot surveyed and trees over 8" diameter manually recorded. There are two areas containing forestry areas of varying size: Athletics Campus (8.4 acres total) and West Campus (35 acres total).

Three assessment approaches were used on each of the larger (1.3-plus acres) parcels: plot sampling, a walk-through survey, and a level 1 visual inspection for areas of public use.

INVENTORY AREA DESIGNATIONS

YALE UNIVERSITY CAMPUS

The Yale University campus refers to the entire Yale campus. The campus is then broken out into five campus inventory area designations: Central North Campus, Central South Campus, Yale School of Medicine, West Campus, and Athletics Campus, totaling approximately 462 out of a total of 565 acres.

Figure 2 Yale Campuses and Locations

Construction areas at the time of the inventory were not included in the inventory acreage though it is anticipated they will be done at a future date. The Yale Golf Course, preserve, and parcels noncontiguous to the above locations were not part of the inventory. City of New Haven trees that border university property were also inventoried but are considered a separate designation.

YALE UNIVERSITY CAMPUS MANAGED AREAS

Managed areas are defined as university campus areas that are maintained with planting beds, open lawn area, meadow plantings with mowing maintenance, parking lots and sidewalk areas. Woodland area inventoried trees are included in the Yale University inventory totals.

Figure 3 Typical Managed Campus

Species Distribution

A total of 7,804 trees were inventoried between all Yale campus designations and the City of New Haven. 6,413 trees were inventoried on Yale property, and an additional 1,391 were City of New Haven trees.

Table 1 – Inventory Distribution by Campus			
Campus	**Yale University**	**City of New Haven**	**Total**
Central North Campus	3,154	597	3,751
Central South Campus	1,086	486	1,572
Medical Campus	422	217	639
West Campus	966		966
Athletics Camus	785	91	876
Total	6,413	1,391	7,804

Table 1 Inventory Distribution by Campus

Trunk Diameter Distribution:

Diameter distribution offers tree data that are presented in terms of diameter size class. This detail is important for determining current management needs as well as anticipating how needs will change, given total numbers and aging of individual species.

Table 4b - Diameter Distribution by Campus						
Diameter Class	Athletics Campus	Central North	Central South	Medical	West	Total
1 - 6"	56	823	410	136	305	1,730
7 – 12"	197	1,059	326	178	352	2,112
13 - 18"	216	546	139	57	177	1,135
19 – 24"	154	319	70	24	76	643
25 - 30"	79	180	43	8	28	338
31 - 36"	40	122	24	3	7	196
37 – 42"	17	51	17	2	2	89
43" +	12	46	12	2	2	74
Other	14	8	45	12	17	96
Total	785	3,154	1,086	422	966	6,413

Table 2 Diameter Distribution by Campus

Managed Area Soil Sampling

Soil samples were taken from sample plots in managed areas (mowed areas and planting beds). The plots were selected as representative of the general physical condition. The samples were tested using a standard nutrient analysis.

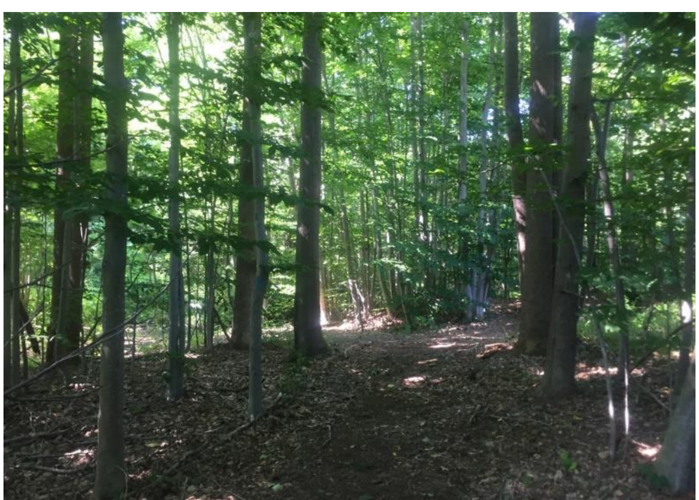

Table 3 Woodland

For the purposes of this analysis, **woodland areas** within Yale properties are sites of intense activity, due to their frequent use by university staff, faculty, students, and visitors, as well as their proximity to managed areas such as roads and sidewalks. Two woodland areas were identified: The Swale and a wooded area south of Prospect Garden Apartments and referred to as Prospect Gardens woodland. All trees over an 8-inch caliper at diameter at breast height (DBH) were inventoried.

YALE UNIVERSITY CAMPUS FORESTED AREAS

Forested areas within Yale University are larger (over 1.3 acres) and have less frequency of use. These areas were inventoried using a basic forest survey with plot sampling (see forested areas). All trees over 8-inch caliper within plots were manually inventoried.

Table 4 Forested Area West Campus

Walk-Through Survey

The walk-through survey is a thorough traverse of the entire parcel. Its purpose is to identify unique, significant trees that the sample survey may miss. The trees, when encountered, were GPS-mapped and recorded on the Yale ArcGIS platform.

Forestry Center Plot Points

Center plot points were geo-recorded as inventoried individual trees geo-identified as item "F" on the data collection for forested areas in West Campus and Athletics

Campus. The locations are recorded on the map as taken directly from the Yale ArcGis platform and are the locations of the center plot points.

YALE UNIVERSITY CAMPUS ECOSYSTEM

An ecosystem analysis was created for the overall Yale Campus, as well as each individual campus designation: Central North, Central South, Yale School of Medicine, West, and Athletics. The analysis was created using i-Tree, an open source service that quantifies ecological benefits of trees based on collected digital data fields. Interpretation of some data fields may vary from the consultants' data, resulting in slightly different tree quantities.

Ecosystem quantities and values per year:

- Carbon sequestration: 56.83 tons with benefits of $9,690/year
- Avoided runoff: 71,330 cubic feet with benefits of $4,770/year
- Pollution removal: 1.29 tons $27,600/year
- Carbon storage: 373,000 tons with benefits of $636,000/year (i-Tree Eco Analysis, Analysis New Haven, 2020).

Avoided Stormwater Runoff

Avoided storm water runoff is water that is utilized by trees before being channeled to a drainage system. The i-Tree analysis only considers precipitation intercepted by leaves, with Yale University trees such as red oak (*Quercus rubra*), pin oak (*Quercus palustris*), and Norway maple (*Acer platanoides*) able to capture the most cubic feet of avoided runoff.

The avoided stormwater runoff also diminishes the extent of surface erosion and soil lost.

Climate Resilience

For the purpose of this report resilience is "the ability of social-ecological systems to absorb and recover from climatic shocks, stresses, and means for living in the face of long-term change and uncertainty" (Intergovernmental Panel on Climate Change) as it relates to climate conditions.

The Yale campus has certain components and environmental conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures, severe weather, wind events, invasive pests, and invasive plants add considerable challenges to a plant's vitality and resilience.

Trees have varying ability to adapt to be resilient in the face of extreme environmental conditions. A greater range of appropriate species can help provide a broader resilience to the climatic factors as well. Pest and disease resistance, heat tolerance, wind resistance can vary even within species. Diversity in species selection can increase tree population resistance and minimize reliance on dominant species planting.

Oxygen Production

Yale campus trees in managed areas contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The earth's atmosphere has substantially more oxygen in its stores even without the contribution of the earth's tree population. (Nowak, 2007).

The overall top producer of oxygen according to the i-Tree Analysis is red oak (*Quercus rubra)* at a count of 354 trees at 20.92 tons. The next highest producer of oxygen is pin oak (*Quercus palustris)* at 18.40 tons, with a count of 308 trees (i-Tree Eco Analysis, Yale 2020).

Canopy and Air Pollution

A tree canopy is the tree's components, such as leaves, branches, and stems that cover the ground beneath the tree. The Yale campus has three distinct canopy covers: managed, woodland, and forest.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed, woodland and forested area according to the i-Tree Analysis is 1.299 tons in a year, with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser-count pollutants (i-Tree Analysis, Yale Campus, 2020).

YALE CAMPUS INTEGRATED PEST MANAGEMENT (IPM)

The Yale campus has 138 trees presently on a pest management program. The majority consist of three species: elm (*Ulmus species*), beech (*Fagus species*), and ash (*Fraxinus species*) to treat Dutch elm disease, emerald ash borer, and multiple beech diseases, respectively. It is important to note that without the emerald ash borer treatment the ash trees would die. The elm trees' survivability without treatment is less known, as some are newly planted hybrids without time-tested proven resistance.

Hardwood species like maples (*Acer species*), elms (*Ulmus species*), birch (*Betula species*), and horse chestnut (*Aesculus species*) within the managed areas are susceptible to identified invasive pests like the Asian longhorned beetle. An integrated pest management plan where regular monthly scouting for signs of a pest or disease allows an appropriate response depending on extent, location, and species.

Integrated Pest Management Levels

Yale University directed the consultants to focus on "priority" trees to distinguish between 138 trees currently on an integrated pest management plan (Level I), 39 trees that need to be on an integrated management plan (Level II) and 282 campus trees that are noteworthy as either specimen, donated tree, milestone tree, culturally significant, or having been identified as rare taxonomy (Level III) with a total of 459 trees currently identified. These quantities change as trees are added, removed, or otherwise updated to the ArcGis platform.

IPM Level I 138 trees are distinguished from the general campus tree population as currently on an integrated pest management plan and shown as IPM Level I on the Yale University ArcGis platform. Level I trees are being treated for pests and disease and should be inspected at regular intervals (30-45 days) during the growing season, usually considered between March and November, for additional problems.

IPM Level II 39 trees are distinguished from the general campus tree population as not currently on an integrated pest management plan but should be on an integrated pest management plan in anticipation. These trees are currently shown as a Level II on the Yale University ArcGis platform with a count of 39.

IPM Level III 282 trees have been identified as specimen, milestone, memorial, donated, culturally significant, or of rare taxonomy. It is possible for trees to be considered for more than one priority designation, such as culturally significant and a specimen. It is also possible for them to be on an IPM program, depending on the tree.

IPM Priority Trees by Campus						
IPM Priority Levels	Athletics Campus	Central North	Central South	Medical	West	Total
Level 1	0	26	51	18	43	138
Level 2	0	38	1	0	0	39
Level 3	0	170	55	43	14	282
Total	0	234	107	61	57	459

Table 5 IPM Priority Trees by Campus

YALE UNIVERSITY CAMPUS TREE VALUATION

The overall Yale campus valuation total for the inventoried tree population is $23,105,485. The figure was calculated from a total of 6,413 university trees inventoried. A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS.

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees. Treble values could be used for unique individual trees and specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). The legal system often determines such specific cases.

CITY OF NEW HAVEN STREET TREES

Overview

The consultants inventoried City of New Haven street trees that bordered Yale University properties. Street trees are generally considered trees that lie between the edge of sidewalks and the edge of street curbs. All the campuses have street trees except for West Campus. Yale University is interested in the trees from an informational standpoint and assumes no responsibility for the condition or maintenance of the trees.

The City of New Haven trees bordering Yale properties total 1,391. The city tree inventoried population on the campuses is Central North Campus 597, Central South Campus 486, Yale School of Medicine Campus 217, West Campus 0, and Athletics Campus 91 (see Table 6).

Species Distribution

The City of New Haven top three species distribution shows that there are 338 pin oak (*Quercus palustris*), 152 London planetree (*Platanus x acerifolia*), and 93 Norway maple (Acer platanoides). The pin oak population represents 24.3 percent of the tree population, the London planetree 10.9 percent, and Norway maple 6.7 percent (see Table 3).

City of New Haven Street Trees Ecosystem

An ecosystem analysis was created for the overall City of New Haven inventoried street trees. The analysis was created using i-Tree, an open source service that quantifies ecological benefits of trees based on collected digital data fields.
The i-Tree contributory structural value for the Yale Campus is $1,860,000 for 1,300 trees with tree cover of 11.29 acres.

Urban trees in New Haven i-Tree Analysis 2020 have the following annual functional value totals:

- Carbon sequestration: $2,230
- Avoided runoff: $896,000
- Pollution removal: $5,610
- Carbon storage: $132,000 (i-Tree Eco Analysis, Analysis New Haven, 2020).

City of New Haven tree species of greatest structural value are pin oak (*Quercus palustris*) highest, London planetree (*Platanus x acerifolia*) (referred to as American sycamore (*Platanus occidentalis*) in New Haven i-Tree analysis) second and Norway Maple (*Acer platanoides)* third.

Avoided Stormwater Runoff

Avoided stormwater runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with the City of New Haven street trees such as pin oak (*Quercus palustris*), London planetree (*Platanus x acerifolia*), and to a lesser degree Norway Maple (*Acer platanoides)a*) able to capture the most cubic feet of avoided runoff. The avoided stormwater runoff also decreases the extent of surface erosion and soil lost.

Climate Resilience

For the purpose of this report, resilience is "the ability of social-ecological systems to absorb and recover from the climactic shocks, stresses, and means for living in the face of long-term change and uncertainty" (Intergovernmental Panel on Climate Change, 2012) as it relates to climate conditions.

New Haven city trees have certain components and environmental conditions that put stress on the ability to be resilient in the face of current climate conditions. The inventoried street tree population usually lies in areas that are surrounded by impermeable surfaces without supplemental irrigation. Drought, higher temperatures, severe weather and wind events, and invasive pests and plants add considerable challenges to a plant's vitality and resilience. The large, impermeable area of sidewalk and street surface area and associated storm drainage system (drainage) do not allow water to permeate the soil, increasing drought effects.

Trees vary in their ability to adapt and become resilient in the face of extreme environmental conditions. A broader range of appropriate species can help provide a broader resilience to pest and disease, and extreme climatic events. Diversity in species selection can increase tree population resistance and minimize reliance on dominant species planting.

Oxygen Production

New Haven trees contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis.

The overall top producer of oxygen, according to the i-Tree Analysis, is pin oak (*Quercus palustris)* at a count of 338 trees at 13.71 tons. The next highest producer of oxygen is

American sycamore (*Platanus occidentalis*) (London planetree) at 6.3 tons with a count of 152 trees.

Canopy and Air Pollution

Tree canopy is the tree's components such as leaves, branches, and stems that cover the ground beneath the tree.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed by New Haven inventoried trees according to the New Haven i-Tree Analysis is 568.2 pounds per year with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser-count pollutants. (i-Tree Analysis, New Haven, 2020).

New Haven Tree Valuation

New Haven city trees' valuation total for the inventoried tree population is $4,629,744.69. The figure was calculated from a total of 1,300 trees inventoried. (See Tree Inventory Valuation Calculation, Appendix 1).

RECOMMENDATIONS

The tree population provides numerous economic and environmental benefits to the community. Larger trees produce considerably more aesthetic and environmental benefits than younger trees and should be maintained at a higher level of care, which ultimately reduces maintenance costs while improving safety and aesthetics. Regular maintenance such as cyclical pruning, monitoring, pest and disease management, inspections, and planting can identify current deficiencies and will improve future urban canopy conditions.

Trees with the highest risk should receive priority attention. Trees recommended for removal often pose the greatest risk, especially larger dead trees in higher pedestrian or vehicular traffic areas. Proactive cyclical pruning can also identify individual tree limbs that pose a risk.

Tree Inspections

As noted, tree inspections provide the information to monitor and manage a tree population. The following tree inspection recommendations are presented to enhance the university's overall vegetation management program.

Inspection Cycle. The consultants recommend a five-year cyclic inspection interval. This is a common inspection interval for a proactive urban forestry program in the United States.

Inspection Type. The standard inspection should be the equivalent of an ISA Level 1–Limited Visual Inspection.

Inspection Methodology. Each Level 1 inspection should include an assessment of the trunk, scaffold branches, and crown

Inspection Scheduling. The optimum time for the inspection cycle to take place is during the summer when the trees have leaves and are fully leafed out. The optimum scheduling would have the trees that are scheduled for pruning during the forthcoming winter season be the trees scheduled for inspection during the prior summer. This would allow trees noted for removal to be mitigated before the pruning cycle begins.

Monitor Trees. Several hundred trees have been identified as requiring monitoring. These trees require annual inspection except as noted in the narrative in the next section. The "Monitor" trees had one or more issues associated with the tree. These could include large stature, high-target area, and/or a structural issue. At the time of the initial inventory assessment, the need for removal was not observed. Future, short-term removals may predominantly come from these trees.

Campus-Specific Considerations. The recommendations noted above should be applied university-wide across all five campuses. Each individual campus, however, has nuances to its specific landscapes that warrant details specific to the campus.

Central North Campus – Central North Campus has the largest number and variety of trees. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice. Two considerations specific to the Central North Campus could affect the recommended inspection cycle.

- Number of Monitor Trees
- Several locations within Central North Campus have several significantly sized trees abutting areas of elevated use

Central South Campus – Central South Campus has the highest density of structures adjacent to mature trees. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice. One consideration specific to South Campus could affect the recommended inspection cycle.

- Old Campus – the historical Old Campus is strongly associated with the identity of Yale. It is the location for many university events tied to the current university community and alumnus. Considering this high visibility and use, maintaining the annual inspection of the Old Campus trees is valid.

Yale School of Medicine Campus – Yale School of Medicine Campus is a relatively new campus and except for those in Amistad Park, the trees are relatively young. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice.

West Campus – Like Yale School of Medicine Campus, West Campus is relatively new, with young trees dominating. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice

- Woodland Site – The largest wooded tract of land at the university is found at West Campus. Because of this woodland size, the trees were not individually tagged and inventoried. An annual limited visual inspection along the trail and perimeter is recommended.

Athletics Campus –There are two considerations specific to the Athletics Campus that affect the recommended inspection cycle. Most of these trees require crown cleaning and heightened care because of the high ecosystem quality of the trees. As such, they should be included in the earliest inspection cycle if an inspection cycle is invoked.

- Wooded Area Northwest of Yale Bowl
- Wooded Area Around Connecticut Tennis Center

Environmental

Resilience

A resilient landscape is achieved through modifying best managed practices based on current research. Updating and sharing proven methods with other stakeholders is an ongoing process.

- Implement and track plant ratio minimums
- Use annual cyclic planting minimums to maintain future canopy cover.
- Use recommended replacement planting for trees lost to damage, construction, or pests.
- Planting pits for trees should be larger and with ideal planting media like "Cornell Mix."
- Implement Integrated Pest Management (IPM) program either in house or by contract, with the goal of reducing pesticide use.
- Encourage and support design programs that integrate bio-swale and stormwater capture on campus and adjacent city properties.

- Encourage repurposing of wood products as the potential for lasting awareness and appreciation of campus trees such as current Yale Bowls project (yalebowls.com).
- Highlight environmental and economic benefits of individual trees by informational posting at tree.

Air Quality

Four main ways that urban trees affect air quality are (Nowak 1995):

- Temperature reduction and other microclimate effects
- Air pollutant removal
- Volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC-emitting species, leads to reduced ozone concentrations in cities (Nowak 2000). Local urban management decisions also can help improve air quality.

Stormwater Retention

Existing trees can be enabled to capture stormwater runoff with mulched beds and beneficial grading. Mulch captures and slows water down, allowing it to percolate into most of the root system just beneath the surface (two to three feet). This capture removes water that otherwise would prone to eroding valuable topsoil.

- Species that are better at Rain Garden areas can utilize trees that favor moist conditions to acquire and hold runoff without an issue.
- Existing areas and future construction sites could install stormwater capture areas.
- Sustainability goals can also be met through stormwater retention projects.

Carbon Sequestration and Storage

The larger the tree, the greater the amount of carbon sequestered. The large trees can be invasive, native, or desirable but still have positive storage results

When considering carbon sequestration and storage, the campus should acknowledge the significant red oak carbon benefits, though there is a need to increase its diversity with the tree population and consider planting larger quantities of smaller-sized trees in variety and increase diversity in larger tree species.

Comprehensive Pruning

Comprehensive pruning refers to trees under a cyclic pruning cycle or any tree that may require corrective pruning due to storm, disease, or insect damage.

Yale University will derive the following benefits from maintaining the cyclic maintenance program.

- Simply by pruning dead wood, the condition ratings will be upgraded for many of the university trees.
- Reactive requests and storm damage will be reduced.

- Cyclic maintenance guarantees that every tree on the university grounds will be regularly inspected by staff and/or contractors.
- The university can demonstrate that it is exhibiting "reasonable care" in maintaining its urban forest. The notion of "reasonable care" is the strongest defense Yale has in litigation due to a tree or tree part failure.

All pruning activity should follow the American National Standard for Pruning (ANSI A300)—specifically for crown cleaning and raising. These pruning operations are best performed during winter months.

Pruning, Cabling, and Removals

Table 13 below shows the count of recommended maintenance action by campus. Of all actions, the identified 158 tree removals should be considered first for action.

The pruning action count is for totals by campus. These are considered part of the recommended pruning cycle and should ideally be considered first over other trees during operational planning.

Tree counts for cabling maintenance or installation are also identified in the table below. Often, they can be combined with scheduled cyclic pruning operations leading to increased efficiency.

Table 7 - Recommended Maintenance Actions				
Action	Yale University		City of New Haven	
	Number	Percent	Number	Percent
Cable	12	0.2%	0	0.0%
Grind Stump	37	0.5%	18	1.3%
Prune: Crown Clean	920	14.3%	329	23.2%
Prune: Clearance	25	0.4%	6	0.4%
Prune: Reduction	58	0.9%	8	0.6%
Prune Structural	6	0.1%	1	0.0%
Remove	158	2.4%	54	4.0%

Table 7 Maintenance Action by Campus

Stump grinding may or may not be a priority to be completed after tree removal based on site use, accessibility, and aesthetics and should be evaluated on a case by case basis as determined by the YR.

Cabling

Cable inspections are noted on ArcGis records as "cable." These trees have cables installed or should have them installed. The cabling operations can often be combined with pruning operations. A minimum number of 12 trees was identified for cabling throughout the campus.

Estimated costs for cabling and pruning operations are in Tables 14 below. The crown cleaning can be incorporated into cyclic pruning operations with a priority for pruning of dead wood and broken or hanging branches in areas of higher traffic prioritized for work first.

Table 8 - Recommended Maintenance Actions by Campus					
Action	Athletics Campus	Central North	Central South	Medical	West
Cable	0	5	5	0	2
Grind Stump	8	12	6	4	7
Prune: Crown Clean	130	526	76	110	78
Prune: Clearance	0	13	6	0	6
Prune: Reduction	2	45	4	5	2
Prune: Structural	1	4	1	0	0
Remove	43	74	15	18	8

Table 8 Recommended Action by Campus

Removals

It is not uncommon after a system-level tree inventory to have the number of removals range from 1.3 to 2 percent of the population. The number of trees identified for removal on the Yale campuses is just above this norm (158). Removals should be prioritized and budgeted separately from cyclic pruning operations. It is recommended that trees that are dead or in extremely poor condition all be removed no later than the first two years of notification.

Table 15 provides a comparison to initial costs of removals and pruning to the campus values. Central South has a relative lower figure of costs to value most likely because of a higher past degree of care, while West has a relatively newer campus planting and smaller trees overall. Yale School of Medicine Campus has higher initial pruning care needs as evident by 14.3 percent of total value.

Table 9 – Estimated Removal Cost by Campus						
Diameter Class and cost per tree	Athletics Campus	Central North	Central South	Medical	West	Total
1 - 6"	Yale Staff	Yale Staff	Yale Staff	Yale Staff	Yale Staff	Yale Staff
7 – 12" $850	$8,500	$23,800	$3,400	$5,950	$1,700	$43,350
13 - 18" $1500	$19,500	$16,500	$4,500	$6,000	$4,500	$51,000
19 – 24" $2000	$14,000	$28,000	$6,000	0	$2,000	$50,000
25 - 30" $2500	$20,000	$7500	$7,500	0	0	$35,000
31 - 36" $3500	$3500	$10,500	0	0	0	$14,000
37 – 42" $5000	$5,000	0	$5,000	0	0	$10,000
43" + $1500	$30,000	$30,000	0	0	0	$60,000
Total	$100,500	$116,300	$26,400	$11,950	$8,200	$263,350

Table 9 Estimated Removal Costs by Campus

Table 10 - Removal and Pruning Costs as a Percent of Campus Tree Value						
Removal/Prune Values	Athletics Campus	Central North	Central South	Medical	West	Total
Valuation	$3,944,193	$ 12,842,549	$3,398,650	$872,561	$2,047,522	$23,105,475
Remove/Prune Costs	$216,150	$709,625	$114,720	$129,050	$36,670	$1,206,215
Percentage of Value	5.4%	5.5%	3.4%	14.7%	1.8%	5.2%

Table 10 Removal and Pruning Costs as a Percent of Value

Plantings

To guarantee the long-term health and perpetuation of the urban forest, a good program must continue to plant trees on regular basis. An important element of a planting program is species diversification. The emerald ash borer is an example of how disaster can destroy poorly diversified urban forests.

The following guidelines provide direction for developing a diverse, healthy, low-maintenance, and aesthetically improved urban forest:

- Long-term (i.e., 20-year) population targets for high-quality species should hover around 5 percent of the current tree population.
- The urban forest like Yale often has a need for numerous smaller trees that take up less space than larger ideal trees like the white oak. The trees occupy less space and contribute less overall to tree value and benefit given their considerably smaller canopy. Planting quantities can be adjusted on a case by case basis though an established minimum tree fund is always recommended.
-

Table 11 – Annual Planting Count by Campus			
Campus	**Quantity**	**2" – 2.5" cal. Tree Budget**	**Specimen 4" – 5" cal. Tree Budget**
Central North Campus	125	43,750	137,500
Central South Campus	41	14,350	45,100
Medical Campus	22	7,700	24,200
West Campus	32	11,200	35,200
Athletics Camus	30	10,500	33,000
Total	250	$87,500	$275,000

Table 11 New Planting Quantities by Campus

After a certain age, all trees decline and require greater maintenance. When large numbers of trees are planted within a short time, they become expensive and difficult to manage all at once. Multiple-aged stands are more desirable because they will disperse maintenance costs.

Slower-growing, longer-living trees minimize maintenance costs. Planting trees that live three times as long means spending approximately one third as much in removal costs over the same number of years. In general, the same slower-growing trees are higher quality and demand less pruning over their lifetime.

Yale University would benefit from a balanced list of non-natives as well as native planting options. Recommended planting suggestions vary from source to source and depend on existing population diversity, present pest problems, and degree of varying climatic conditions. The consultants recommended a broader range of species for increased biodiversity as identified by University of Massachusetts in their 2019 publication, *Planting for Resilience: Selecting Urban Trees in Massachusetts,* by Ashley M. McElhinney and Richard Harper.

Regular, annually scheduled tree plantings with target goals will assist in maintaining healthy canopy conditions for the future. Unforeseen events like storms, pathogens, and insect infestations can devastate an existing urban forest. A broad, diverse, and healthy planting will offer some insurance against such events. There is often flexibility in size of trees at time of planting, giving some leeway on budgetary options. First-year care is critical and should provide and maintain watering options such as Gator bags with regular fillings. A target number for new annual campus-wide plantings would be 250.

INTRODUCTION

Yale's Tree-Related History

Yale University has unique and varied campus communities enriched with forested areas and a lush urban canopy that are intertwined with the cities of New Haven, West Haven, and Orange, Connecticut. Yale's oldest municipal relationship has been with the city of New Haven, dating from 1716, according to Judith Schiff, chief archivist of Yale University Manuscripts and Archives, when residents were able to welcome the college after winning a competitive bid, having offered more money and land than other towns. A more current (2007) large-scale Yale University acquisition was a large, contiguous suburban tract of approximately 136 acres (out of a total 565 current campus acres) complete with buildings, and an open managed landscape bisected by a forested segment from the Bayer Corporation, that warranted its own designation: West Campus.

Figure 4 New Haven Green, looking south on College Street

Yale campus is separated from the historical New Haven Green by College Street. A nine-square design layout with the open green centrally placed was submitted to the city in 1641. Whoever made the plan is unknown, surveyor John Brockett is often credited with its layout—possibly the first in the country (Sheridan, 2019). Elm trees were first planted as early as 1686 on the New Haven Green, having been given as gifts to Reverend James Pierpont of Center Church by parishioners.

Yale graduate, politician, attorney, and New Haven resident James Hillhouse (1754-1832) performed tree planting of mostly elms throughout the city, contributing to its nickname of "The Elm City." In fact, New Haven is credited with implementing the first public tree-planting program in America because of Hillhouse's efforts. Hillhouse Avenue is named after the visionary. Today the avenue is flanked by numerous Yale administration-related buildings, from Admissions to the President's House. Once lined with stately American elms that later succumbed to Dutch elm disease, Hillhouse Avenue now boasts large, stately pin oaks.

Creating the Tree Management Plan

Yale University contracted with Treefoil LLC in September 2019 to complete a tree inventory for a major portion of the campus tree population. In addition to the inventory, the consultants also created a comprehensive tree management plan.

Trefoil LLC staff involved with the project include Bradley Painter, principal, Connecticut licensed arborist (S-6397), International Society of Arboriculture certified arborist (6931-A) and ISA Tree Risk Assessment Qualified, and American Society of Consulting Arborist registered consulting arborist (RCA), # 634; Isabelle Zaffetti, Connecticut licensed arborist # S-6691; and Georgia Hann, arborist technician; in collaboration with Mark Duntemann, senior consultant, International Society of Arboriculture Board Certified Master Arborist and Tree Risk Assessment Instructor, and American Society of Consulting Arborists registered consulting arborist (RCA), # 656.

The Yale Office of Facilities team included Dev Hawley, Director, University Planning and Facilities Operations; Kristina Chmelar, Major Projects Planner; and Michael West, Manager of Planning and Standards. An accompanying ArcGIS tree map was developed by Michael Slattery, Web Developer for the School of Forestry and Environmental Sciences and liaison with Urban Resources Initiative (URI) for coordination with previous inventory efforts.

Yale area supervisor representatives from the Office of Facilities Landscape, Grounds, and Maintenance—Walter Debboli, James Reid, Joseph Signore, Paul Catalano, and Edward Mockus—provided insight and support for their campus areas.

The Yale University tree management team requested quantification of the campus and adjacent City of New Haven tree population. The team sought to have an individual tree tag number, location, size, condition, and species recorded on an entirely new ArcGIS digital tree map platform. Priority trees with distinct qualities such as noteworthy, specimen, cultural significance, donated tree, milestone, and rare taxonomy were recorded after input from a variety of staff, and with special attention to import this relevant tree history from URI's inventory. A field (IPM Level 1) is also dedicated to identifying 138 trees under a current integrated pest management (IPM) program and a separate designation (IPM Level 2) for 39 trees that should be under an IPM program in the future and IPM Level III for 282 trees that are dedication, memorial, milestone, specimen or have rare taxonomy. All IPM level trees are noted for additional care and/or recognition over the remaining campus trees. Actual tree counts will be updated to the ArcGis platform when trees are added or removed.

The current tree inventory now integrates with numerous university functions such as project planning, utility locations, and maintenance operations while supporting tree management operations such as pruning cycles, inspections, treatments, and budget establishment. The future tree inventory can be updated as required for individual tree status, such as “planted” and “removed” trees, or to identify, locate, and quantify species that are susceptible to new pests or pathogens.

The Yale team established city tree and university criteria as well as campus area designations and the sequence for data collection. Yale University’s campus is divided into six similar yet distinct areas: a central campus, which is broken into two parcels: **Central North** and **Central South**, **Yale School of Medicine**, **West**, **Athletics,** and the **City of New Haven** area (street trees bordering Yale properties).

Yale Campus and New Haven city trees were to be tagged, assessed, and separately cataloged and inventoried on all campus areas. Portions of campus areas also were identified as having managed, woodland, forested areas, and construction zones.

Figure 5 Yale Campus Locations and Borders

Managed areas are defined as university campus areas that are maintained with planting beds, open lawn area, meadow plantings with mowing maintenance, parking lots and sidewalk areas.

For the purposes of this analysis, woodland areas within Yale properties are sites of intense activity, due to their frequent use by university staff, faculty, students, and visitors, as well as their proximity to managed areas such as roads and sidewalks.

Forested areas within Yale University are larger (over 1.3 acres) and have less frequency of use. These areas were inventoried using a basic forest survey with plot sampling (see forested areas). All trees over 8-inch caliper within plots were manually inventoried.

Figure 6 Forested Area

Unique data collection criteria were developed for managed, woodland, and forested designations. Construction zones were not inventoried during the initial phase, for safety reasons. These construction zones will be inventoried following project completion.

The Treefoil consultants referenced numerous sources for information: Connecticut Agricultural Extension Service, Dirr's *Manual of Woody Plants*, International Society of Arboriculture (ISA) publications, Tree Risk Assessment Qualification manual by ISA, University of Connecticut Plant Database and i-Tree Analysis for Yale, New Haven, and the campuses. The consultants also drew on their experience to interpret any subjective data collection pertaining to interpreting tree architecture, health, conditions, and future prognosis.

METHODOLOGY

The consultants separated the inventory into three distinct phases: pre-inventory, inventory phase of managed areas (data collection), and development of the tree management plan.

Pre-Inventory Phase

The purpose of the pre-inventory phase was to:

- Review and finalize the data to be collected and the valid responses to each field.
- Finalize the data structure for the ArcGIS-compatible deliverables.
- Identify project liaisons from all involved parties and establish a protocol for communications for, among other things, project updates, notification of high and extreme risk trees, and additional data requests.
- Schedule the retrieval of pertinent data on past tree-related events.
- Discuss tree identification tag considerations.

Inventory Phase

Data collection occurred in all university campus areas (Central North, Central South, Yale School of Medicine, West Campus and Athletics) starting in Central North Campus in October 2019 and completing in Athletics in March 2020. The inventory team consisted of Bradley Painter of Treefoil LLC and subconsultant Mark Duntemann of Duntemann Urban Forestry LLC, joined by Treefoil LLC arborist technicians Isabelle Zaffetti and Georgia Hann for tagging responsibilities. All trees with trunks four inches and greater in diameter within managed areas were tagged, assessed, and digitally mapped; some smaller trees in newly landscaped areas were also tagged, assessed, and inventoried.

Development of the Tree Management Plan

This tree management plan and associated recommendations were developed after a review of each campus GIS tree inventory data results. It provides specific recommendations for arborist contract management and anticipated budgeting purposes for facilities planning, maintenance, inspections, resilience, and planting based on tree location, size, species, condition, and priority level. The ArcGis platform can be manually updated to include future removals, maintenance actions, plantings, and more.

Data Collection

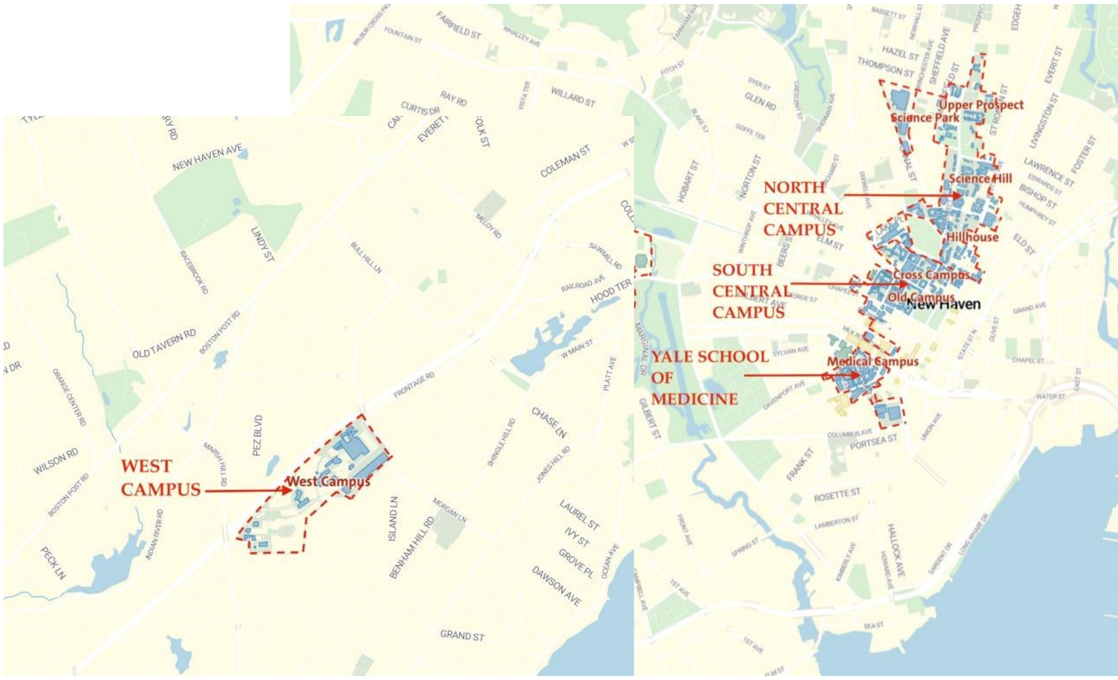

Table 12 Yale Campus Locations and Borders

Bradley Painter from Treefoil LLC and subconsultant, Mark Duntemann were the primary collectors of data, using handheld Trimble GeoExplorer 6000Series GeoXT satellite receivers.

Inventory collection began in late October on Central North
Campus, proceeding to Central South Campus, then Yale School of Medicine Campus, ending with Athletics and West campuses by January 2020. Updates and data refinements continued into March 2020.

The data were downloaded, post-processed, edited, and then provided to Yale University to test data integrity and system compatibility on Yale's existing ArcGis platform. The locations were recorded for data post-processing activities and made available to the Yale tree management team for upload onto the existing Yale ArcGIS map platform where the tree locations and collected information are plotted and reviewed.

Data Collection Fields

The following data fields are the final list of data the project team agreed to have collected during the initial design phase. The following narrative describes the data field and the parameters used within each field. In some instances, additional comments are provided to present discussions on relevance and ramifications of the data collected, which should serve as guidance documentation for staff and contractors.

1. Inventory Date. Date tree was inventoried. Trimble automatically fills the field.

2. Assessor Name. Name of person collecting data. (Drop Down List) Autofill

3. Tag Number. Number on tag attached to tree. Manually entered. Old tag numbers were manually entered. Separate staff tagged most of the trees in advance of the assessors. In most cases, the tags were placed at a height of seven feet on the south side of the tree. Street trees were tagged on the street side. Stumps that were encountered were given the number "1" and not actually tagged. Trees that had no discernable tags when assessed were also assigned a "1" to allow easy filtering in the ArcGIS to allow subsequent tagging.

4. Organization. Identifies the owner of the subject tree. This consisted of either Yale University or the City of New Haven. This distinction will allow Yale staff to filter exclusively for trees owned, managed, and maintained by the university.

5. Campus. Name of the campus in which the subject tree resides. The choices were either Central North, Central South, School of Medicine, Athletics, or West. This field will allow Yale staff to filter data to the campus level to facilitate arboricultural operations for area supervisors.

6. Event 1. Assigned the event type of "Inventory" to the record. The date would identify when the record for the subject tree was created and create the opening register of an ongoing maintenance history.

7. Item Type. Identifies the item as a **T**ree, **P**lanting (identified planting site) or **R**emoved Tree (a previously inventoried tree that is now gone.) As the inventory is used, trees that are removed are changed from a T to an R. All the data associated with the removed tree would remain, but be filtered from view, unless required.
8. Common Name. The common name assigned to the inventoried tree. List was based on the species list provided by Yale. "Unknown" was assigned if the species was not discernable or the species did not exist in the picklist. In this case, the species was noted in the comments and updated to the current species list.

9. Diameter. The diameter was measured to the nearest inch. Trees four inches or greater were measured at diameter breast height (DBH), four and a half feet above ground. Trees less than four inches were measured at six inches above the ground.

10. Condition. The condition of the subject tree was assigned based on the 10th edition of the ISA's plant appraisal guide, which is a composite rating (Excellent, Good, Fair, Poor, Very Poor, and Dead) informed by the tree's health, structure, and form. (See Appendix 1).

Note: The condition rating does imply or assign a maintenance action or risk to the subject tree. In most cases, however, trees noted as “Very Poor” or “Dead” were marked for removal. Exceptions would include trees that were in the interior of a woodland with no discernable frequent target. A tree in Poor condition does not imply a hazard exists. The recommended actions reflect what the assessor felt was required of the tree, given the specific contexts observed.

11. Defects. A defect is a visible flaw or an aberration that causes an item to be less than perfect. In regard to trees, any singularly observed defect can range from benign to severe. Noting a defect, therefore, does not necessarily or automatically constitute a hazardous situation. The severity of the issue observed by the assessor informs, along with other details on the recommended mitigation action. Seven defects were identified during the design phase of the project on which the assessors focused.

12. Cavity/Decay. Cavity/decay is the deterioration of wood by a decay fungi. It is a natural process in mature trees and occurs at every form of wounding, including pruning cuts. Depending on the tree and fungi species, the ability of the tree to compartmentalize decay can be very localized or extensive. The presence of decay fungi conk (fruiting body) is a positive indicator of decay. When a conk was observed, the name of the decay fungi, if known, was noted in comments.

    As with any defect, the presence of a conk does not necessarily identify a high-risk issue. Decay fungi vary in their ability to deteriorate xylem, as detailed below.

Polyporous squamosus *(Figure 7)* is a white rot. While often a large conk, it is relatively benign and often found on old pruning wounds.

Figure 7 Polyporous squamosus

Figure 8 Ganoderma lucidum

Ganoderma lucidum *(Figure 8)* is a white rot typically found at the base of a tree. Its presence can be an indicator of extensive basal or root decay. Further investigation is typically warranted.

Ganoderma applanatum *(Figure 9)* is a white rot typically found along a trunk stem. Its presence can be an indicator of extensive trunk decay. Further investigation is typically warranted.

Figure 9 Ganoderma applanatum

Figure 10 Cerrena unicolor

Cerrena unicolor *(Figure 10)* is a white rot that decays the outer shell of a tree stem. The fungi grow on dead cambium. The significance of observing this decay fungi is that the outer rings of the tree experience the highest stresses when the stem bends to dynamic loading. With a compromised shell, an increased chance of the stem fracturing in cross-section increases.

Laetiporous sulfereus (*Figure 11)* is white rot that is typically found along a trunk stem. Its presence can be an indicator of extensive basal or root trunk decay. Further investigation is typically warranted.

Figure 11 Laetiporous sulfereus

Crack (*Figure 12*) is a separation of wood. A crack can range from benign, such as a rib crack that is sealing over to a shear crack in which separation has occurred across the neutral plane separating the tree part into two distinct and independently moving parts. Cracks that are associated with codominant stems can be of concern if it appears that the crack has recent movement along the vertical plane of the tree part.

Figure 12 Crack

Canker (*Figure 13)* is an area of dead cambium typically caused by a bacteria. It typically does not seal over and expands with each new annual ring. Decay from canker can extend into the interior of the trees. Trees with canker that exceeds 30 percent of the circumference of the infected part have an elevated risk of failure. However, context specific to the subject tree should be considered—for instance, loading above the issue and compounding factors. Canker that

Figure 13 Canker

appears at branch attachments is typically more problematic than stem canker, as the attachment is a location for enhanced load stress.

Decline occurs when the tree exhibits visually obvious signs of vigor and health decline. Trees noted as decline often are identified as in fair or poor condition. Unabated, a tree in decline is more than likely a removal in the not-so-distant future.

Poor Attachment occurs when the tree has one or more codominant stems. This issue can include bark inclusions and recent cracks which would potentially heighten the likelihood of failure.

13. Event 2. Recommended maintenance actions, other than "Inventory". The selections included: Prune, Removal, Cable, and Grind Stump. If more than one maintenance action was assigned, they were noted in the comments field.

14. Prune. If Prune was selected in Event 2, a specific type of pruning was noted in this field. This list consisted of all A300 recommended pruning:

- ***Cleaning***–Removal of all dead, crossing, and diseased branches in the trees. Crown cleaning is the industry standard for conducting a comprehensive arboricultural maintenance action on a tree.

- ***Clearance***–Pruning to reduce a range of obstructions. These included street, sidewalk, and line-of-sight clearances.

- ***Reduction***–An arboricultural practice that serves to meet a range of goals. These include reducing weight on a high-stress point or reducing building obstructions.

- ***Structural*–**An arboricultural practice typically assigned to younger trees. The primary purpose of structural pruning is to prepare the form of the tree for its mature phase and to reduce future risk issues.

15. Monitor. Tree had some structural aberration that requires a shorter inspection interval.

16. Priority. A picklist provided by the university that identifies trees of exceptional value or local importance. Choices included: Memorial, Milestone, Donated, and Specimen. When possible, the name of the individual a tree memorializes was listed in comments.

17. Utility. Recorded presence of overhead utility lines (transmission, distribution, or service). Yes/No response. No is default.

18. Latitude. 1984 State Plane Coordinates—Connecticut

19. Longitude. 1984 State Plane Coordinates—Connecticut

20. Comments. Field for additional details to be recorded. When conks were encountered, if discernable, the type of conk was entered here. Several defects not included in the original list were also noted here, such as lean.
21. Value. A calculated value for each tree based on the diameter, condition, functional depreciation, and external depreciation of each tree. Dollar value will be based on the average wholesale purchase price and size of trees the university plants. An average installation cost is also required. Rough formula: ((Cross sectional area of subject tree x unit cost) x (depreciation factors (condition, functional and external))) + installation cost.

METHODOLOGY SOIL SAMPLING

Managed Area Soil Sampling

Soil samples were taken from sample plots in managed areas only. The plots were selected as representative of the general physical conditions: planting beds and turf area. The samples were collected from the upper 8-inch soil A horizon (2015, Penn State) using a 24-inch ADS soil core sampler and tested using a standard nutrient analysis (Morgan Method performed by Connecticut Agricultural Experiment Station). The results are varied, most likely due to construction activities, previous lawn treatments, or heavily irrigated sectors (see Appendix 3).

The consultants recommend establishing a general baseline reference, as opposed to using the results for establishing fertilization (or other) treatment rates (see Soil Test Results, Appendix 3A) for adjacent trees. Any future specific tree needs should be tested independently from the current results.

Forested Area Soil Sampling

Forested areas were determined by Yale University Owner's Representatives. The forested areas were in West Campus and Athletics Campus. The consultants collected soil samples from the 8-inch (A-horizon) depth using a 21-inch AMS soil borer. The areas were selected after initial onsite review and selection as determined by the character of the plot (grade, water course, existing vegetation) while recognizing relative consistent spacing between collection points. The plot points were representative of the overall character of the sample region.

Three evenly spaced (12.4 feet) samples were taken from a south to northern (magnetic) line within a 37.24-foot radius and combined for one soil sample. The samples were delivered to the UConn Soil Nutrient Analysis Laboratory for analysis.

The consultants chose the University of Connecticut Soil Testing Laboratory primarily for its ability to test for percent soil organic material (SOM) using the carbon loss on ignition test in addition to a basic nutrient analysis. New England soils are usually in the 2 to 4 percent range and generally no higher than 8 (UMASS rev. 2013). Higher soil organic matter is an indicator of the ability for the soil to hold large amounts of water or that a higher water table is present. Soils with higher levels of organic content are also able to store more nutrients, are less likely to erode and minimize the likelihood of compaction. Most of the soil samples indicated high levels of soil organic matter (see Soil Test Results, Appendix 3B). The soil test results are recommended as a baseline reference.

FORESTRY AREA SURVEY

Based on a site review of the forest area assigned to the project, the consultants inventoried all trees with trunks eight inches or greater in parcels that are 1.2 acres or less in size. The reasoning for this is that in most cases, the number of trees in these parcels are manageable from an inventory perspective. Additionally, the narrow width of these parcels means that, in most cases, the trees have a potential impact on targets outside the forest perimeter. These adjacent areas include campus sites and non-campus sites.

There are two areas containing forestry areas: Athletics Campus (8.4 acres) and West Campus (35 acres). Plot areas were assigned to Athletics as A and D. West Campus areas of forestry were also assigned as A and D. Plots were surveyed and soil samples collected. Woodland areas are considered an extension of managed areas and were treated differently, with all trees over 8-inch DBH inventoried. Soil samples were not collected from woodland areas (See Yale Campus Woodland Area, Appendix 3)

Three assessment approaches were used on each of the larger (1.3-plus acres) parcels: plot sampling, a walk-through survey, and a level 1 visual inspection for areas of public use.

Plot Sampling—10 percent of each parcel was sampled using 1/10-acre sample plots. The sample plots were a circle with a radius of 37.24 feet. The number of plots were ultimately determined by the woodland homogeneity of the parcel.

The sample plot locations were geocoded, and a temporary pin was placed at each the center point of each plot. Within each plot, all trees with a diameter of eight inches or greater were individually inventoried. The data fields included species, diameter, condition, and attributes that are unique to the tree. An observational narrative was also made for vegetation under four inches. This narrative included observations on seedling and sapling presence, invasive plants and any unique forbs encountered.

Walk-Through Survey—The walk-through survey is a thorough traverse of the entire parcel. The purpose of the walk-through survey is to identify unique, significant trees that the sample survey may miss. The project team conferred with Yale staff during the pre-inventory meeting to confirm the parameters for identifying a tree as "significant." Examples include wildlife habitat, unique species, culturally significant, etc. The trees, when encountered, were GPS-mapped for inclusion in the ArcGIS mapping. Data collected included species, diameter, condition, and observations about the quality of the tree and recommended care.

Level 1 Visual Assessment—An ISA Level One Visual Assessment was carried out for areas of the forested parcels that have elevated public use. These include any trails, perimeters, or sites within the parcels where the public may congregate. The purpose of the assessment to identify any risk issues of imminent concern for campus management. All project staff were ISA Tree-Risk Assessment Qualified.

INVENTORY AREA DESIGNATIONS

YALE UNIVERSITY CAMPUS

The Yale University campus refers to the entire Yale campus. The campus is then broken out into five campus inventory area designations: Central North Campus, Central South Campus, Yale School of Medicine, West Campus, and Athletics Campus, totaling approximately 462 out of a total of 565 acres. Construction areas at the time of the inventory were not included in the inventory acreage though it is anticipated they will be done at a future date. City of New Haven trees that border university property were also inventoried but are considered a separate designation.

The Yale Golf Course, preserve, and parcels noncontiguous to the above locations were not part of the inventory. West Campus is located on a separate parcel located approximately seven miles to the west from the main campus and is situated within the towns of Orange and West Haven. Athletics Campus is also located off the main campus about two miles to the west in New Haven.

The Central North, Central South, and Yale School of Medicine campuses are flanked by Highland Street on the northernmost border, Whitney Avenue and Church Street on the eastern border, Howard and Columbus Avenue on the southern border, and Mansfield Street, Lake Place, and Howe Street on the western border.

Figure 14 Yale Campus Locations and Borders

West Campus at 100 West Campus Drive in Orange, Connecticut, is bisected by two towns: Orange and West Haven. The campus is flanked by Interstate 95 on the northern border, Morgan Lane (West Haven) on the eastern border, Amtrak southbound on the southern border, and Marsh Hill Road (Orange) on the western border.

YALE UNIVERSITY CAMPUS MANAGED AREAS

Managed areas are defined as areas that are maintained with planting beds, open lawn area, meadow plantings with mowing maintenance, parking lots and sidewalk areas. Tagging of each inventoried tree within all campus managed areas occurred from early to late fall 2019 and inventorying took place from October 2019 through March 2020

City of New Haven trees were also tagged and separately inventoried when bordering university campus areas. City trees are most often usually the trees that are located within the planting strips between sidewalks and streets or park areas. the street trees located within 12 feet of the curb line.

A total of 7,804 trees were inventoried between all Yale campus designations and the City of New Haven. 6,413 trees were inventoried on Yale property, and an additional 1,391 were City of New Haven trees (see Table 13).

Table 13 – Inventory Distribution by Campus			
Campus	**Yale University**	**City of New Haven**	**Total**
Central North Campus	3,154	597	3,751
Central South Campus	1,086	486	1,572
Medical Campus	422	217	639
West Campus	966		966
Athletic Camus	785	91	876
Total	6,413	1,391	7,804

Table 13 Inventory Distribution by Campus

Species Distribution

The Yale Campus's top three species distribution shows 390 white pine (*Pinus strobus*), 364 Norway maple (*Acer platanoides*), and 354 red oak (*Quercus rubra*) (see Table 14). The white pine population represents approximately 6.1 percent of the tree population; Norway maple, 5.7 percent; and red oak, 5.5 percent.

Table 14 - Species Distribution Yale University	
Species	**Number**
Pine, Eastern White	390
Maple, Norway	364
Oak, Red	354
Oak, Pin	309
Maple, Red	308
Dogwood, Kousa	290
Crabapple	274
Maple, Sugar	271
Serviceberry	200
Dogwood, Flowering	173
Balance of Species	3,480
Total	6,413

Table 14 Yale Species Distribution

The City of New Haven area's top three species distribution shows 338 pin oak (*Quercus palustris*), 152 London planetree (*Platanus x acerifolia*), and 93 Norway maple (*Acer platanoides*). The pin oak population represents approximately 24.3 percent of the tree population; London planetrees, 10.9 percent; and Norway maples, 6.7 percent (Table 15).

Table 15 - Species Distribution City of New Haven	
Species	**Number**
Oak, Pin	338
London Planetree	152
Maple, Norway	93
Elm Species	78
Elm, Hybrid	72
Elm, Homestead	68
Maple, Red	67
Oak, Red	62
Zelkova, Japanese	52
Sweetgum	41
Balance of Species	368
Total	1,391

Table 15 Species Distribution City of New Haven

Trunk Diameter Distribution:

Diameter distribution offers tree data that are presented in terms of diameter size class. This detail is important for determining current management needs as well as anticipating how needs will change, given total numbers and aging of individual species. The size distribution within a tree population influences present and future costs as well as the flow of benefits. A staggered or unevenly aged population allows managers to allocate annual maintenance costs uniformly over many years and assure continuity in overall tree canopy coverage. Table 16 provides diameter class data for the trees assessed for Yale's trees as well as New Haven trees. Total diameter inches for each class are provided as it may inform on some potential maintenance costs derived by total class-size inches.

Table 16 - Diameter Distribution						
	Yale University		City of New Haven		Total	
Diameter Class	Quantity	Total Inches	Quantity	Total Inches	Quantity	Total Inches
1 - 6"	1,730	7,492	338	1,404	2.068	8,896
7 – 12"	2,112	19,774	404	3,873	2,516	23,647
13 - 18"	1,135	17,205	341	5,167	1,476	22,372
19 – 24"	643	13,744	157	3,337	800	17,081
25 - 30"	338	9,216	81	2,194	419	9,635
31 - 36"	196	6,481	35	1,163	231	6,712
37 – 42"	89	3,511	10	394	99	3,905
43" +	74	3,951	6	286	80	4,237
Other	96	0	19	0	115	0
Total	6,413	81,374	1,391	17,818	7,804	99,192

Table 16 Diameter Distribution Yale and New Haven

Table 17 - Diameter Distribution by Campus						
Diameter Class	Athletic Campus	Central North	Central South	Medical	West	Total
1 - 6"	56	823	410	136	305	1,730
7 – 12"	197	1,059	326	178	352	2,112
13 - 18"	216	546	139	57	177	1,135
19 – 24"	154	319	70	24	76	643
25 - 30"	79	180	43	8	28	338
31 - 36"	40	122	24	3	7	196
37 – 42"	17	51	17	2	2	89
43" +	12	46	12	2	2	74
Other	14	8	45	12	17	96
Total	785	3,154	1,086	422	966	6,413

Table 17 Diameter Distribution by Campus

YALE UNIVERSITY CAMPUS WOODLAND AREAS

Two wooded areas were considered as woodland zones. For the purposes of this analysis, **woodland areas** within Yale properties are considered to be sites of intense activity, due to their frequent use by university staff, faculty, students, and visitors, as well as their proximity to managed areas such as roads and sidewalks. All trees over an 8-inch caliper at DBH were inventoried and recorded.

The woodland areas, The Swale and Prospect Gardens, lie within Central North Campus. The woodlands are sometimes used for educational classes or research projects. The Swale has an informal trail with educational signage describing forest elements.

YALE UNIVERSITY CAMPUS FORESTED AREAS

The Yale management team agreed that any wooded area larger than 1.3 acres (except Central North Campus areas "The Swale" and "Prospect Gardens") on the designated campus areas would be treated as a "forested" area. West and Athletics campuses contain areas considered forest. West Campus has 35 acres and Athletics Campus has 8.4 acres designated as forested.

Forestry Plot Sampling

Approximately 10 percent of each parcel was sampled using 1/10-acre circular sample plots with a radius of 37.24 feet. The number of plots was ultimately determined by the woodland homogeneity of the parcel.

The sample plot center point locations were geocoded and associated with individual trees. A temporary pin was placed at each plot's center point. Within each plot, all trees with a diameter of eight inches or greater were individually recorded for species, diameter, condition, and attributes that are unique to the tree. An observational narrative was also made for vegetation under four inches. This narrative included observations on seedling and sapling presence, invasive plants and any unique forbs encountered.

Walk-Through Survey

The walk-through survey is a thorough traverse of the entire parcel. Its purpose is to identify unique, significant trees that the sample survey may miss. The project team conferred with Yale staff during the pre-inventory meeting to confirm the parameters for identifying a tree as "significant." Examples include wildlife habitat, unique species, culturally significant, etc. The trees, when encountered, were GPS-mapped and recorded on the Yale ArcGIS platform. Data collected included species, diameter, condition, and observations about the quality of the tree and recommended care.

Forestry Center Plot Points

Center plot points were geo-recorded as inventoried individual trees geo-identified as item "F" on the data collection for forested areas in West Campus and Athletics

Campus. The locations are recorded on the map as taken directly from the Yale ArcGis platform and are the locations of the center plot points.

YALE UNIVERSITY CAMPUS ECOSYSTEM

An ecosystem analysis was created for the overall Yale Campus, as well as each individual campus designation: Central North, Central South, Yale School of Medicine, West, and Athletics. The analysis was created using i-Tree, an open source service that quantifies ecological benefits of trees based on collected digital data fields. Since 2006, i-Tree has been a cooperative effort between the USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, and SUNY College of Environmental Science and Forestry. Interpretation of some data fields may vary from the consultants' data, resulting in slightly different tree quantities.

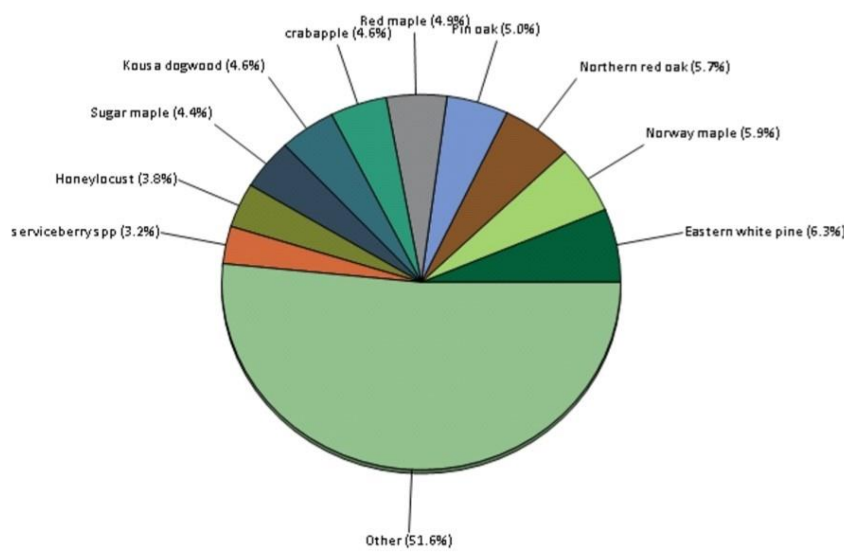

Figure 15 Species Percent Distribution

The three most common species are 390 white pine (*Pinus strobus*), 364 Norway maple (*Acer platanoides*), and 354 red oak (*Quercus rubra*). Despite there being 390 white pine (*Pinus strobus*), the annual totals of values and sequestered carbon are noticeably less than red oak (*Quercus rubra*), pin oak (*Quercus palustris*), and Norway maple (*Acer platanoides*). The leaf and overall branching area are considerably smaller on white pine, leading to less carbon sequestered (i-Tree Eco Analysis, Yale 2020). “Other” is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $9,390,000 for 6,159 trees with tree cover of 47.98 acres within 462 acres. The. The i-Tree formulae provides this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs.

University tree species of greatest structural value are red oak (*Quercus rubra*) followed by pin oak (*Quercus palustris*), with white pine (*Pinus strobus)* a close third. The i-Tree results of the values demonstrate that generally trees of greater size, quantity, and increased environmental value also increase structural and eco-value (i-Tree Eco Analysis, Analysis Yale 2020).

Urban trees in Yale University in 2020 have the following annual functional value totals:

- Carbon sequestration: $9,690
- Avoided runoff: $4,770
- Pollution removal: $27,600
- Carbon storage: $636,000 (i-Tree Eco Analysis, Analysis Yale 2020)

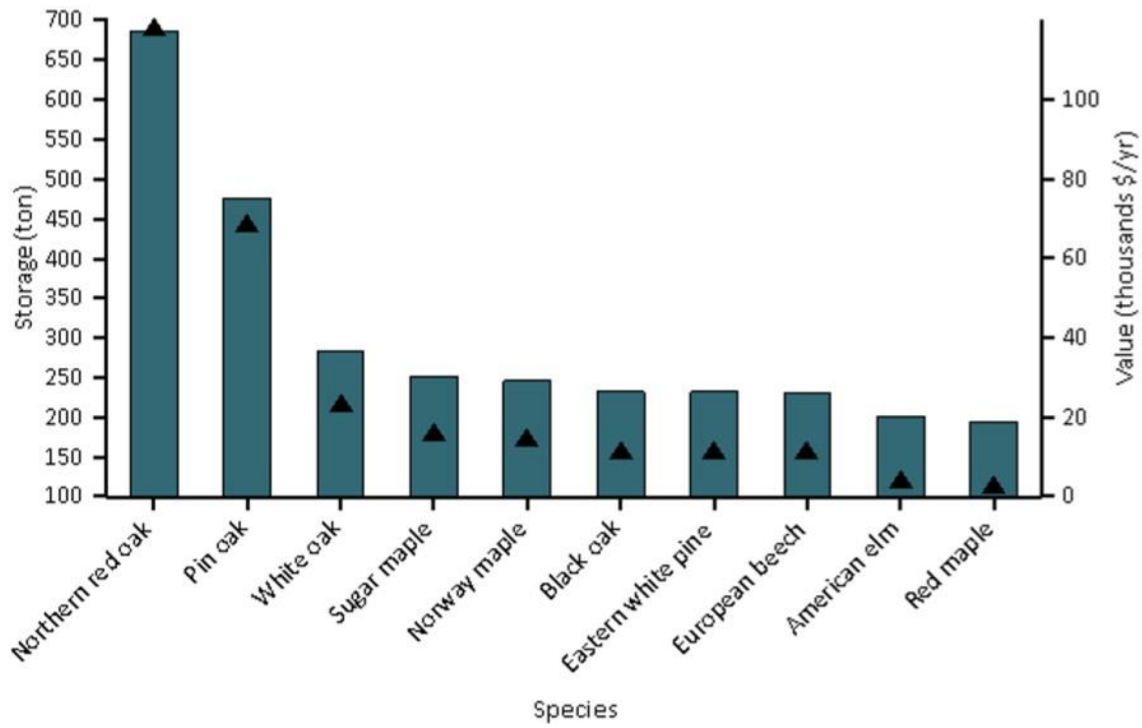

Figure 16 Yale Carbon Storage Quantities and Values (i-Tree, Yale, 2020)

Avoided Stormwater Runoff

Avoided storm water runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with Yale University trees such as red oak (*Quercus rubra*), pin oak (*Quercus palustris*), and Norway maple (*Acer platanoides*) able to capture the most cubic feet of avoided runoff. The avoided stormwater runoff also diminishes the extent of surface erosion and soil lost.

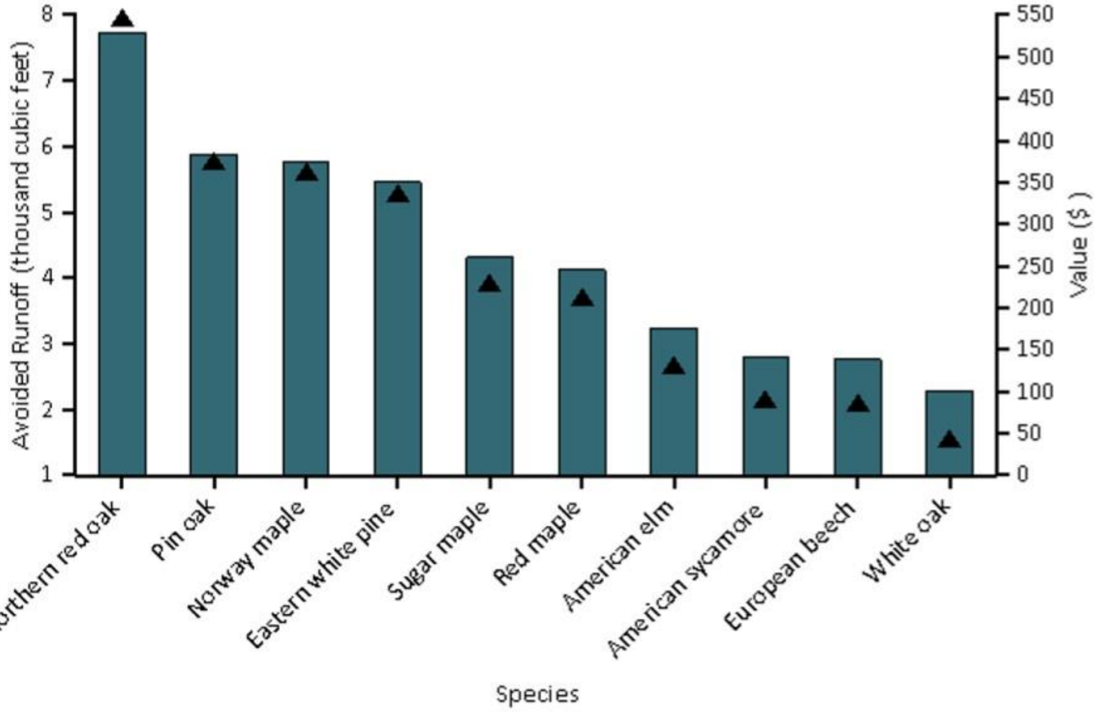

Figure 17 Yale Campus Avoided Runoff and Value by Species

Climate Resilience

For the purpose of this report resilience is "the ability of social-ecological systems to absorb and recover from climatic shocks, stresses, and means for living in the face of long-term change and uncertainty" (Intergovernmental Panel on Climate Change) as it relates to climate conditions.

The Yale campus has certain components and environmental conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures, severe weather, wind events, invasive pests, and invasive plants add considerable challenges to a plant's vitality and resilience. The large area of parking lot space and associated storm drainage system (drainage) does not allow water to permeate into the ground. Naturally occurring water is diverted from absorption into the ground due to the impermeability of the asphalt surface. At times of severe drought, it is not practical to provide enough irrigation for numerous roots that are located two feet deep and extend well past the edge of tree canopies.

Trees have varying ability to adapt to be resilient in the face of extreme environmental conditions. A broader range of appropriate species can help provide a broader resilience to the climatic factors as well. Pest and disease resistance, heat tolerance, wind resistance can vary even within species. Diversity in species selection can increase tree population resistance and minimize reliance on dominant species planting.

The Yale campus has numerous groups of monoculture plantings consisting of crabapples (*Malus species),* white ash (*Fraxinus Americana),* sugar maple (*Acer saccharum),* and elm species (*Ulmus species)* planted in rows and groups.

Two of these species are currently under treatment for the invasive insect pest emerald ash borer (ash) and Dutch elm disease (elms). Other potentially invasive pests such as the Spotted Lanternfly also threaten the health of maples and other trees within the Yale urban forest, given current outbreaks in Pennsylvania. The sugar maple population is also susceptible to the invasive Asian longhorned beetle, though the nearby outbreak in New York City was declared eradicated in 2019 (New York City Parks, 2020, nycgovparks.org). These scenarios expose a high number of trees to potential pests and disease while increasing preventative maintenance costs. Ideally tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing temperatures.

Like-species plantings have historically provided a sense of order, aesthetic beauty and uniformity to street and landscape plantings throughout the United States and the world. When these monocultures are prone to broken branches during storm events or pest and disease, the planting shows a lack of resilience where a broader species planting with similar habit can increase resilience.

Oxygen Production

Yale campus trees in managed areas contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The earth's atmosphere has substantially more oxygen in its stores even without the contribution of the earth's tree population. (Nowak, 2007).

The overall top producer of oxygen according to the i-Tree Analysis is red oak (*Quercus rubra)* at a count of 354 trees at 20.92 tons. The next highest producer of oxygen is pin oak (*Quercus palustris)* at 18.40 tons, with a count of 308 trees (i-Tree Eco Analysis, Yale 2020).

Canopy and Air Pollution

A tree canopy is the tree's components, such as leaves, branches, and stems that cover the ground beneath the tree. The Yale campus has three distinct canopy covers: managed, woodland, and forest.

The managed area canopy cover is relatively sparse in comparison to the woodland and forested areas. The managed area canopy is defined by individual trees, due to the open ground area between trees, while woodland and forest area tends to be a contiguous canopy providing overlapping branch cover between adjacent trees.

The woodland area canopy cover provides cover from heavy rains by breaking the fall of precipitation. It also provides cover from the solar rays that would otherwise heat open ground contributing to evaporation and water loss.

Forest areas also provide the same benefits, with the leaf cover that protects the ground from heavy rains, as well as from solar rays that heat open ground and lead to evaporation.

Both woodland and forested areas do not have separate physical characteristics. These areas were inventoried in different manners: forest survey for forested areas and full inventory for trees over 8-inch DBH.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed, woodland and forested area according to the i-Tree Analysis is 1.299 tons in a year, with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser-count pollutants. (i-Tree Analysis, Yale Campus, 2020). This does not include the predominantly deciduous area in the forested areas. It is safe to assume that the benefits pertaining to air pollutant removal would be increased. Most of the air pollutants removed are linked to health problems.

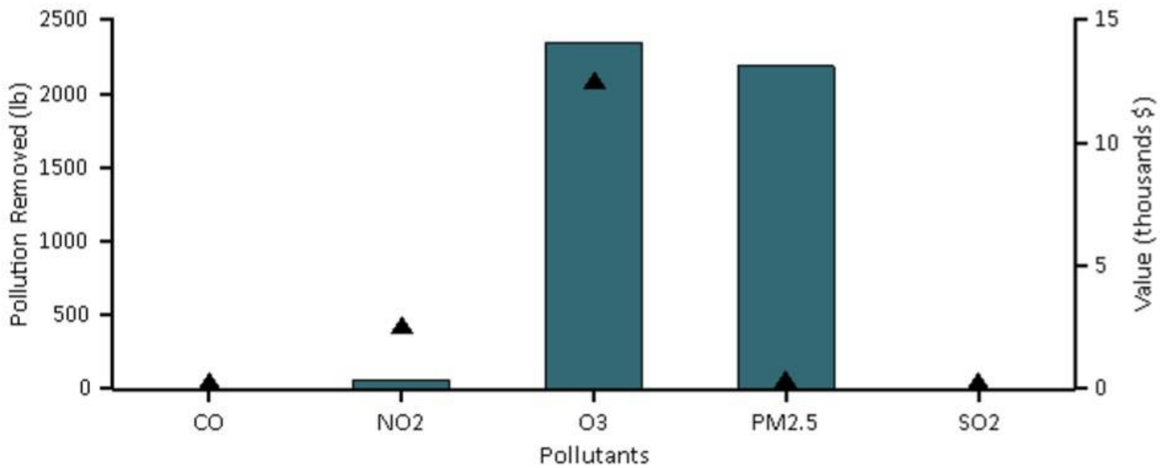

Figure 18 Yale Pollutants Removed and Value (i-Tree, Yale, 2020)

YALE CAMPUS INTEGRATED PEST MANAGEMENT (IPM)

The Yale campus has 138 trees presently on a pest management program. The majority consist of three species: elm (*Ulmus species*), beech (*Fagus species*), and ash (*Fraxinus species*) to treat Dutch elm disease, emerald ash borer, and multiple beech diseases, respectively. It is important to note that without the emerald ash borer treatment the ash trees would die. The elm trees' survivability without treatment is less known, as they are newly planted hybrids without time-tested proven resistance.

Hardwood species like maples (*Acer species*), elms (*Ulmus species*), birch (*Betula species*), and horse chestnut (*Aesculus species*) within the managed areas are susceptible to identified invasive pests like the Asian longhorned beetle. An integrated pest management plan where regular monthly scouting for signs of a pest or disease allows an appropriate response depending on extent, location, and species.

Integrated Pest Management Levels

Yale University directed the consultants to focus on "Priority" trees to distinguish between trees currently on an integrated pest management plan (Level I), trees that need to be on an integrated management plan (Level II) and campus trees that are noteworthy as either specimen, donated tree, milestone tree, culturally significant, or having been identified as rare taxonomy (Level III) with a total of 459 trees currently identified (see Table 5). These quantities change as trees are added, removed, or otherwise updated to the ArcGis platform. All IPM Level I-III are or should be on an IPM program.

IPM Level I Priority 138 trees are distinguished from the general campus tree population as currently on an integrated pest management plan and shown as IPM Level I on the Yale University ArcGis platform. Level I trees are being treated for pests and disease and should be inspected at regular intervals (30-45 days) during the growing season, usually considered between March and November, for additional problems.

IPM Level II Priority trees are distinguished from the general campus tree population as not currently on an integrated pest management plan but should be on an integrated pest management plan in anticipation. These trees are currently shown as a Level II on the Yale University ArcGis platform with a count of 39.

IPM Level III Priority trees are considered as to be noteworthy, having been identified as specimen, milestone, memorial, donated, culturally significant, or of rare taxonomy is 252. It is possible for trees to be considered for more than one priority designation, such as culturally significant and a specimen. It is also possible for them to be on an IPM program, depending on the tree.

IPM Level III Specimen trees have been identified as having exceptionally good or an unusual shape or size for the species as determined at the time of inventory or as advised by Yale representatives.

IPM Level III Milestone trees have been planted in recognition of Yale employees' milestone years of service. Often, more than one employee is associated with each tree.

IPM Level III Memorial trees are planted in memory of individuals who have been involved in various capacities with Yale University.

IPM Level III Donated trees have been donated by individuals involved with the university. They can be of varying size and species.

IPM Level III Culturally Significant trees have been identified as culturally or historically important trees. They might be associated with a Yale tradition, or noted individuals.

IPM Level III Rare Taxonomy trees (30) have been identified by Yale staff as unusual or unique species that warrant recognition.

Priority Trees in IPM Program by Campus						
IPM Levels	Athletics Campus	Central North	Central South	Medical	West	Total
Level 1	0	26	51	18	43	138
Level 2	0	38	1	0	0	39
Level 3	0	170	55	43	14	282
Total	0	234	107	61	57	459

Table 18 Trees in IPM Level I-III by Campus

YALE UNIVERSITY CAMPUS TREE VALUATION

The overall Yale campus valuation total for the inventoried tree population is $23,105,485. The figure was calculated from a total of 6,413 trees inventoried using the cost approach further explained below.

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The i-Tree formulae provide this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs (See Appendix 8 Sample i-Eco Report).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated “added value”.

Treble values could be used for individual trees within specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). It is suggested that a determined bond value be set by the university when construction occurs within root protection areas. This will only provide incentive to protect the tree as actual tree replacement is not practical, reasonable, or feasible for such unique trees. The legal system often determines such specific cases on a case by case basis as there are no accepted industry standards in these cases.

CITY OF NEW HAVEN STREET TREES

Overview

The consultants inventoried City of New Haven street trees that bordered Yale University properties. Street trees are generally considered trees that lie between the edge of sidewalks and the edge of street curbs. All the campuses have street trees except for West Campus. Yale University is interested in the trees from an informational standpoint and assumes no responsibility for the condition or maintenance of the trees.

Species Distribution

The City of New Haven top three species distribution shows that there are 338 pin oak (*Quercus palustris*), 152 London planetree (*Platanus x acerifolia*), and 93 Norway maple (Acer platanoides). The pin oak population represents 24.3 percent of the tree population, the London planetree 10.9 percent, and Norway maple 6.7 percent.

Table 19 - Species Distribution City of New Haven	
Species	**Number**
Oak, Pin	338
London Planetree	152
Maple, Norway	93
Elm Species	78
Elm, Hybrid	72
Elm, Homestead	68
Maple, Red	67
Oak, Red	62
Zelkova, Japanese	52
Sweetgum	41
Balance of Species	368
Total	1,391

Table 19 City of New Haven Species Distribution

The City of New Haven trees bordering Yale properties total 1,391. The city tree inventoried population on the campuses is Central North Campus 597, Central South Campus 486, Yale School of Medicine Campus 217, West Campus 0, and Athletics Campus 91 (see Table 6)

City of New Haven Street Trees Ecosystem

An ecosystem analysis was created for the overall City of New Haven inventoried street trees.

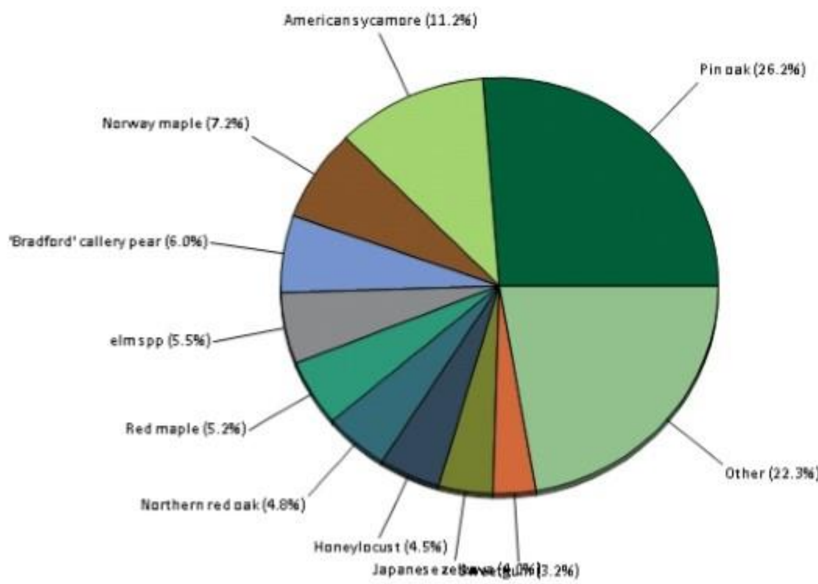

Figure 19 City of New Haven Species Distribution

The analysis was created using i-Tree, an open source service that quantifies ecological benefits of trees based on collected digital data fields. Since 2006, i-Tree has been a cooperative effort between the USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, and SUNY College of Environmental Science and Forestry.

Interpretation of some data fields may vary from the consultants' data, resulting in slightly different tree quantities, with 1,300 city trees considered with i-Tree data analysis and overall inventoried street trees. London planetree (*Platanus x acerifolia*) was interpreted as American sycamore (*Platanus occidentalis*) by the i-Tree data.

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $1,860,000 for 1,300 trees with tree cover of 11.29 acres.

City of New Haven tree species of greatest structural value are pin oak (*Quercus palustris*) highest, London planetree (*Platanus x acerifolia*) (referred to as American sycamore (*Platanus occidentalis*) in New Haven i-Tree analysis) second and Norway Maple (*Acer platanoides)* third.). "Other" is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

Urban trees in New Haven i-Tree Analysis 2020 have the following annual functional value totals:

- Carbon sequestration: $2,230
- Avoided runoff: $896,000
- Pollution removal: $5,610
- Carbon storage: $132,000 (i-Tree Eco Analysis, Analysis New Haven, 2020).

Avoided Stormwater Runoff

Avoided stormwater runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with the City of New Haven street trees such as pin oak (*Quercus palustris*), London planetree (*Platanus x acerifolia*), and to a lesser degree Norway Maple (*Acer platanoides)a*) able to capture the most cubic feet of avoided runoff. The avoided stormwater runoff also decreases the extent of surface erosion and soil lost.

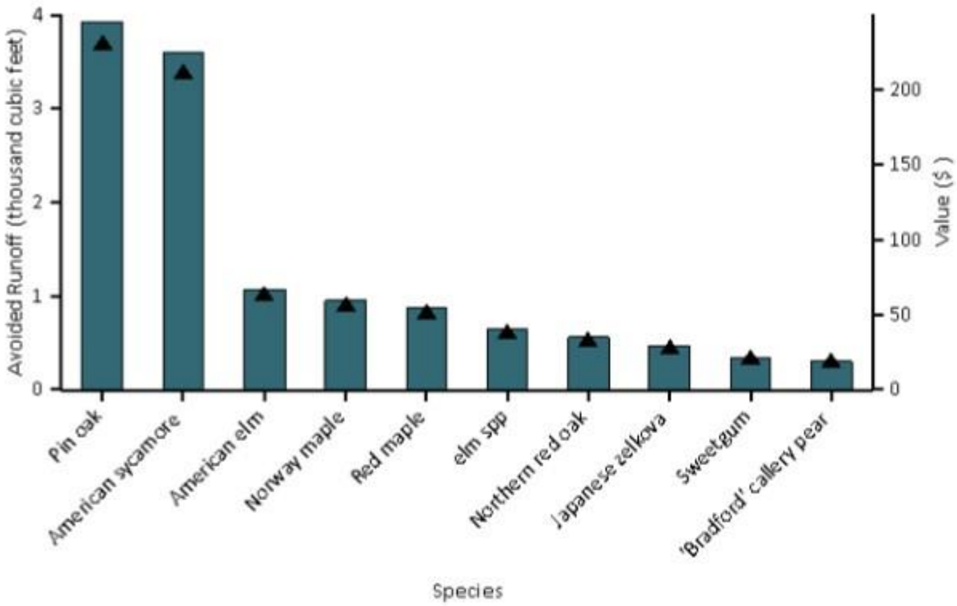

Figure 20 City of New Haven Avoided Runoff and Values by Species (i-Tree, City New Haven, 2020)

Climate Resilience

For the purpose of this report, resilience is "the ability of social-ecological systems to absorb and recover from the climactic shocks, stresses, and means for living in the face of long-term change and uncertainty" (Intergovernmental Panel on Climate Change, 2012) as it relates to climate conditions.

New Haven city trees have certain components and environmental conditions that put stress on the ability to be resilient in the face of current climate conditions. The inventoried street tree population usually lies in areas that are surrounded by impermeable surfaces without supplemental irrigation. Drought, higher temperatures, severe weather and wind events, and invasive pests and plants add considerable challenges to a plant's vitality and resilience. The large, impermeable area of sidewalk and street surface area and associated storm drainage system (drainage) do not allow water to permeate the soil, increasing drought effects.

Trees vary in their ability to adapt and become resilient in the face of extreme environmental conditions. A broader range of appropriate species can help provide a broader resilience to pest and disease, and extreme climatic events. Diversity in species selection can increase tree population resistance and minimize reliance on dominant species planting.

Two groups of monoculture plantings are apparent: pin oak and London planetree. Numerous streets are lined with London planetree as well as pin oak. The planting of pin oak on Hillhouse Avenue is high profile, given the administrative buildings, including the President's House, and the large size of the trees, the uniform rows, and, when in leaf, the broad canopy extending over the street.

It is interesting to note that Hillhouse Avenue was also once lined with elegant American elms that have since succumbed to Dutch elm disease. Ideally tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing temperatures.

Oxygen Production

New Haven trees contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees (see Nowak, 2007).

The overall top producer of oxygen, according to the i-Tree Analysis, is pin oak (*Quercus palustris)* at a count of 338 trees at 13.71 tons. The next highest producer of oxygen is American sycamore (*Platanus occidentalis*) (London planetree) at 6.3 tons with a count of 152 trees.

Canopy and Air Pollution

Tree canopy is the tree's components such as leaves, branches, and stems that cover the ground beneath the tree.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed by New Haven inventoried trees according to the New Haven i-Tree Analysis is 568.2 pounds per year with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser-count pollutants. (i-Tree Analysis, New Haven, 2020).

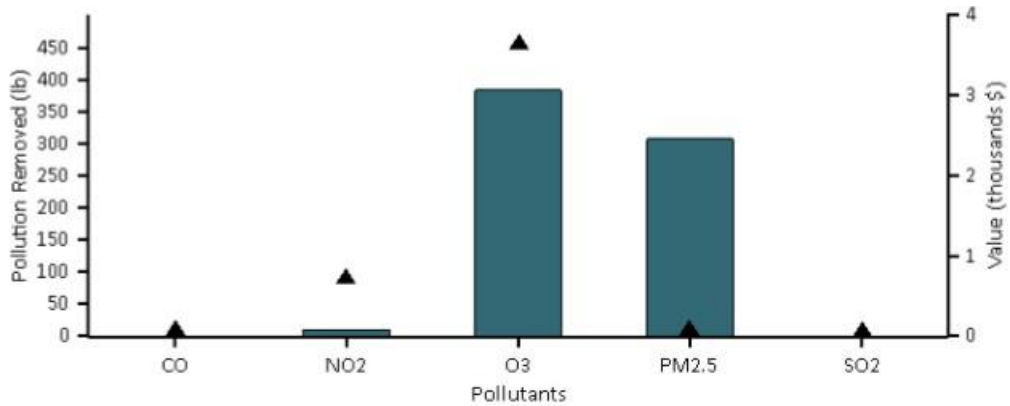

Figure 21 City of New Haven Pollutants Avoided and Values

New Haven Tree Valuation

New Haven city trees' valuation total for the inventoried tree population is $4,629,744.69. The figure was calculated from a total of 1,300 trees inventoried using the cost approach. (See Tree Inventory Valuation Calculation, Appendix 2).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The i-Tree formulae provide this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs (See Appendix 8 Sample i-Eco Report).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated "added value".

CENTRAL NORTH CAMPUS

Overview

Central North Campus is the northernmost Yale campus. Approximately 100 acres in size, it lies between Grove Street to the south and Highland Street to the north. The eastern side runs adjacent to Whitney Avenue and a small portion of St. Ronan Street, with the western side, is adjacent primarily to sections of Prospect Street and Mansfield Street. The campus's westernmost outcrop is adjacent to Division Street and a portion of upper Canal Street. The consultants did not inventory this portion, as it is considered within a construction zone.

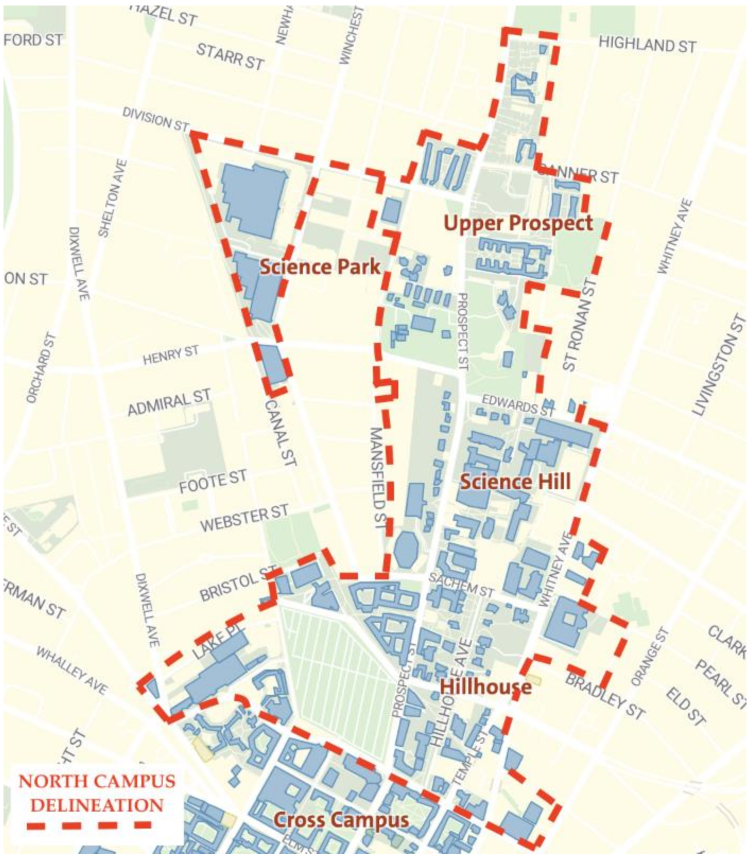

Figure 22 Central North Campus and Boundaries

It is important to note that there are two areas on Central North Campus that were considered woodland and inventoried as such (all trees over 8-inch caliper at DBH were inventoried). They are located on the west side of Prospect Street and north of Sachem Street and to the south of Hillside Place adjacent to Prospect Gardens. For purposes of the current management discussion all trees are currently considered within the Central North Campus managed area. The New Haven street trees (trees typically found between the sidewalk and street) adjacent to Yale-owned property were inventoried and processed separately.

The terrain of Central North Campus slopes somewhat gently down from the higher points on Upper Prospect to the lower elevations along Grove Street. There are larger 100-year-old (plus or minus) residences, some of which have been converted to housing or university office space, within the bounded "swale" forest block bordered by Prospect Street and Mansfield Street. Several large diameter (30-plus inch DBH) trees are scattered throughout the Upper Prospect area along St. Ronan Street, Marsh Botanical Garden, and Farnam Gardens, which contain larger or more exotic species than observed elsewhere on the Yale campus. The managed area is generally an open lawn adjacent to historic buildings found in the Divinity School, with a mix of trees from large 75-foot-plus trees to smaller trees under 25 feet. As the

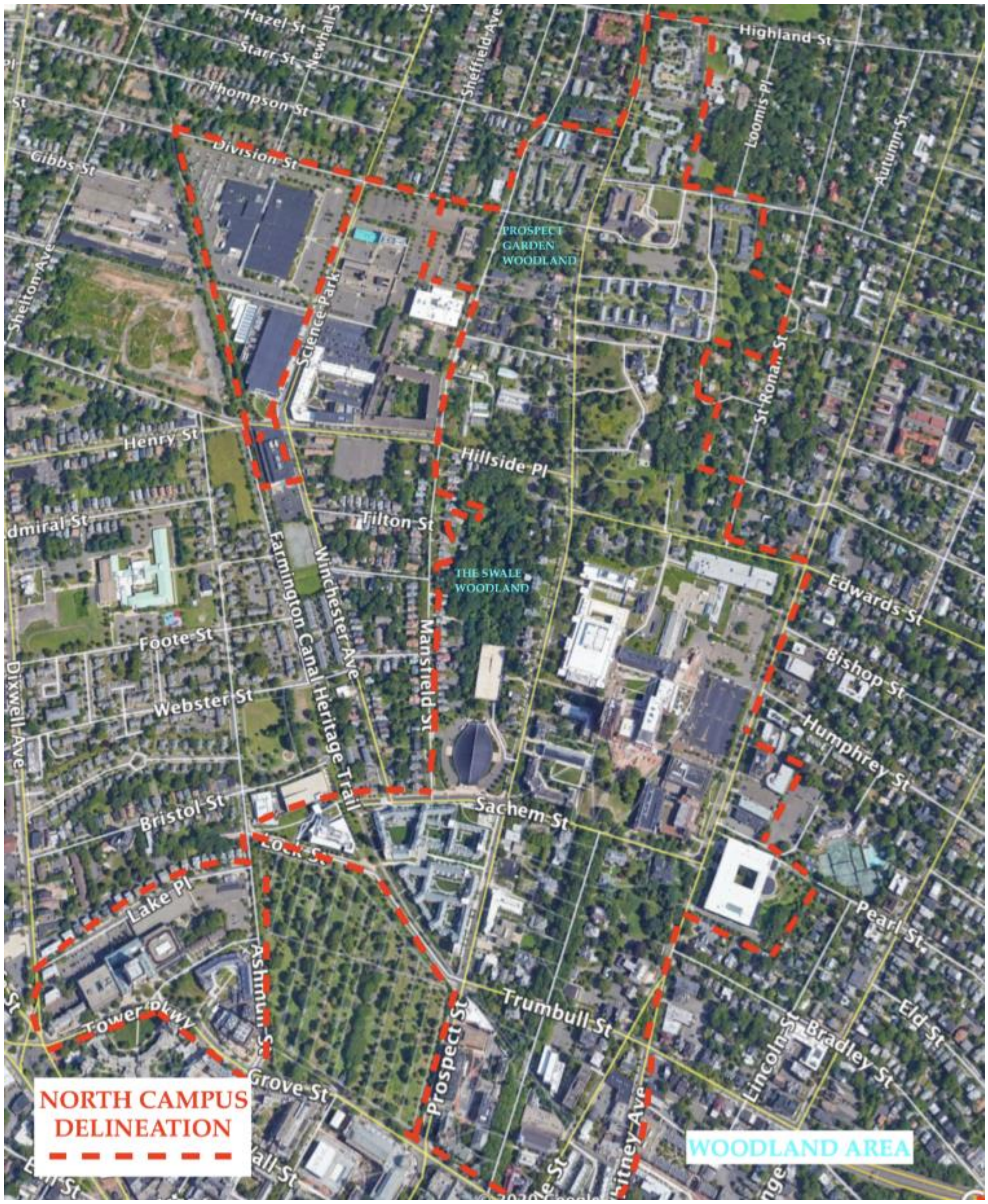

Figure 23 Central North Boundaries (Satellite View)

grade slopes gently down toward the south side of Central North Campus, there is a noticeable increase in the frequency and height of the buildings on Science Hill. They are framed at informal intervals by trees, the larger (75-plus feet) of which are predominantly oak (*Quercus species*) varieties.

The southern outcrop north of Tower Parkway and south of Lake Place contains Payne Whitney Gymnasium and nearby Baker Hall and Central Power Plant. This area was considered Central North Campus for the purpose of the tree inventory work.

Central North Campus Managed Area

The tagging of each inventoried tree within the approximately 100-acre inventoried area occurred during fall 2019, with active inventorying occurring from late fall 2019 into early 2020.

The inventory distribution in the managed and woodland area is a mix of established and new plantings. The inventory is broken out into 3,154 Yale trees and 597 New Haven street trees for a total of 3,751 inventoried. Norway maples (*Acer species)* were the most prevalent at 292 count, red oak (*Quercus rubra*) the second most populous at 180, followed by pin oak (*Quercus palustris*) at 169.

Central North Campus Woodland Designated Areas

The Swale

Overview. The Swale is a woodland site located within the Central North Campus. Its approximate four acres are bounded by Hillside Place on the north and the backs of residences on Prospect Street (east) and Mansfield Street (west). The south boundary is the Prospect-Sachem parking garage. The property lines for the adjacent properties are poorly defined, making the demarcation of woods and properties difficult.

The Swale has what appears to be an ephemeral stream or low wet area that bisects the property evenly on an approximate north-south axis. The site is mostly flat to within a few hundred feet of its east boundary. At that point, a steep slope with a west-facing aspect rises to the back of the properties on Prospect Street.

The Marshfield Community Garden is located on the west side of the property and slightly north of the center of the plot. The garden was fenced in and appeared to have seen limited use and was not considered as part of the inventory. Dispersed throughout the remainder of the property were plots used for hydrologic testing. No clear trail system existed.

Woodland Trees: 189 trees were inventoried and mapped on this property, with 22 species identified; 87 Norway maple (*Acer platanoides*), 12 red oak (*Quercus rubra*), and 24 black walnut (*Juglans nigra*) were dominant. These three species comprise 65 percent of the trees on the site. Some noteworthy species included white oak (*Quercus alba*), Hophornbeam (*Ostrya virginiana*), and European beech (*Fagus sylvatica*). Diameters ranged from 8 to 44 inches, with the mean being 11 inches. Table 7 presents the condition distribution of the inventoried trees. There is an even balance between trees in Good and Fair condition.

Table 20 – The Swale Woodland Condition Distribution

Condition	Quantity	Percent
Excellent	0	0.0%
Good	72	38.1%
Fair	95	50.3%
Poor	20	10.6%
Very Poor	0	1.9%
Dead	2	1.1%
Total	189	100%

Table 20 Condition Distribution The Swale

The relatively smaller diameters of the trees found on this site would account for the greater number in Good condition, compared to other woodland sites within the campus system.

Prospect Gardens

Table 21 – Prospect Gardens Woodland Condition Distribution		
Condition	**Quantity**	**Percent**
Excellent	0	0.0%
Good	42	27.3%
Fair	89	57.8%
Poor	16	10.4%
Very Poor	3	1.9%
Dead	4	2.6%
Total	154	100%

Table 21 Condition Distribution Prospect Gardens

Overview. Prospect Gardens is a woodland site located near the north end of the North Central campus and south of the Prospect Gardens apartment complex. Its 2.82 acres are bounded by Prospect Street and residences on the east, Division Street on the north, and Mansfield Street on the west. The south boundary is a mix of residential properties and apartments. The site appears to have previously been a series of residential properties that have been vacated, with the residences torn down. This is evident by the many overgrown spoil piles and some construction debris. The property is relatively flat, with the northeast corner having a slightly higher elevation than the western portion of the property. There are some minor hillocks in the center of the site that also may be spoil piles.

Three areas of the property have community gardening activities with individual plots marked out. They are in the northeast corner, the near northwest corner, and the near southwest corner. A significant amount of gardening debris is found on the site. This tends to mostly be one-gallon plastic bottles. The northeast corner gardens are in an open area that includes managed turf. A large watering tank is in this garden. The remaining understory throughout the site is overgrown, unmanaged grasses, forbs, and understory shrubs. The south-central part of the woodland has an extensive growth of raspberry canes.

Woodland Trees. One hundred fifty-four trees were inventoried and mapped on this property, with 19 species identified. Norway maple (*Acer platanoides*), red oak (*Quercus rubra*), black locust (*Robinia pseudoacacia*), and sugar maple (*Acer saccharum*) predominate. These five species comprise 76 percent of the trees on the site. Some noted species include horse chestnut (*Aesculus hippocastanum*), tulip tree (*Liriodendron tulipifera*), and black cherry (*Prunus serotina*). Diameters ranged from 6 to 42 inches, with a mean diameter of 13 inches. Table 8 presents the condition distribution of the inventoried trees. A significant number of the assessed trees had observable deadwood. This would account for the high percentage of Fair condition trees. The seven noted as extremely poor or dead are included in the 11 trees recommended for removal.

Central North Campus Soil Samples

Soil samples were taken from 15 sample plots in managed areas only. The plots were selected as representative of the general physical conditions: planting beds and turf area. The samples were collected from the upper 8-inch soil A horizon (2015, Penn State) using a 24-inch ADS soil core sampler and tested using a standard nutrient analysis (Morgan Method performed by Connecticut Agricultural Experiment Station). The results are varied, most likely due to construction activities, previous lawn treatments, or heavily irrigated sectors.

The consultants recommend establishing a general baseline reference, as opposed to using the results for establishing fertilization (or other) treatment rates (see Soil Test Results, Appendix 3) for adjacent trees. Any future specific tree needs should be tested independently from the current results.

Central North Campus Ecosystem

i-Tree Analysis

The i-Tree analysis for Central North Campus is based on all Yale University inventoried trees within the managed and woodland areas (The Swale and Prospect Gardens) and excludes all City of New Haven trees. There is a discrepancy between trees inventoried (3,154) and the i-Tree count. This is most likely the result of the data that were submitted by the consultants and unknown variation in data interpretation by the i-Tree model.

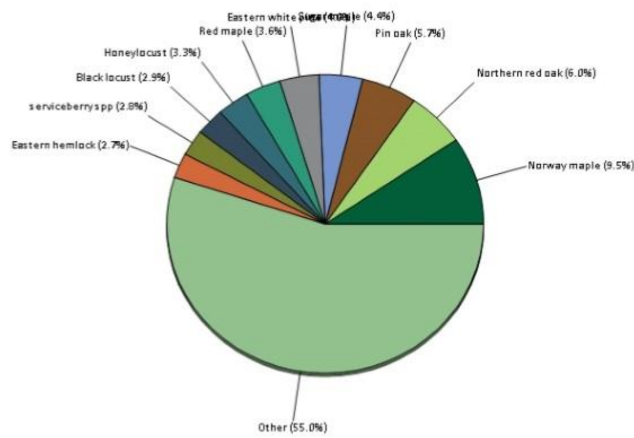

Figure 24 Central North Species Distribution (i-Tree, Central North, 2020)

The most common species are 292 Norway maples (*Acer platanoides)*, 180 red oak (*Quercus rubra),* and 169 pin oak *(Quercus palustris).* Although the Norway maple is the most prevalent species in North Campus, it is only third in carbon sequestration and fourth in storage values (see Figure 8 in Central North i-Tree Analysis, 2020). Northern red oak and pin oak are first and second, respectively, most likely due to their overall size contribution (Central North i-Tree Analysis, 2020). "Other" is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

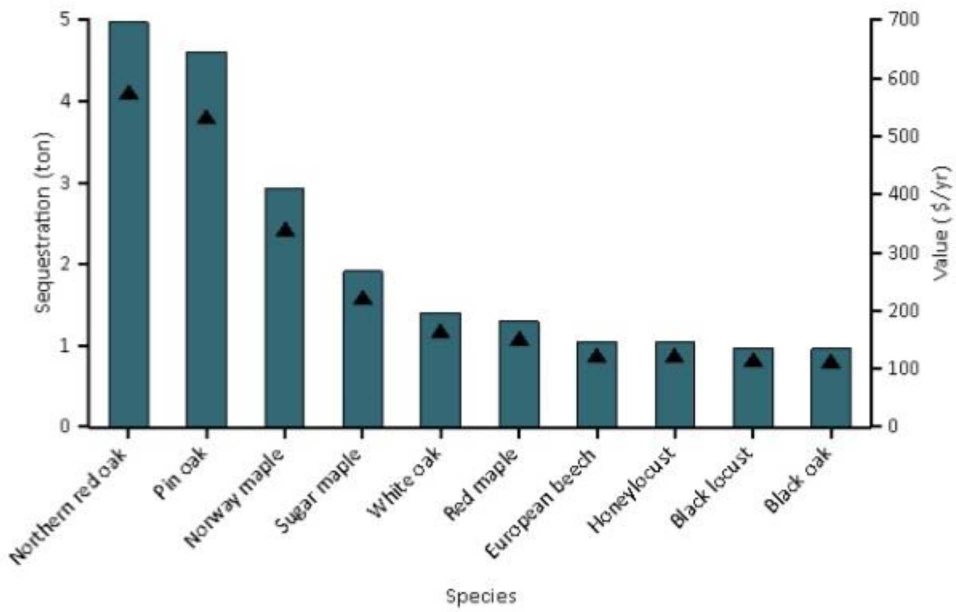

Figure 25 Central North Carbon Sequestered and Value (i-Tree, Central North, 2020)

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $5.12 million for 3,041 trees, with tree cover of 25.01 acres within 100 acres. The i-Tree results of the values demonstrate that generally trees of greater size, quantity, and increased environmental value also increase structural and eco value (i-Tree Eco Analysis, Yale, 2020).

Avoided Stormwater Runoff

Avoided stormwater runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with Central North Campus trees such as the Norway maple able to capture the most cubic feet of avoided runoff, with the northern red oak second and pin oak third. The overall population, tree, and leaf size provide a rainfall capture cushion over the ground below. The avoided stormwater runoff diminishes the extent of surface erosion and soil lost (Central North Campus, i-Tree Analysis, 2020).

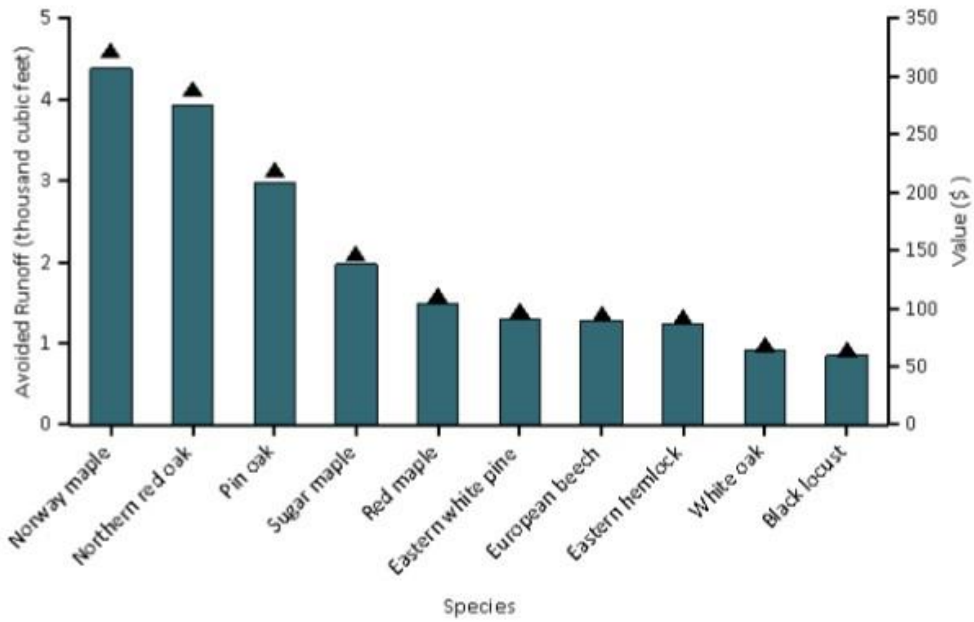

Figure 26 Avoided Runoff and Value, Central North i-Tree 2020)

The estimated amount of avoided runoff is 37.98 thousand cubic feet/year ($2.54 thousand/year) based on a 2016 annual regional rainfall of 30.3 inches and $0.07 per cubic foot.

Climate Resilience

Central North Campus has certain components and conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures, severe weather, wind events, and invasive pests and plants add considerable challenges to a plant's vitality.

The relatively larger managed areas of Central North Campus have a greater degree of rainwater permeability than an area occupied by building space and parking lots. Naturally occurring water is absorbed into the ground and made available to extensive root systems of individual and group plantings of trees. The turf area helps slow and absorb water, minimizing runoff potential, while the additional understory cover in woodland areas also increases runoff capture despite an area of greater slope (the west-facing aspect of The Swale).

Central North Campus has limited groups of monoculture plantings, reducing vulnerability to pests and pathogens. For example, Hillhouse Avenue has rows of 20- to 30-plus-inch DBH pin oaks (*Quercus palustris*) lining the street side. The large quantity of like species planted consecutively over a large area is vulnerable to pathogens or pests, where a mixed -species landscape planting would be less vulnerable and more resilient.

There are two species currently under treatment for the invasive insect pest emerald ash borer (ash) and Dutch elm disease (elms) on the Yale campus. Ideally, tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing temperatures.

Oxygen Production

North Campus trees in managed areas contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees (See Nowak et al.: *Oxygen Production by Urban Trees Arboriculture & Urban Forestry* 2007. 33(3):220–226).

This campus produces 86.67 tons of oxygen per year. The top producer of oxygen, according to the i-Tree Analysis, is Northern red oak (*Quercus rubra*) at a count of 182 trees at 8,164.35 pounds. The next highest producer of oxygen is pin oak (*Quercus palustris)* at 7,575.40 pounds, with a count of only 172 trees (Central North, i-Tree Analysis, 2020).

Canopy and Air Pollution

A tree canopy consists of components such as leaves, branches, and stems that cover the underlying ground beneath the tree.

The managed-area canopy cover is spread out in comparison to the condensed woodland canopy area, and is defined by individual trees, due to the open ground between trees, while the woodland area tends to be a contiguous canopy providing overlapping branch cover between adjacent trees.

The woodland-area canopy provides shelter from heavy rains by breaking the fall of precipitation. It also offers cover from the solar rays that would otherwise heat open ground, contributing to evaporation and water loss.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed area, according to the i-Tree Analysis, is 1,371 pounds in a year, with ozone comprising the largest portion of removed pollutants out of carbon dioxide, nitrogen dioxide, and other lesser count pollutants. (i-Tree Analysis, Central North Campus, 2020). This total also includes the predominantly deciduous forest area in the woodland. Most of the air pollutants removed are linked to health problems (see Hirabayashi, Nowak, 2016).

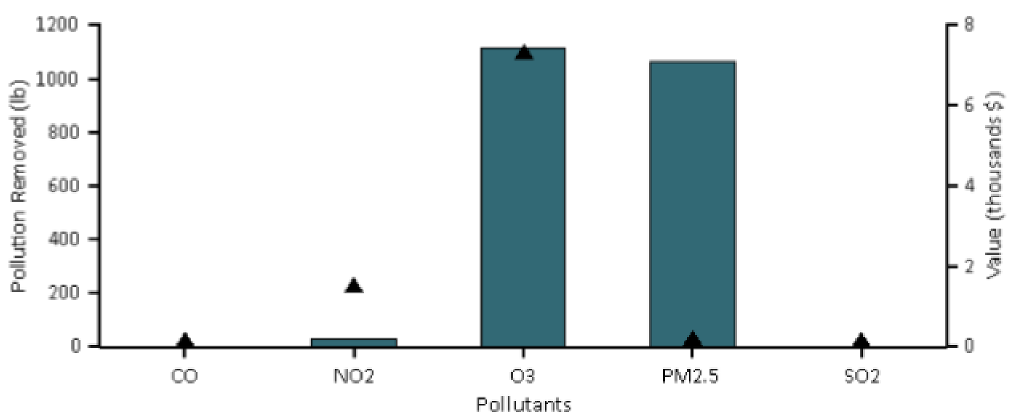

Figure 27 Pollutants Removed and Value (i-Tree, Central North, 2020)

Central North Campus Tree Valuation

The Central North Campus valuation total for the inventoried tree population is $12,842, 548.53. The figure was calculated from a total of 3,154 campus trees inventoried. (See Tree Inventory Valuation Calculation, Appendix 2).

CENTRAL SOUTH CAMPUS

Overview

Central South Campus is approximately 80 acres, stretching between its most southern boundary—a single building between southern North Frontage Street and northern George Street—and eastern College Street and western York Street. The remaining contiguous campus begins to the north on Crown Street and runs to its most northerly boundary of Grove Street. 1017 Yale University-owned trees and 485 City of New Haven trees were inventoried. The consultants did not inventory construction zones (approximately six acres) at various Central South Campus locations.

The campus is situated in a heavily settled area consisting of managed areas within residential campus communities and associated interior courtyards with significantly sized trees within well-managed areas of lawn, planting beds, and walkways. The largest and heavily managed trees (elms) reside within the campus courtyards and along popular walkways such as Library Walk. There are no woodlands or forested areas within Central South Campus.

The terrain remains relatively flat, accentuated by wide, bordering sidewalks and tree-lined, one-way streets. This area differs noticeably from the rest of Central South Campus due to the density of the historical campus buildings, and increased size and

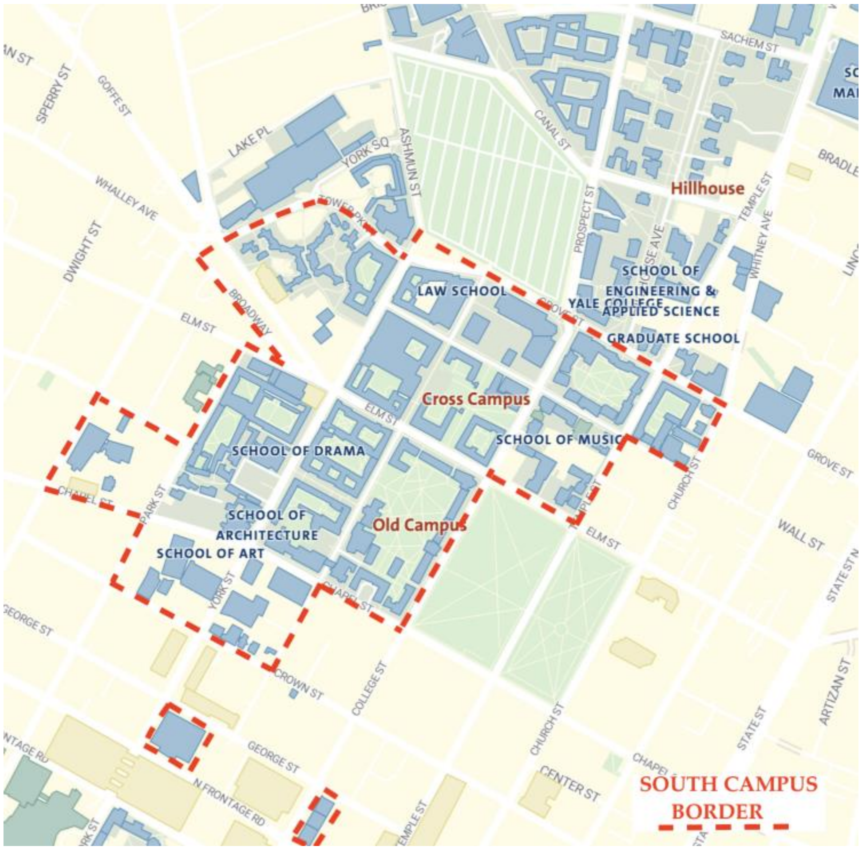

Figure 28 Central South Location and Boundaries

number of elm trees. Specifically, Cross Campus, located at the corner of Elm Street and College Street, and Old Campus, one block to the south,

have noticeably larger trees and associated canopies with many mature elms. The transition to an urban setting is marked by popular retail stores, restaurants, and bars, and a few markets. The streets are lined with a variety of mature city street trees of varying condition, flanked by wide sidewalks heavily used by pedestrians.

The dense urban infrastructure on most of Central South Campus is unique, presenting challenges not found on the other campuses. Access to rainwater for trees is limited, due to a larger amount of impermeable surface area of roof and pavement. The destination of captured (gutter system) and channeled rainwater is to the city storm system. The pitch of the land and the catch basins found along streets and courtyards are designed to take runoff out of the area. Ideally, this water can percolate into the soil, providing water to trees. Irrigation heads are present in many of the interior courtyards, though it is not known to what extent these systems are utilized.

Central South Campus Managed Area

The inventory distribution in the managed area consists mostly of established and new plantings within Yale University and New Haven City Street tree designation. Kousa dogwood (*Cornus kousa*) was the most prevalent at 170 count, Serviceberry (*Amelanchier canadensis*) was second-most populous at 83, and flowering dogwood (*Cornus florida*), third at 63.

Central South Campus Soil Samples

Soil samples were taken from five sample plots in managed areas only. The plots were selected as representative of the general physical conditions: planting beds and turf area. The samples were collected from the upper 8-inch soil A horizon (Penn State, 2015) using a 24-inch ADS soil core sampler and tested using a standard nutrient analysis (Morgan Method performed by Connecticut Agricultural Experiment Station). The results are varied, most likely due to construction activities, previous lawn treatments, or heavily irrigated sectors.

The consultants recommend establishing a general baseline reference as opposed to using the results for establishing fertilization (or other) treatment rates (see Soil Test Results, Appendix 3A) for adjacent trees. Any future specific tree needs should be tested independently from the current results.

Central South Campus Ecosystem

i-Tree Analysis

The i-Tree analysis for Central South Campus is based on all Yale University inventoried trees within the managed and excluded all City of New Haven trees. There is a discrepancy between trees inventoried and the i-Tree count of 997 versus the 1086 inventory count. The eco-benefits are most likely higher. This is most likely the result of the data that were submitted by the consultants and unknown variation in data interpretation by the i-Tree model.

The most common species are Kousa dogwood (*Cornus kousa)*, at 170, Serviceberry (*Amelanchier canadensis*) at 83, and flowering dogwood (*Cornus florida*) at 63. Though the Kousa dogwood is the most prevalent species in West Campus, they are second in carbon sequestration and seventh in storage values (see Figures 8 and 9 in Central South i-Tree Analysis, 2020). Pin oak are first in both carbon storage and sequestration, most likely due to their overall size contribution (Central South i-Tree Analysis, 2020). "Other" is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

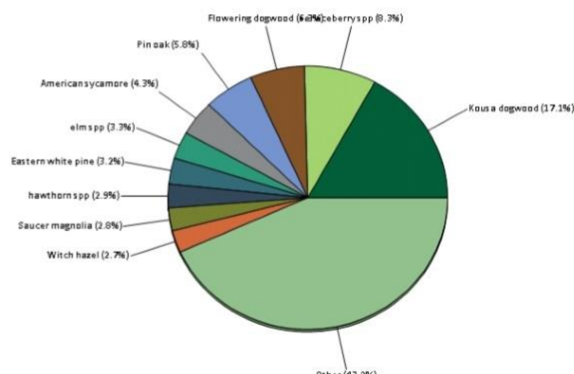

Figure 29 Species Distribution, South (I-Tree, South, 2020)

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $ 1.41 million for 997 trees, with tree cover of 7.845 acres within approximately 80 acres. The i-Tree results of the values demonstrate that generally trees of greater size, quantity, and increased environmental value also increase structural and eco-value (i-Tree Eco Analysis, Analysis Yale, 2020).

Avoided Stormwater Runoff

Avoided storm water runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with South Campus trees such as the pin oak (*Quercus palustris*)able to capture the most cubic feet of avoided runoff, with the American elm (*Ulmus americana*) second and kousa dogwood (*Cornus kousa*) third. The overall population, tree and leaf size provide a rainfall capture cushion over the ground below. The avoided stormwater runoff diminishes

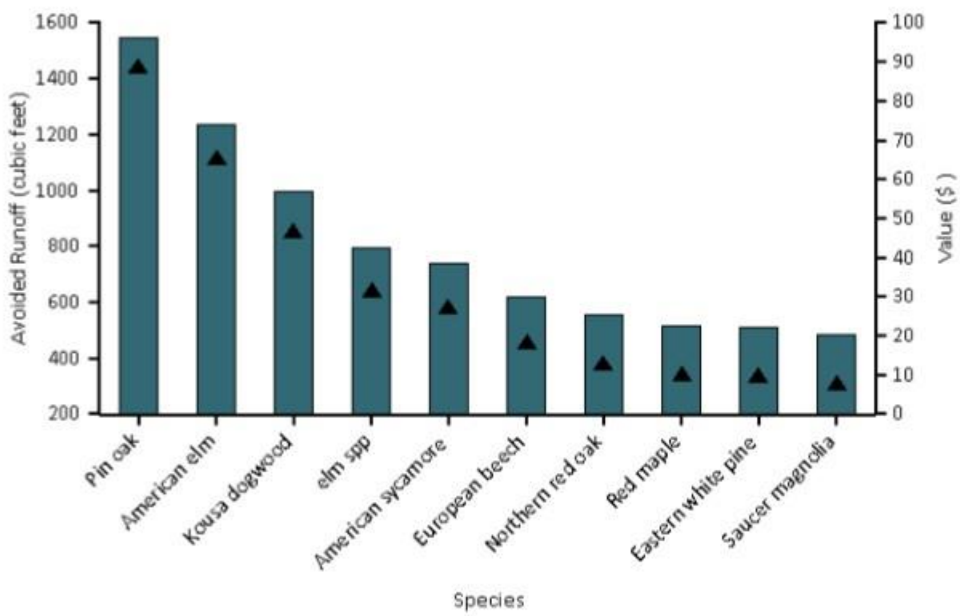

Figure 30 Avoided Runoff and Value,(South, i-Tree, 2020)

the extent of surface erosion and soil lost (Figure 10, South Campus, i-Tree Analysis, 2020).

The estimated amount of avoided runoff is 9.982 thousand cubic feet/year ($667/year) based on a 2016 annual regional rainfall of 30.3 inches and $0.07 per cubic foot.

Climate Resilience

Central South Campus has certain components and conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures and associated heat island effects, severe weather, wind events, and

Figure 31 Central South Avoided Runoff and Value (i-Tree, 2020)

invasive pests and plants add considerable challenges to a plant's vitality.

The managed areas of Central South Campus have a greater degree of rainwater permeability than the area occupied by building space and parking lots. Naturally occurring water is absorbed into the ground and made available to extensive root systems of individual and group plantings of trees. The turf area helps slow and absorb water, minimizing runoff potential.

Central South Campus has some groups of monoculture plantings, increasing vulnerability to pests and pathogens. For example, numerous interior courtyard quads have single standing American elms that could be considered a grouping. The American elm is under a current treatment for Dutch elm disease. The large quantity of species planted consecutively over a large area is vulnerable to pathogens or pests, where a mixed species landscape planting would be less vulnerable and more resilient.

There are two species currently under treatment for the invasive insect pest emerald ash borer (ash) and Dutch elm disease (elms) on the Yale campus. Ideally tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing temperatures

Oxygen Production

South Campus trees in managed areas contribute to oxygen production released into the atmosphere. More importantly, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees (Nowak et al., "Oxygen Production by Urban Trees," *Arboriculture & Urban Forestry* 2007, 33(3):220–226).

Central South Campus produces 24.17 tons of oxygen per year. The top producer of oxygen, according to the i-Tree Analysis, is pin oak (*Quercus palustris*) at a count of 58 trees at 10,662.33 pounds. The next highest producer of oxygen is kousa dogwood (*Cornus kousa)* at 1,445.13 pounds, with a count of 170 trees (Central South Campus, i-Tree Analysis, 2020).

Canopy and Air Pollution

A tree canopy is the tree's components, such as leaves, branches, and stems, that cover the ground beneath the tree. The managed area canopy cover is spread out, in comparison to the condensed woodland canopy area. It is defined by individual trees, due to the open ground between trees, while the woodland area tends to be a contiguous canopy providing overlapping branch cover between adjacent trees.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the Central South Campus i-Tree Analysis is 392.2 pounds in a year with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide and other lesser count pollutants. (i-Tree Analysis, Central South Campus, 2020). Most of the air pollutants removed are linked to health problems (Hirabayashi, Nowak, 2016)

Central South Campus Tree Valuation

Central South Campus valuation total for the inventoried tree population is $3,398, 660. The figure was calculated from a total of 1,017 trees inventoried using the cost approach further explained below. (See Tree Inventory Valuation Calculation, Appendix 2.)

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The i-Tree formulae provides this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs (See Appendix 8 Sample i-Eco Report).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated "added value".

Treble values could be used for individual trees within specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). It is suggested that a determined bond value be set by the university when construction occurs within root protection areas. This will only provide incentive to protect the tree as actual tree replacement is not practical, reasonable, or feasible for such unique trees. The legal system often determines such specific cases on a case by case basis as there are no accepted industry standards in these cases.

YALE SCHOOL OF MEDICINE CAMPUS

Overview

The Yale School of Medicine Campus inventoried area is approximately 36 acres, the smallest acreage of all campuses, consisting of Yale School of Medicine and numerous supporting offices and service buildings. This campus is located between northernmost York Street and southern Columbus Avenue. There is also an adjacent small park, Amistad Park, to the south of the medical school and office complex.

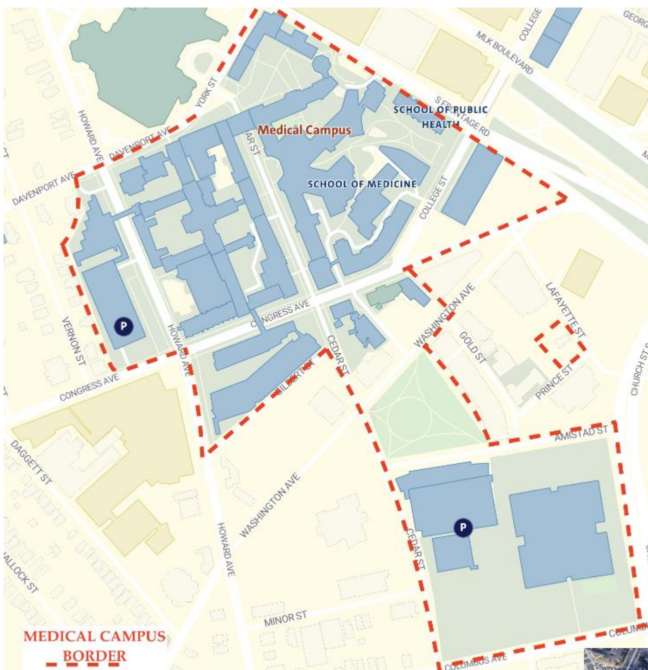

Figure 33 Yale School of Medicine

There is some variation of the density of the Yale School of Medicine Campus just south of Yale New Haven Hospital and York Street. Interior courtyards of managed turf areas contain several mature trees and specimen trees. Supporting utility infrastructure also lies within the interior of the medical complex. There are some established plantings that have maintained a foothold through obvious construction activities over the years.

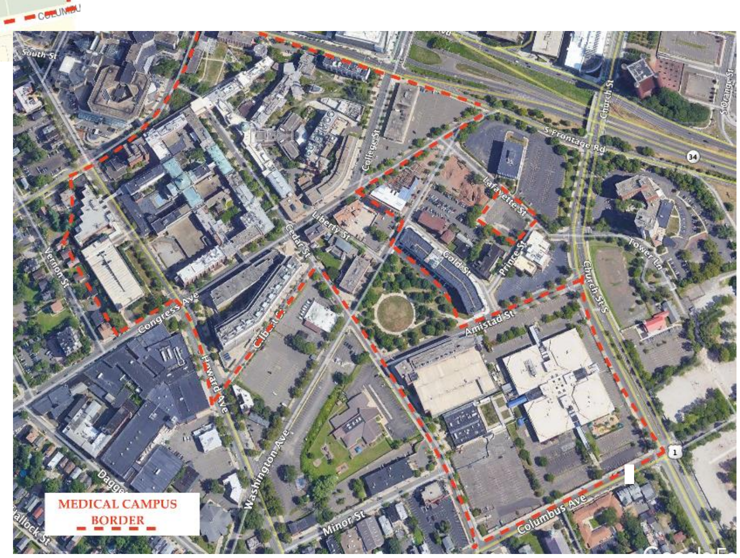

Figure 32 Yale School of Medicine, Sat. View

The City of New Haven street trees are of varying condition and size and species. The trees tend to run as similar species per street on
the block. For example, pin oaks are found on Cedar Street in front of the Yale School of Medicine and London plane trees are found just north on York Street. A cluster of Bradford pear trees are found on city property at the corner of Cedar and York streets, while small groups of crabapples are found along the interior courtyards and building exteriors.

The area just south of Congress Street gradually evolves into a less congested space. Buildings tend to have more space between them, with more open space for city trees on sidewalk areas. Numerous parking lots adjacent to these southern areas greatly contribute to increased city temperatures, as materials heat up and the tree canopy cover provides minimal shade. Trees in these areas tend to become easily drought stressed, given the potential for heat buildup and associated water loss to the runoff entering the stormwater system.

Amistad Park lies in the southern area of the campus, providing shade and open managed lawn area. There are several large and small-sized species densely spread out informally over the park. Most of the species are in good condition, providing shade and desirable canopy.

South of Amistad Park is another relatively open space with large surface areas exposed (unprotected by canopy), lending itself to heating up during hot days. The surfaces typically collect stormwater and remove it from the site, contributing to the likelihood of drought conditions and stressing plants. Leaf cover tends to be less effective at collecting pollutants as well as oxygen

Yale School of Medicine Campus Managed Area

Tagging of each inventoried tree within the 36-acre area occurred during fall 2019 and inventorying took place from late fall 2019 into early 2020. Most trees in this area are deciduous and had minimal, if any, leaves, given the time of year.

The tree population in the managed area is also a mix of established and new plantings. The Yale School of Medicine Campus trees total 412 and City of New Haven trees total 212. The campus tree count is 79 crabapples (*Malus species)* as the most prevalent, Norway spruce (*Picea abies*) as the second most populous at 37, and flowering dogwood (*Cornus florida*) coming third at 28. There are small groups of like species established plantings of crabapples (*Malus species),* and established specimen American elms (*Ulmus americana)* within mulched planting beds and turf areas. "Other" is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

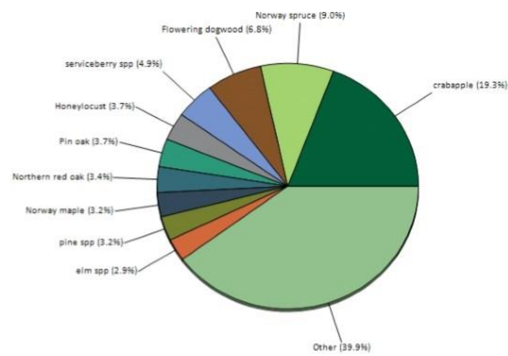

Figure 34 Yale School of Medicine, Species Distribution, i-Tree, Medical, 2020)

Yale School of Medicine Campus Soil Samples

There were no soil samples drawn from the Yale School of Medicine Campus. The area is varied, with smaller established planting beds and open managed areas of established lawn, new areas, and current construction.

Yale School of Medicine Campus Ecosystem

i-Tree Analysis

The i-Tree analysis for Yale School of Medicine Campus is based on inventoried trees within the managed area and excludes street trees that are considered City of New Haven trees. There is a difference of three trees between the 409 analyzed from the i-Tree Analysis and the 412 trees inventoried. This is most likely the result of the data that were submitted by the consultants and unknown variation in data interpretation by the i-Tree model.

The most common species are 79 crabapple (*Malus species),* 37 Norway spruce (*Picea abies*), and 28 flowering dogwood *(Cornus florida).* The most populous group of 79 crabapple trees sequestered just over 550 pounds of carbon. Despite the smaller stature, usually under 25 feet, the high number of 79 crabapples accounts for the largest percent leaf area at 10.9 percent (i-Tree Eco Analysis, Yale School of Medicine Campus 2020).

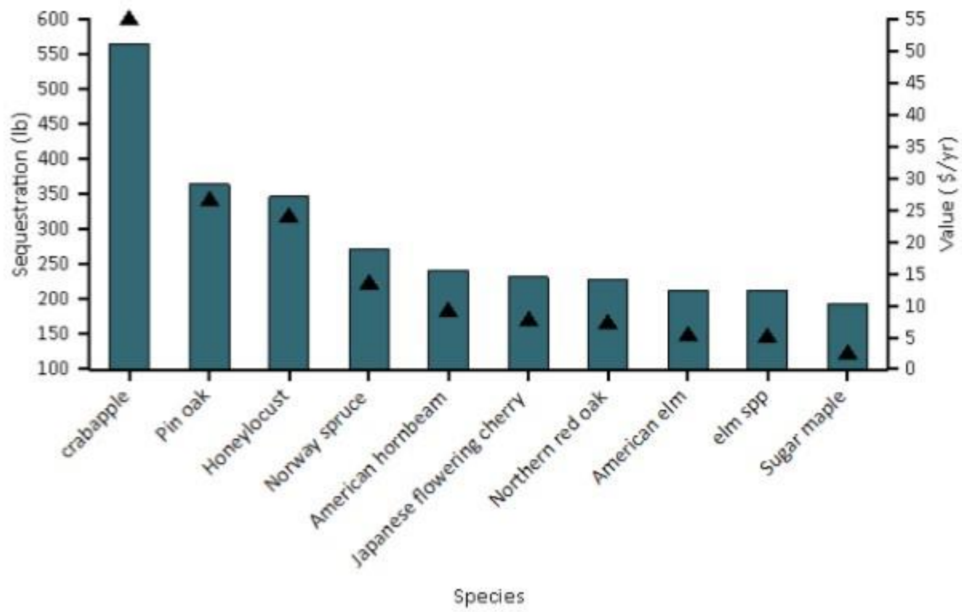

Figure 35 Carbon Sequestered Quantity and Value, School of Medicine, (i-Tree, 2020)

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $334,000 for 409 trees, with tree cover of 1.959 acres within 36 acres. This is considerably less than the other campus areas, primarily due to the smaller-acreage, high-density parcel of Yale School of Medicine Campus. The i-Tree results of the values demonstrate that generally trees of greater size, quantity, and increased environmental value also increase structural and eco-value (i-Tree Eco Analysis, Analysis Yale 2020).

Avoided Stormwater Runoff

Avoided storm water runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with Yale School of Medicine Campus trees such as the crabapple (*Malus species*) capturing the highest quantity of runoff, at just under 300 cubic feet a year, and Norway spruce (*Picea abies*) capturing just under 250 cubic feet of avoided runoff (i-Tree, Yale 2020–Medical). The total avoided stormwater runoff of 2,801 cubic feet a year is based on an associated value of $190. The avoided runoff also reduces the extent of surface erosion and soil lost.

Climate Resilience

Yale School of Medicine Campus has certain components and conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher

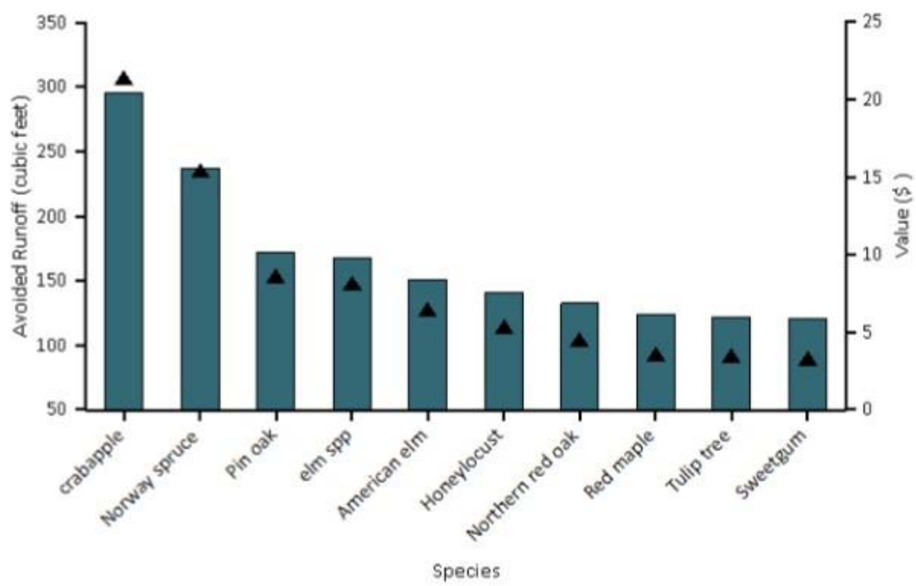

Figure 36 Avoided Runoff and Value, Yale School of Medicine, (i-Tree 2020)

temperatures, severe weather and wind events, and invasive pests and plants add considerable challenges to a plant's vitality.

The large area of parking lot space and associated storm drainage system (drainage) do not allow water to permeate into the ground. Naturally occurring water is diverted from absorption into the ground due to the impermeability of the asphalt surface. Though most areas of the managed lawn are irrigated, the depth and permeability of irrigated water to reach tree roots is extremely limited. At times of severe drought, it is not practical to provide enough irrigation for numerous roots located two feet deep and extending well past the edge of tree canopies.

The campus has several small groups of monoculture plantings consisting of crabapples (*Malus species)* and elm species (*Ulmus species)*. There are groups of these species in planting beds and, to a lesser degree, open turf area. Species diversity will provide protection against disease, pest, or pathogen susceptibility. Ideally, tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing climatic temperatures.

Oxygen Production

Yale School of Medicine Campus trees contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees (see Nowak, 2007).

The campus's top producer of oxygen, according to the i-Tree Analysis, is crabapple (*Malus species)* at a count of 79 trees at 1,599.60 pounds. The next highest producer of oxygen is pin oak (*Quercus palustris)* at 909.69 pounds, though with a count of only 15 trees.

Canopy and Air Pollution

A tree canopy is the tree's components such as leaves, branches, and stems that cover the ground beneath the tree. Yale School of Medicine Campus has one distinct canopy cover within the managed area, consisting of individual trees planted in open turf areas and planting beds usually located adjacent to the buildings.

The managed area canopy cover provides cover from heavy rains by breaking the fall of precipitation. It also provides cover from the solar rays that would otherwise heat open ground contributing evaporation and water loss. The 409 trees provide a tree cover area of 1.959 acres.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed area according to the i-Tree Analysis is 103.6 in a year with ozone being the largest the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser count pollutants. (i-Tree Analysis, Yale School of Medicine Campus, 2020). It is safe to assume that the benefits pertaining to air pollutant removal would be increased. Most of the air pollutants removed are linked to health problems (Hirabayashi, Nowak, 2016).

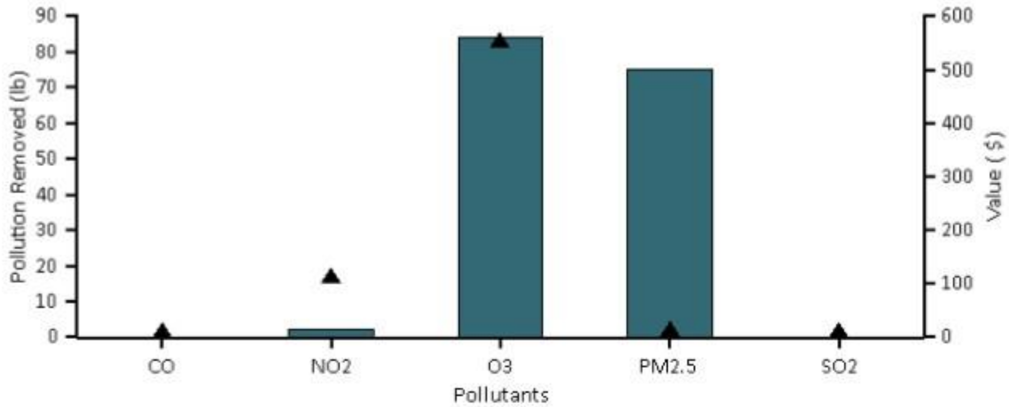

Figure 37 Yale School of Medicine Avoided Runoff and Value (i-Tree, 2020)

Yale School of Medicine Campus Tree Valuation

The Yale School of Medicine Campus valuation total for the inventoried tree population is $873,000. The figure was calculated from a total of 412 trees inventoried using the cost approach explained below. (See Tree Inventory Valuation Calculation, Appendix 2).

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10^{th} Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The i-Tree formulae provides this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs (See Appendix 8 Sample i-Eco Report).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated "added value".

Treble values could be used for individual trees within specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). It is suggested that a determined bond value be set by the university when construction occurs within root protection areas. This will only provide incentive to protect the tree as actual tree replacement is not practical, reasonable, or feasible for such unique trees. The legal system often determines such specific cases on a case by case basis as there are no accepted industry standards in these cases.

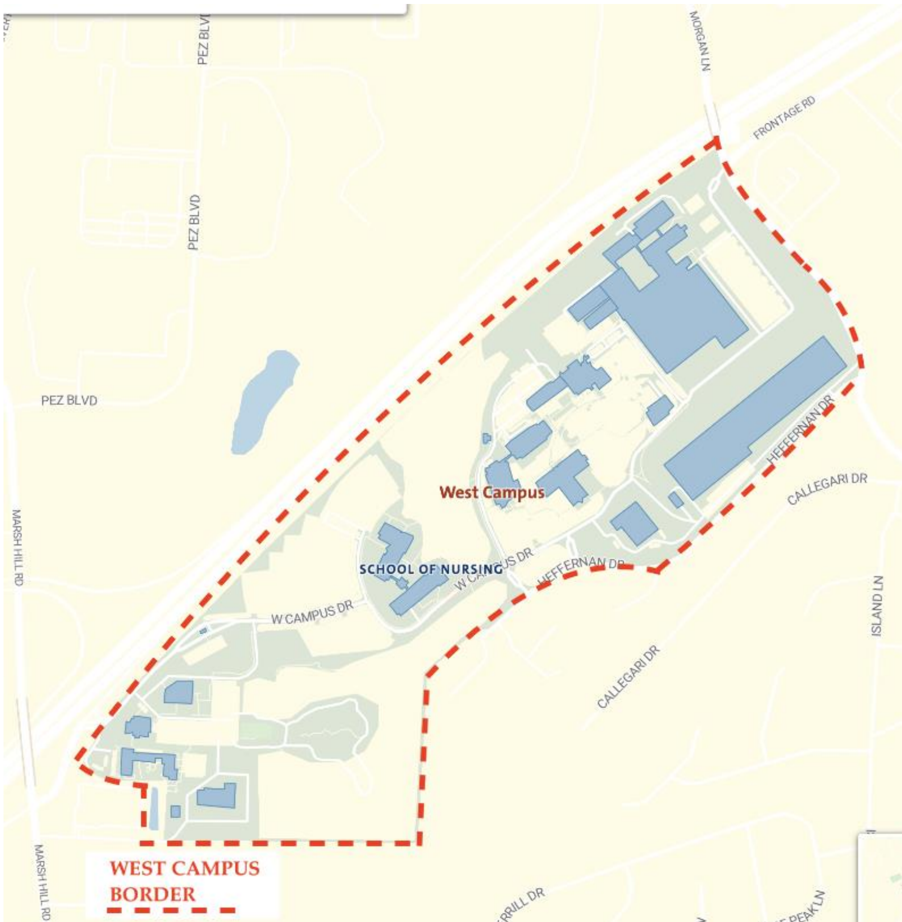

Figure 38 West Campus Border

WEST CAMPUS

Overview

The West Campus site is unique. The 136 acre campus parcel runs parallel to the south side of Interstate 95. Of the 136 acres, approximately 35 acres were treated as forest and surveyed accordingly with sample plots. The campus is gated and has no public streets or sidewalks and is well outside the city of New Haven by approximately seven miles, lying in the towns of West Haven and Orange. The campus is in an area where there are no public city trees, sidewalks, or city trees. There are several significant commercial buildings constructed by the previous corporate owner. Used by Yale students and staff in the nursing school and research facilities, the buildings and access drives are framed by managed areas

Figure 39 West Campus Satellite View of Border

consisting of planting beds, lawn, and trees that in turn are bordered by three-plus decades old post-disturbance forest.

Some approximate 101 acres of managed campus areas have renovated buildings with newly installed landscapes consisting of trees and shrubs in mulched planting beds bordered by lawn areas.

Other areas of the campus have well-established landscapes with trees large and small in variety, bordered by bands of forested areas. There are several ash trees in managed areas that are undergoing preventative treatment for the invasive insect emerald ash borer, as well as a population of native ash in the forested area that are not under treatment. The borer primarily feeds in the vascular system on ash trees and, at times, on fringe tree (*Chionanthus virginicus),* usually resulting in mortality.

There are forested areas with trails that incorporate a stream entering the property from the northern property border via a large culvert under Interstate 95. The stream meanders on a gentle downward slope in a southerly direction through a post-disturbance land of native forest where poplar, beech, maple, ash, oak, red maple, and birch have been establishing from what appears to be the last three to four decades.

A few evergreens are found in the naturally occurring reclaimed areas, as well as signs of wildlife; the consultants observed wild turkey with their young, deer, and numerous stream-side tracks of raccoon, fox, and others.

A sugar shack for processing maple syrup is in a clearing in the wooded area on the southern portion of the campus. The area has informational signage and is used for educational purposes.

West Campus Forested Areas

The approximately 35-acre hardwood forest bisects the remaining managed 101 acres of West Campus. The southern length of the forest abuts Heffernan Drive, three commercial properties, and an adjacent continuation of woodland. A 10-foot-high chain link fence borders the southern property line, with Amtrak train service visible within the adjacent bordering property. A narrow, marked trail with a small bridge and inconspicuous educational signage meanders somewhat parallel to the stream and appears to have minimal foot traffic, although the site was observed during December 2019. There are also a few scattered, nonfunctioning upright lamp posts that remain from a previous, unknown use.

The forested area has a winding, south-flowing rocky moraine streambed, the Oyster River, that accesses the property via an eight-plus-foot pipe under the adjacent Interstate 95 highway. Culverts on either side of the pipe funnel runoff into the waterway. The stream depths vary from six inches to two feet, with widths ranging from five to 20 feet. The west side of the streambed is flanked by a steep slope of varying degree that was created during initial construction grading. Portions of the west-facing aspect along the northeast quadrant of the forest are populated with established Russian olive and crabapple plants, while the west-facing aspect on the less-disturbed southeast quadrant has larger mixed hardwoods with a mixed invasive understory.

The quadrant to the northwest of the streambed gradually rises from a relatively flat overflow wetland, transitioning from mixed hardwoods to numerous pockets of 2- to

4-inch caliper American beech interspersed with larger oaks. The understory plants are mixed natives with smaller pockets of invasive barberry and wild rose.

Forested Area Designations A-D

The forested area was broken into four designated zones: A (approximately 11 acres), B (17 acres), C (3 acres), and D (4 acres), as noted on the West Campus map, with other areas in green generally considered managed areas (see map below).

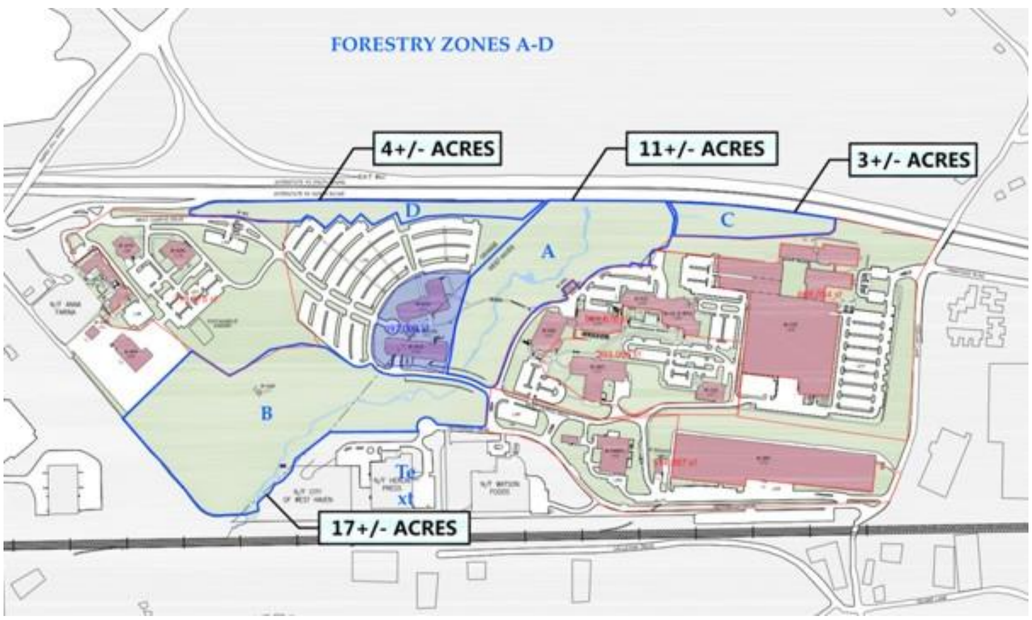

Figure 40 Forestry Zones A - D West Campus

Forestry Plot Sampling

Figure 41 Isabelle Zaffetti Measuring DBH

Approximately 10 percent of each parcel was sampled using 1/10-acre sample plots. These were a circle with a radius of 37.24 feet. The number of plots was ultimately determined by the woodland homogeneity of the parcel.

The sample plot center point locations were geo-coded and associated with individual trees. A temporary pin was placed at each plot center point. Within each plot, all trees with a diameter of eight inches or greater were individually recorded for species, diameter, condition, and attributes that are unique to the tree. An observational narrative was also made for vegetation under four inches. This narrative included observations on seedling and sapling presence, invasive plants, and any unique forbs encountered.

Walk-Through Survey

The walk-through survey is a thorough traverse of the entire parcel. Its purpose is to identify unique, significant trees that the sample survey may miss. The project team conferred with Yale staff during the pre-inventory meeting to confirm the parameters for identifying a tree as "significant." Examples include wildlife habitat, unique species, culturally significant, and so forth. The trees, when encountered, were GPS-mapped.

Data collected included species, diameter, condition, observations about the quality of the tree, and recommended care.

Forestry Center Plot Points

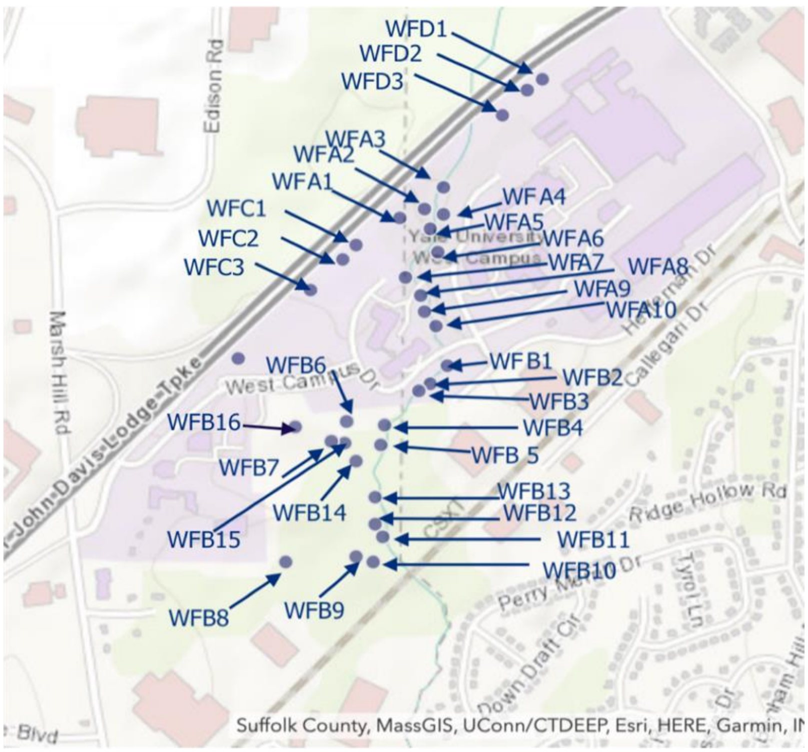

Figure 42 West Campus Forestry Center Plot Points

Center plot points were geo-recorded as inventoried, individual trees geo-identified as item F on the data collection for forested areas in West Campus. The locations are recorded on the map as taken directly from the Yale ArcGis platform, and are the locations of the center plot points WFA1-WFA11), WFB1-WFB16, WFC1-WFC3, and WFD1-WFD3 where WFA stands for West Forestry Zone A, etc.

Zone A

The northern forested edge of area A has a higher gradient that is susceptible to rainfall erosion during high-precipitation events, as evidenced by sporadic brookside scouring. A few invasive species of Norway maple trees, along with small pockets of green briar, wild rose, and honeysuckle, dominate the understory.

Areas of thick underbrush and swampy ground make traversing the plots challenging. Some shrubby clusters of box elder, highbush blueberry, and invasive Russian olive comprise the mid-story. Most trees with a diameter at breast height greater than eight inches included tulip trees, oaks, and birch. There are some emerging beech stands that will become more prevalent in the landscape in the next 10 years.

With trees producing a healthy harvest of beechnuts and acorns, there was plenty of wildlife food. Deer tracks were present through the plot, particularly in the muddy areas around the running creek. A chain-link fence runs through portions of the western edge, preventing wildlife from freely wandering the area. Many kinds of wildlife can jump or fly over the fence, but it is still a deterrent to natural wildlife corridors.

An established trail wanders through plots A and B, with entry points near the nursing school and parking lot. The survey was conducted in December 2019, and while few individuals were seen on the trails, once the weather is more temperate, more trail activity is anticipated.

Zone A Species Distribution

The following sample plot results are for the forestry survey for species count (see Abbreviations). Note: All plot survey areas also had soil samples collected from them. (See Soil Test Results, Appendix 3.)

WOODLAND PLOT POINTS ZONE A SPECIES COUNT (WFA stands for West Forestry Zone A, sample 1, etc.):

WFA1 (West Forestry Zone A, Sample 1).

Mature Tree Species: 4 - Bl (5), Ba (4), Lt (2), Qr (1)

WFA2.

Mature Tree Species: 6 - Lt (4), Ba (3), Qr (2), Ar (2), Qa (1), Fa (1)

WFA3.

Mature Tree Species: 8 - Qa (3), Pd (2), Ps (1), Fa (1), Co (1), Fg (1), Ar (1), Qb (1)

WFA4.

Mature Tree Species: Qr (10), Lt (5), Ba (2), Qa (1), Fa (1), Bl (1), Ar (1)

Burning bush and crabapple clutter the shrub layer.

Five-year Projection: Green ash saplings will continue to fight for understory

WFA5.

Mature Tree Species: Fg (4), Bl (3), Qr (1), Ba (1)

WFA6.

Mature Tree Species: Lt (4), Qr (3), Bl (2)

WFA7.

Mature Tree Species: Lt (5), Qa (3), Bl (1), Qv (1)

WFA8.

Mature Tree Species: Lt (9), Bl (4), Qr (3)

Five-year Projection: A stand of American beeches will become more prevalent.

WFA9.

Mature Tree Species: Lt (10), Bl (2), Qa (1) Qr (1), Ba (1)

Five-year Projection: A stand of American beeches will become more prevalent.

WFA10.

Mature Tree Species: Lt (16), As (1), Sa (1), Bl (1)

WFA11.

Mature Tree Species: Lt (12), As (5), Qr (3), Fa (1), Qv (1), Bl (1), Sa (1)

Russian olive fills much of the bank.

Five-year Projection: Many American beech suckers will become more prevalent.

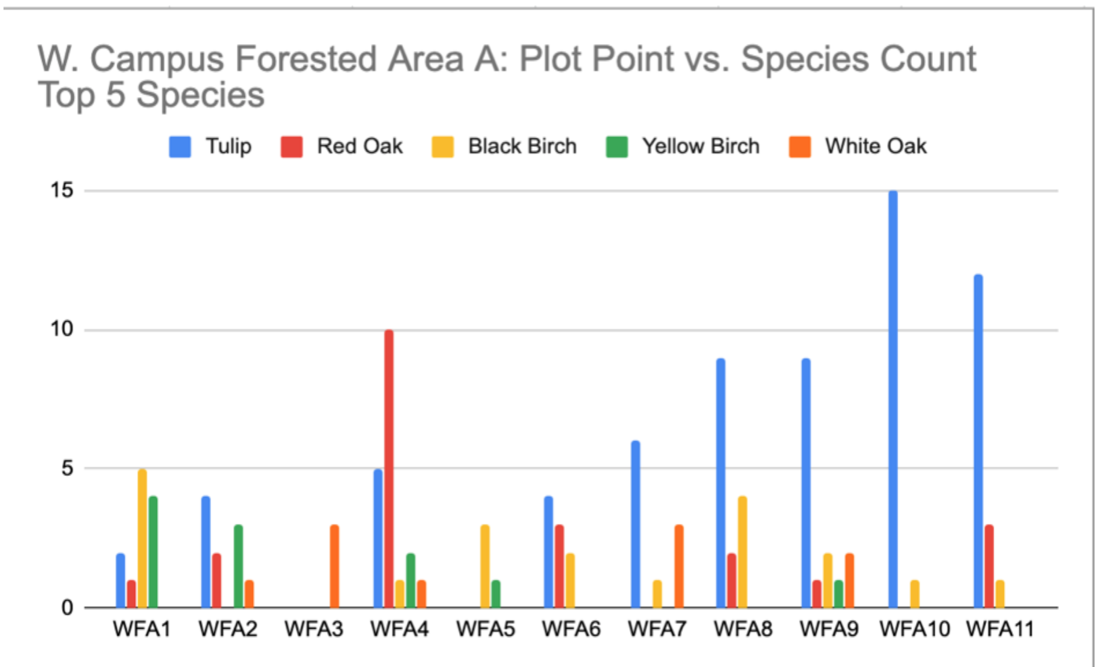

Figure 43 West Campus Plot Points Area or Zone A Species Count

Zone B

Situated south of the main West Campus roadway, Zone B is connected to Zone A by an underpass and the stream bed. This area is more varied than Zone A, as it has a steep-grade riparian catch basin, upper planes used for educational purposes, and a reclaimed forested construction depository. The natural catch basin does not have a significant percentage of invasive species, but both other areas have a primarily invasive understory and mid-story.

An interior stretch of the educational trail is the site of a sugar house for the manufacture of maple syrup, with the capacity to shelter a limited number of individuals. Another part of the trail also shows the negative effects of Japanese knotweed as part of an ongoing study for control of the invasive plant.

The Oyster River continues south through Zone B to a gentle, lower gradient. The adjacent west-facing aspect generally slopes steeply up in an easterly direction to the top of the grade. A small stand of six to seven large ash trees (*Fraxinus americana*) occupies the southern end of Zone B adjacent to the Western flatlands by the river. They show no outward apparent signs of emerald ash borer infestation.

A male and female deer as well as a large flock of turkeys were observed at the time of the survey. Numerous unknown waterside animal tracks were also visible.

The remaining southwest portion of the property is a limited area (approximately three acres) that was relatively free of trees. It was populated by a mix of three- to four-foot perennial growth and a border stand of invasive, dying Russian olive (*Elaeagnus angustifolia)* that had established on multiple four- to five-foot mounds of closely spaced excavation spoils.

Zone B Species Distribution

The following sample plot results are for the forest survey for species count Note: All plot survey areas also had soil samples collected from them (see Soil Test Results, Appendix 3.)

WFB1. (West Forestry Zone B, Sample1)

Mature Tree Species: Lt (5), Pd (2), Qv (2), Fg (1), As (1)

WFB2.

Mature Tree Species: Qa (6), Qr (2), Pd (2), Fg (2), Ar (1)

WFB3.

Mature Tree Species: Fg (3), Qa (2), Cg (1), Lt (1), Qr (1)

WFB4.

Mature Tree Species: Ar (3), Bl (2), Fa (1), Fg (1), Qa (1)

Five-year Projection: Young Ironwood

WFB5.

Mature Tree Species: Ar (5), Fg (1), Qa (1), Qr (1)

Five-year Projection: This swampy area has pockets of privet, grapevines, and honeysuckle. They will continue to spread along the ground and beat out other native saplings and shrubs for sunlight.

WFB6.

Mature Tree Species: Ar (5), Qa (2), Ba (1), Bl (1), Lt (1), Pd (1)

WFB7.

Mature Tree Species: Ar (3), As (3), Lt (1), Qa (1)

WFB8.

Mature Tree Species: Ar (2), Bl (2), Qr (2), Ea (1), Ap (1), Fg (1), Ps (1), Qa (1)

Five-year Projection: Despite this healthy diversity of trees, some Russian olive has snuck into this area from the nearby material deposit. Wild rose, winterberry, and barberry clutter the understory with thorny invasives. There is an occasional spicebush, but they may be choked out within the next couple years.

WFB9.

Mature Tree Species: Pd (16), Ea (3)

Five-year Projection: This site was an old material deposit. There is an access road along the edge of Yale's property that is steep and salted. This will kill most native forest trees. Old metal chunks and concrete slabs clutter the area. It is dense with invasive Russian olive. Stringy poplars shoot upward, fighting for resources. This area will continue its progression of invasive overload.

WFB10.

Mature Tree Species: Qa (2), Ar (1), Ea (1), Pd (1)

WFB11.

Mature Tree Species: Ar (1), Co (1), Fa (1), Lt (1), Qa (1), Qr (1), Qv (1)

Five-year Projection: Broken black cherry trees have started to collapse, creating pockets of sunlight. Wild rose has taken advantage of the light. This invasive species may continue to develop in the understory.

WFB12.

Mature Tree Species: Ar (3), Qa (2), Lt (2), Cc (1), Cg (1), Qv (1)

Five-year Projection: This area is relatively open on the forest floor, with healthy fern beds and smaller native trees. A few young hophornbeam and ironwood trees will continue to grow into the mid-story.

WFB13.

Mature Tree Species: Qr (2), Ar (1), Lt (1), Ov (1), Qa (1)

Five-year Projection: This area was previously a material deposit. There are tires and bricks dumped throughout the site. This is preventing a healthy understory or new sapling growth, but previously developed mature trees do not seem to be affected.

WFB14.

Mature Tree Species: Fa (3), Qa (3), Ar (2), Fg (2), Lt (1), As (1), Qr (1)

Five-year Projection: This area has a grove of mature white ash. With the impending infections of emerald ash borer, unless treated, this grove will die and fall, leaving large open swaths of canopy. This may encourage a new shrub layer to develop.

WFB15.

Mature Tree Species: Ar (2)

Five-year Projection: This open area is filled with phragmites and knotweed, both invasive weeds. The trees stand alone and have extremely limited chance of successful sapling growth in such an aggressive understory. This area will likely continue as it is currently.

WFB16.

Mature Tree Species: Ar (5), Fa (3), Fa (2), Qr (1)

Five-year Projection: Bittersweet vines, which can grow as much as 15 feet in a year, are currently hanging off some of these trees. If left to continue, the vines may pull down some mature trees and continue to propagate more saplings along the forest floor.

WFB17.

Mature Tree Species: Aa (2), As (2), Ms (1), Qa (1)

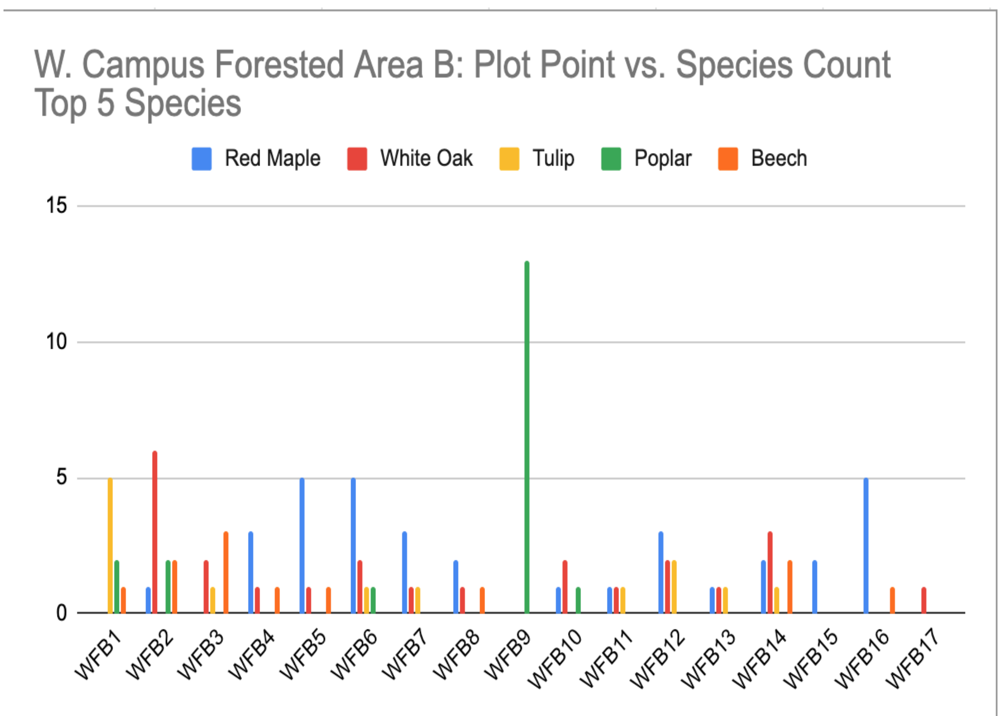

Figure 44 West Campus Area or Zone B Species Count

Figure 45 West Campus Forrestry Zone B

Above: Zone B trail taken 12/13/19. This visual shows the trail system meant for educational development. The signs have information regarding different species of flora, fauna, and what the land is being used for. A nearby sugar house attracts people to this trail system. The understory here is invasive knotweed, as depicted on the sign. The aggressive shrub prevents other species from establishing in the area (Zaffetti, 2019).

Zone C

This zone is situated parallel to Route 95 northbound on the eastern side of campus. The area is bisected by a drainage culvert that appears to have been installed during I-95 construction.

An eight-foot-high chain link fence separates the plot from the adjacent northbound Interstate 95 highway. The culvert bed is bordered by several native species, as well as Norway maple, invasive rose, green briar, and minimal bittersweet. The upper bank on the building running parallel to the culvert is populated with crabapple, assorted three-foot-tall weed growth and some black cherry growth, as well as Russian olive.

The sample plots were sparsely inhabited by mixed species that were competing for light, given the lower grade and harsh, rocky growth conditions.

Zone C Species Distribution

The following sample plot results are for the forest survey for species count. Note: All plot survey areas also had soil samples collected from them (see Soil Test Results, Appendix 2.)

WFC1 (West Forestry Zone C, Sample1)
Mature Tree Species: Bl (1), Fa (2), Ar (2), Qr (2)
WFC2.
Mature Tree Species: Bl (1), Fa (3), Ar (1)
WFC3.
Mature Tree Species: Ar (6)

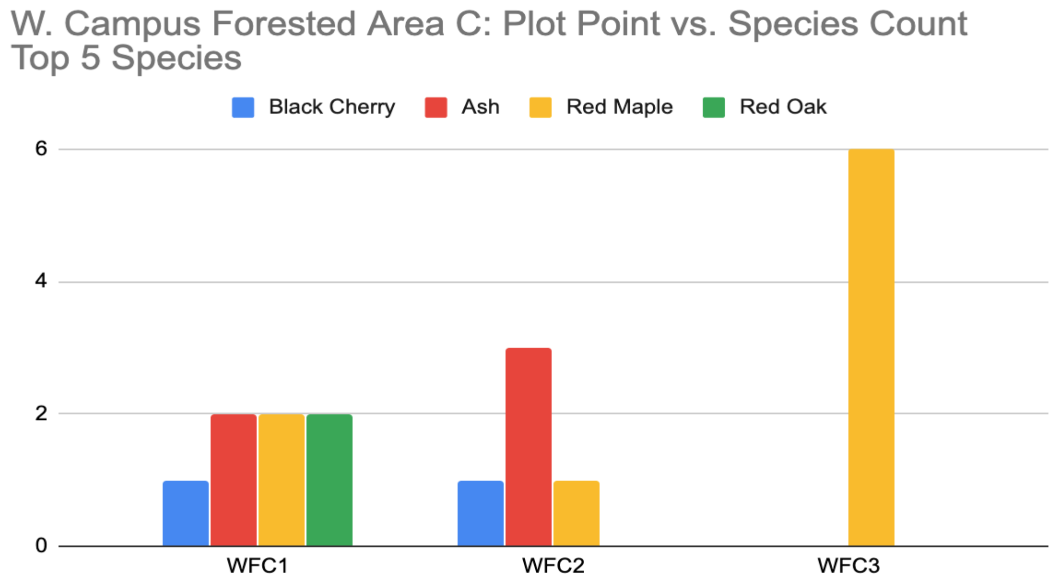

Figure 46 West Campus Forested Area or Zone C Species Count

Zone D

Zone D is situated parallel to Route 95 northbound on the western side of campus. The area is also bisected by a drainage culvert that appears to have been installed during I-95 construction. The culvert bed is bordered by several native species, as well as Norway maple, invasive rose, green briar, and minimal bittersweet, black cherry, and some white birch.

The sample plots were sparsely inhabited by mixed species that were competing for light, given the lower grade and harsh rocky growth conditions. The terrain, border fence, and grade created a barrier to wildlife, as well as to humans who might consider traveling there.

Zone D Species Distribution

The following sample plot results are for the forest survey for species count. Note: All plot survey areas also had soil samples collected from them (see Soil Samples below).

WFD1.

Mature Tree Species: Qv (1), Qr (1),

WFD2.

Mature Tree Species: Qv (2), Qr (2),

WFD3.

Mature Tree Species: Ar (2)

WFD4.

Mature Tree Species: Ar (10), Qv (1)

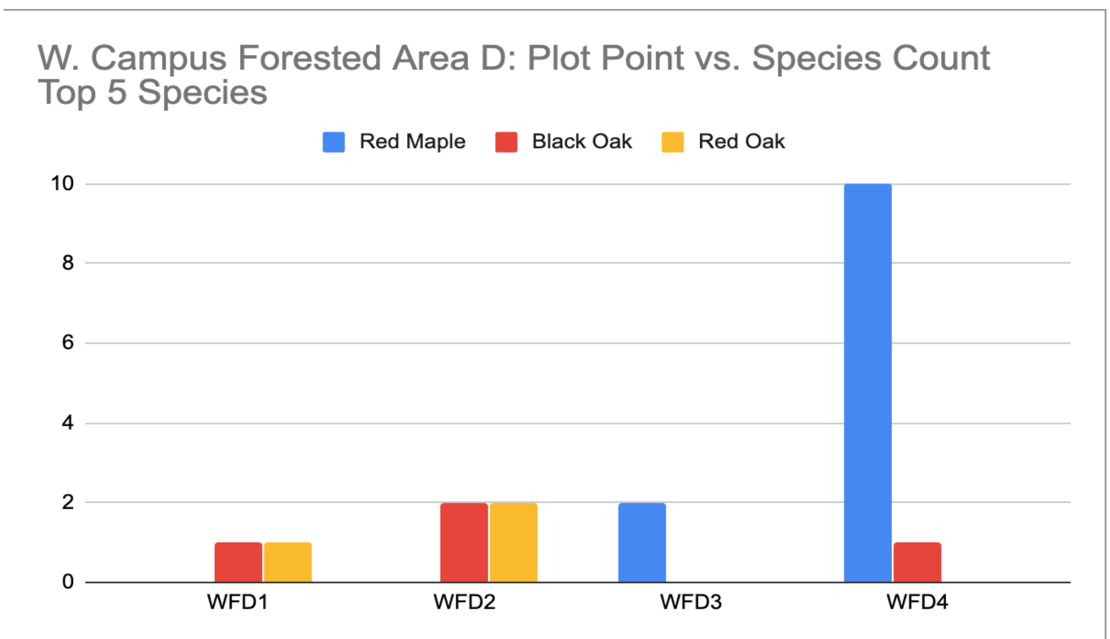

Figure 47 West Campus Area or Zone D Species Count

West Campus Soil Samples

Managed Areas

Soil samples were taken from eight sample plots selected as representative of the general physical conditions: planting beds, and turf area. The samples were collected from the upper eight-inch soil A horizon (2015, Penn State) using a 24-inch ADS soil core sampler and tested using a standard nutrient analysis (Morgan Method performed by Connecticut Agricultural Experiment Station). The results vary, most likely due to construction activities, previous lawn treatments, or heavily irrigated sectors.

The consultants recommend establishing a general baseline reference, as opposed to using the results for establishing fertilization (or other) treatment rates (see Appendix 3) for adjacent trees. Any future specific tree needs should be tested independently from the current results.

Forested Areas

Forested areas were determined by Yale University Office of Facilities. The forested areas were in West Campus and Athletics Campus. The consultants collected soil samples from the 8-inch (A-horizon) depth using a 21-inch AMS soil borer. The areas were selected after initial onsite review; selection was determined by the character of the plot (grade, water course, existing vegetation) while recognizing relative consistent spacing between collection points. The plot points were representative of the overall character of the sample region.

Three samples evenly spaced (12.4 feet apart) were taken from a southern to northern (magnetic) line within a 37.24-foot radius and combined for one soil sample. The samples were delivered to the UConn Soil Nutrient Analysis Laboratory for analysis.

The consultants chose the UConn Soil Nutrient Analysis Laboratory primarily for its ability to test for percent soil organic material (SOM) using the carbon loss on ignition test in addition to a basic nutrient analysis. New England soils are usually in the 2 to 4 percent range and generally no higher than 8 percent (UMASS rev. 2013). Higher soil organic matter is an indicator of the soil's ability to hold large amounts of water, or that a higher water table is present. Soils with higher levels of organic content are also able to store more nutrients, are less likely to erode, and better minimize the likelihood of compaction. Most of the soil samples indicated high levels of soil organic matter (see Forest Samples, Appendix 3b). The soil test results are recommended as a baseline reference.

West Campus Ecosystem

i-Tree Analysis

The i-Tree analysis for West Campus is based primarily on inventoried trees within the managed area. The woodland area was surveyed with 33 total plot points where only the center points (individual trees) were geo-located and recorded. The trees found within the survey plot area were only manually recorded and not geo-located. Trees within the remaining 35-acre forest outside the plot survey zone were not included in the i-Tree data submittal; this accounts for why there is only an i-Tree canopy cover listed at 4.637 acres, with a total of 19.91 acres of leaf area (i-Tree Ecosystem, Analysis Yale 2020).

The most common species are 118 crabapple (*Malus species),* 84 sugar maple *(Acer saccharum),* and 83 red maple *(Acer rubrum)*. Despite there being 118 crabapple trees, their annual totals of values and sequestered carbon are noticeably less than sugar maples, red maples, and pin oak. The trunk, branch, and leaf area is considerably smaller on crabapples than those of the taller and much larger maples and oaks, proportionately reducing their contribution, of which 32.4 percent of the inventoried trees are less than 6-inch caliper (i-Tree Eco Analysis, Analysis Yale 2020). “Other” is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

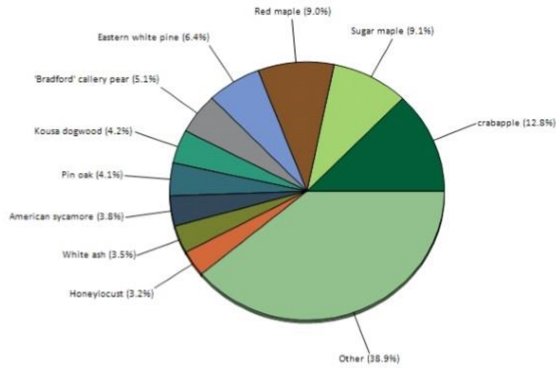

Figure 48 West Campus Species Count (i-Tree, 2020)

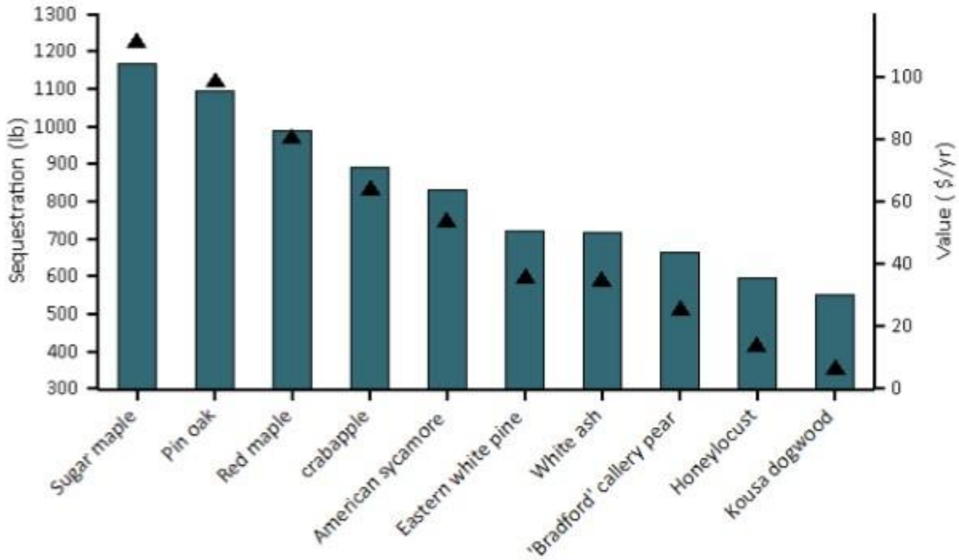

Figure 49 West Campus Carbon Sequestration and Value

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) for West Campus is $814,000 for 925 trees with tree cover of 4.637 acres within 101 acres. This is considerably less than North Campus, which has a comparable 100 acres. North Campus does have 3,041 trees, a tree cover of 25.01 acres, and a structural value of $5.12 million. West Campus, however, has a similar-sized area with a smaller quantity of trees, a smaller size of tree, and less overall structural value. The i-Tree results of the values demonstrate that, generally, trees of greater size, quantity, and increased environmental value also increase structural and eco value (i-Tree Eco Analysis, Analysis Yale 2020).

Avoided Stormwater Runoff

Avoided stormwater runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with West Campus trees such as the sugar maple and red maple able to capture the most cubic feet of avoided runoff, despite having lower-count numbers than the higher-count crabapples with their smaller leaf surface (i-Tree, Yale Analysis 2020). The avoided stormwater runoff also lessens the extent of surface erosion and soil lost.

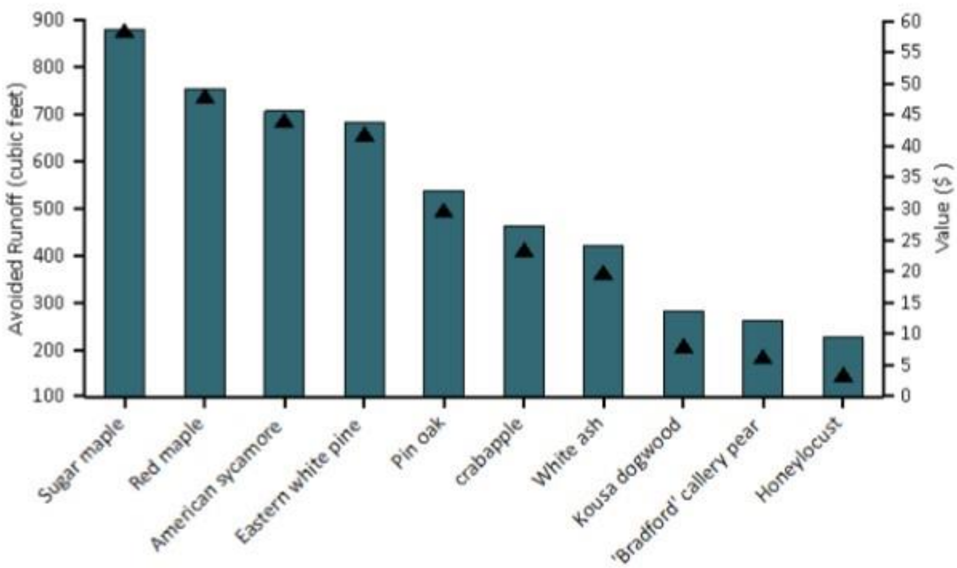

Figure 50 West Campus avoided Stormwater Runoff and Value

Climate Resilience

West Campus has certain components and conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures, severe weather and wind events, and invasive pests and plants are considerable challenges to a plant's vitality. The large area of parking lot space and associated storm drainage system does not allow water to permeate into the ground. Naturally occurring water is diverted from absorption into the ground due to the impermeability of the asphalt surface. Though most areas of the managed lawn are irrigated, the depth of tree roots and surface impermeability limits irrigated water's ability to reach *the roots. At times of severe drought, it is not practical to provide enough irrigation for numerous roots located two feet deep and extending well past the edge of tree canopies.

West Campus has numerous monoculture plantings consisting of crabapples (*Malus species),* white ash (*Fraxinus americana),* sugar maple (*Acer saccharum),* and elm species (*Ulmus species),* planted in rows and groups.

Two of these species are currently under treatment for the invasive insect pest emerald ash borer (ash) and Dutch elm disease (elm). The remaining sugar maples are susceptible to the invasive Asian longhorned beetle. These monoculture scenarios expose a high number of trees to potential pests and disease while increasing preventative maintenance costs. Ideally, tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing temperatures

Oxygen Production

West Campus trees in managed areas contribute to oxygen production released into the atmosphere. More important, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees.

On West Campus, the top producer of oxygen according to the i-Tree Analysis is sugar maple (*Acer saccharum)* at a count of 84 trees at 3,258.62 pounds. The next highest producer of oxygen is pin oak (*Quercus palustris)* at 2,979.65 pounds, with a count of only 38 trees.

Canopy and Air Pollution

A tree canopy consists of components such as leaves, branches, and stems that cover the ground beneath the tree. West Campus has two distinct canopy covers: managed and woodland.

The managed area canopy cover is relatively sparse compared to the woodland area. The former's canopy is defined by individual trees, due to the open ground between trees. while the latter tends to be a contiguous canopy providing overlapping branch cover between adjacent trees.

The woodland area canopy cover provides cover from heavy rains by breaking the fall of precipitation. It also offers cover from the solar rays that would otherwise heat open ground, contributing to evaporation and water loss.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed area according to the i-Tree Analysis is 248 pounds in a year, with ozone the largest portion of removed pollutants, out of carbon dioxide, nitrogen dioxide, and other lesser count pollutants. (See i-Tree Analysis, West Campus, 2020.) This does not include the predominantly deciduous forest area in the woodland. It is safe to assume that the benefits pertaining to air pollutant removal would be increased. Most of the air pollutants removed are linked to health problems.

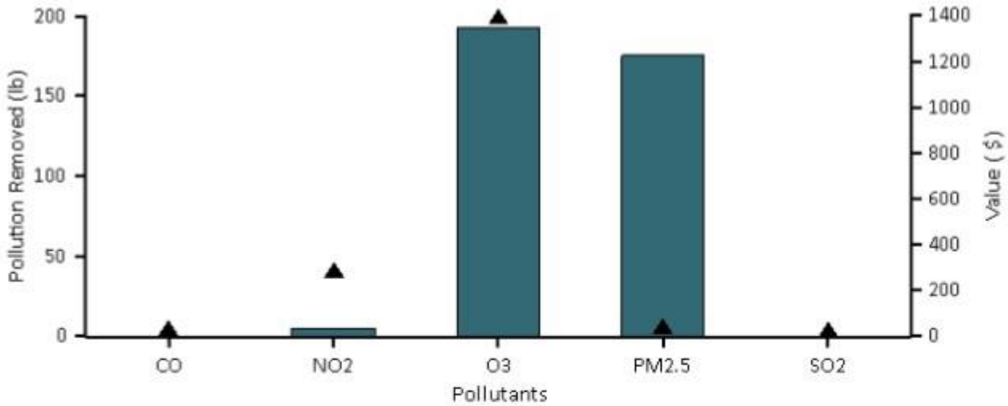

Figure 51 West Campus Pollutants Captured and Value

West Campus Tree Valuation

The West Campus valuation total for the inventoried tree population is $2,433,082.31. The figure was calculated from a total of 966 trees inventoried using the cost approach explained below (see Tree Inventory Valuation Calculation, Appendix 2).

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The i-Tree formulae provides this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear, and meeting tree watering needs (See Appendix 8 Sample i-Eco Report).

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated "added value".

Treble values could be used for individual trees within specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). It is suggested that a determined bond value be set by the university when construction occurs within root protection areas. This will only provide incentive to protect the tree as actual tree replacement is not practical, reasonable, or feasible for such unique trees. The legal system often determines such specific cases on a case by case basis as there are no accepted industry standards in these cases.

ATHLETICS CAMPUS

Overview

Athletics Campus is located approximately two miles to the west from South Campus. It is bisected by Central Avenue and Yale Avenue and bordered by Chapel Street to the north and Derby Avenue to the south. There are varying densities of use of tennis, softball, baseball, and football activities, supported by large open spaces of managed athletic turf fields connected by primarily level, open lawn areas.

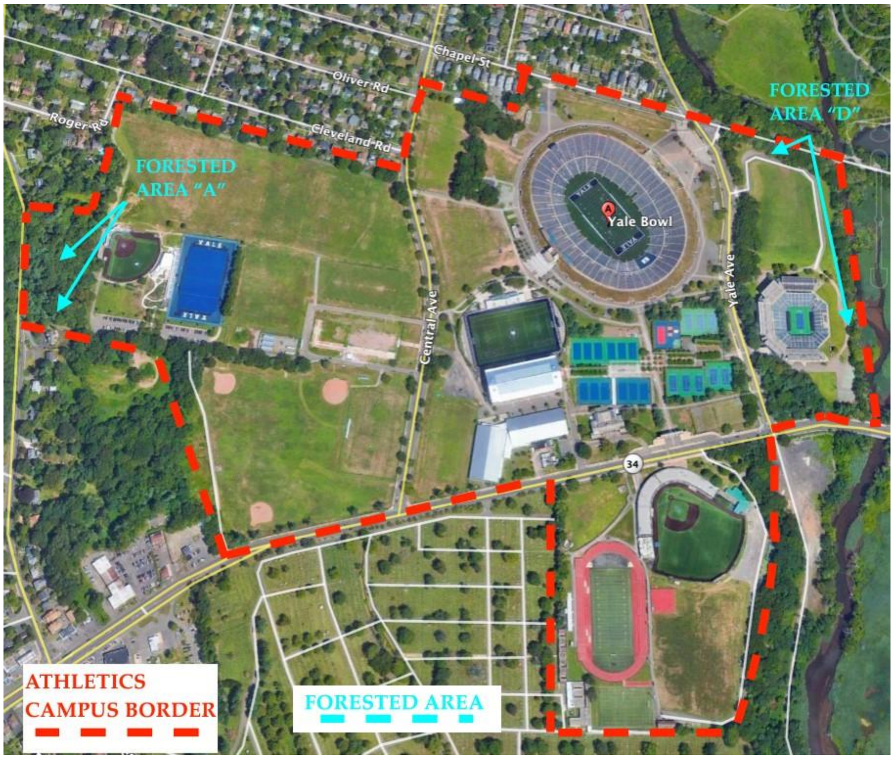

Figure 52 Athletics Borders Satellite Map View

Figure 53 Athletics Campus Border Map

The largest structure is the Yale Bowl stadium on the southern side of Chapel Street. Four athletic offices and supporting facilities are to the south of the Yale Bowl and just north of Derby Avenue. The Connecticut Tennis Center is to the east of Yale Avenue and the baseball stadium, Yale Field, is located to the south of Derby Avenue. It is interesting to note that portions of the open lawn nonathletic space serve as a parking area during heavily attended events.

Athletics Managed Area

Tagging of each inventoried tree within the 156-acre area occurred during fall 2019 and inventorying took place from late fall 2019 into early 2020. Most trees in this area are evergreen, while the deciduous trees mostly lacked leaves, given the time of year.

Yale University trees inventoried on the campus total 785, while City of New Haven trees total 91. The campus tree population in the managed area is also a mix of established as well as new plantings. White pine (*Pinus strobus)* were the most prevalent at 173, red oak (*Quercus rubra*), the second most populous at 138, and red maple (*Acer rubrum*) third at 79. There are groups of like species established plantings of red oak (*Quercus rubra*) and white pine (*Pinus strobus*) on the edges of some property borders, as well as 21 American elms (*Ulmus americana*) adjacent to the Yale Bowl. No soil samples were taken from Athletics campus.

Athletics Campus Forested Areas

Athletics' forested areas occupy two plots totaling 8.4 acres out of the 156-acre campus. One area is on the east side of the campus adjacent to the Connecticut Tennis Center and consists of approximately 3.4 acres; it is referred to here as Zone D. The second area is on the western edge of the campus, consisting of approximately five acres, and is referred to as Zone A. All other forested areas less than 1.3 acres were addressed, with all trees over eight inches in diameter inventoried. No soil samples were taken from Athletics forested areas.

Forestry Plot Sampling

Approximately 10 percent of each parcel was sampled using 1/10 acre sample plots. The sample plots were circular with a radius of 37.24 feet. The number of plots were ultimately determined by the woodland homogeneity of the parcel.

The sample plot center point locations were geo-coded and associated with individual trees. A temporary pin was placed at each plots center point. Within each plot, all trees with a diameter of eight inches or greater were individually recorded for species, diameter, condition, and attributes that are unique to the tree. A narrative was also created for vegetation under four inches that included observations on seedling and sapling presence, invasive plants, and any unique forbs encountered.

Walk-Through Survey

The walk-through survey is a thorough traverse of the entire parcel. The purpose of the walk-through survey is to identify unique, significant trees that the sample survey may miss. The project team conferred with Yale staff during the pre-inventory meeting to confirm the parameters for identifying a tree as "significant." Examples include wildlife habitat, unique species, culturally significant, etc. The trees, when encountered, were GPS-mapped. Data collected included species, diameter, and condition; observations about the quality of the tree and recommended care were also noted.

Forestry Center Plot Points

Center Plot points were geo-recorded as inventoried individual trees geo identified as item F on the data collection for forested areas in Athletics. The locations are recorded on the map as taken directly from the Yale ArcGis platform and are the locations of the center plot points ACA1-ACA5) and ACD1-ACD4, where ACA and ACD stand for Athletics Campus A and plot location number, etc.

Zone A Species Distribution

Zone A forested area has a bordering forest with housing at either end and Forest Road (Route 122) running parallel on the west side.

The area had a number of native trees: ash (*Fraxinus americana*), white pine (*Pinus strobus*), sugar maple (*Acer saccharum*), black oak (*Quercus velutina*), black birch (*Betula lenta*), black cherry (*Prunus serotina*), white oak (*Quercus alba*), and red oak (*Quercus rubr*a). The invasive tree species were minimal, with the tree-of-heaven (*Ailanthus altissima*) and Norway maple (*Acer platanoides*) present.

The forest floor is relatively open and walkable, most likely the result of large mature trees that cast full shade on the forest floor, inhibiting understory growth. A runoff channel from road culverts slopes inward and through the forest, depositing remaining runoff into a buried culvert.

ACA1.

Mature Tree Species: Fa (1), Pi s (6), As (2), Qv (1), Bl (1)

ACA2.

Mature Tree Species: Pi s (6), As (4)

ACA3.

Mature Tree Species: As (15), Ap (1), Ar (3), Fa (1), Ps (1), Bl (1)

ACA4.

Mature Tree Species: Ap (9), As (4), Bl (1)

Invasive: Burning bush and Crabapple apparent in understory layer

Five-year Projection: Green Ash saplings will continue to fight for understory dominance.

ACA5.

Mature Tree Species: Ap (6), Ar (8), Qa (1), Qr (2), As (1)

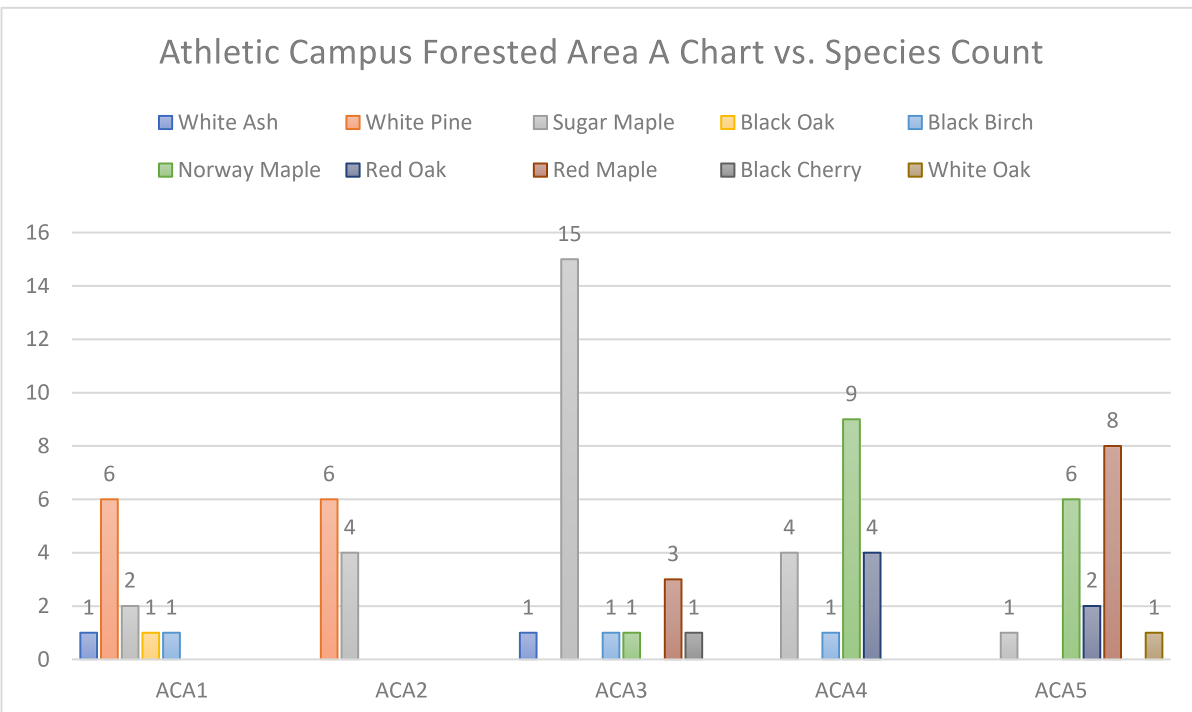

Figure 54 Athletics Campus Area or Zone A Species Distribution at Plot Points

Zone D Species Distribution

Zone D forested area has a number of native trees: red maple (Acer rubrum), red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), black oak (*Quercus velutina*), white oak (*Quercus alba*), black locust (*Robinia pseudoacacia*), box elder (*Acer negundo*), black cherry (*Prunus serotina*), elm (*Ulmus species*), eastern red cedar (*Juniperus virginiana*), eastern white pine (*Pinus strobus*), and tupelo (*Nyssa sylvatica*). Invasive plants were Norway Maple (*Acer platanoides*), and tree-of-heaven (*Ailanthus altissima*).

The understory is relatively open—most likely the result of large, mature trees that cast full shade on the forest floor, inhibiting growth.

The portions of both Chapel Street and Yale Avenue bordering the tennis stadium where Zone D is located have overhanging dead limbs from the forest border that need to be removed by bucket truck.

ACD1.

Mature Tree Species: Fa (1), Pi s (6), As (2), Qv (1), Bl (1)

ACD2.

Mature Tree Species: Pi s (6), As (4)

ACD3.

Mature Tree Species: As (15), Ap (1), Ar (3), Fa (1), Ps (1), Bl (1)

ACD4.

Mature Tree Species: Ap (9), As (4), Bl (1)

Invasive: burning bush and crabapple clutter the shrub layer

Five-year Projection: green ash saplings will continue to fight for understory.

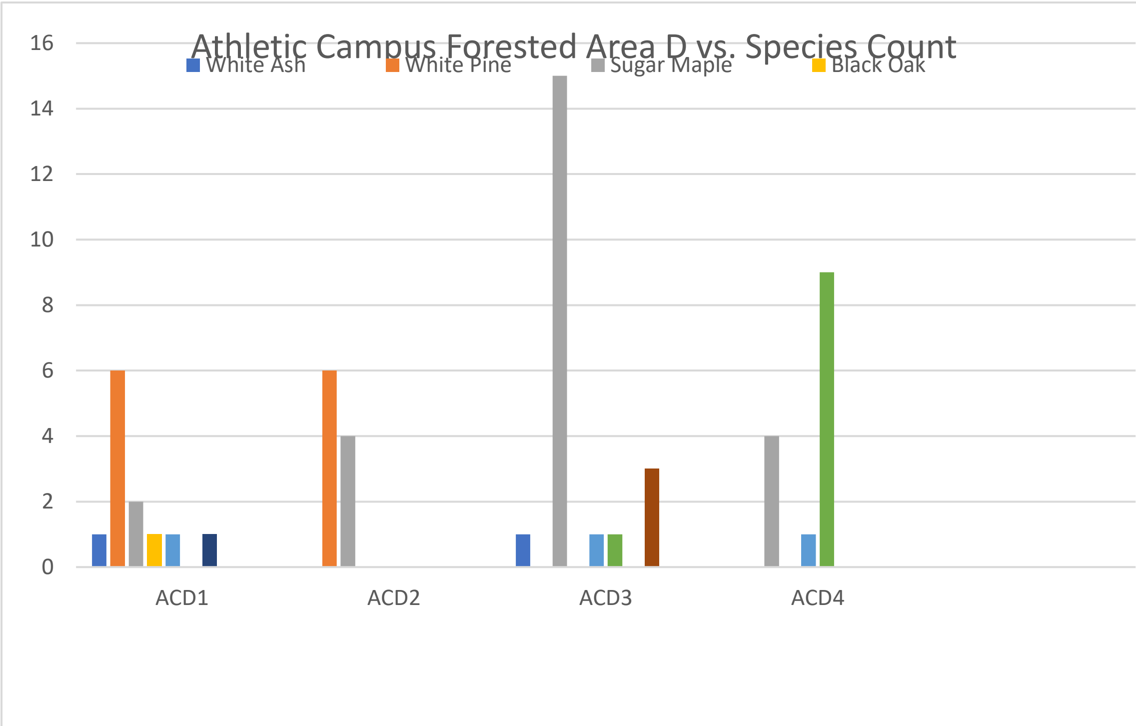

Figure 55 Athletics Area or Zone D Species Count at Plot Points

Athletics Ecosystem

i-Tree Analysis

The i-Tree analysis for Athletics Campus is based on inventoried trees within the managed area. The consultants recorded 785 tree points and i-Tree considered 768 trees when assessing the submitted data. Variation in data processing interpretation is most likely the reason for this discrepancy.

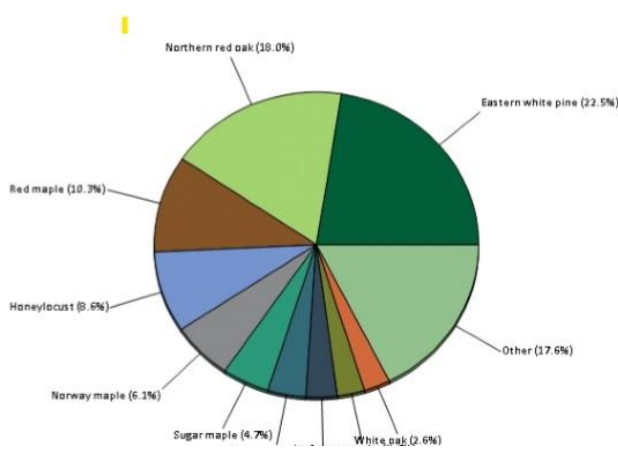

Figure 56 Athletics Campus Species Distribution (i-Tree, 2020)

The most common species is 173 white pine *(Pinus strobus),* followed by 138 red oak (*Quercus rubra*), and 61 honey locust *(Gleditsia triacanthos).*

The i-Tree contributory structural value (using the income approach provides a current dollar value from future benefits) is $1,700,00 for 768 trees with tree cover of 8.414 acres within 156 acres (i-Tree Eco Analysis, Analysis Yale 2020).). “Other” is the balance of lesser percentage trees on the campus not listed but considered part of ecosystem benefit calculation.

Avoided Stormwater Runoff

The avoided runoff estimated by i-Tree is 13,300 cubic feet per year with an estimated value of $890 based on $0.07 per cubic foot.

Avoided stormwater runoff is water that is utilized by trees before being channeled to a drainage system. Usually the channeled water is lost or wasted as it ends up in a watercourse that drains to a large body of water such as Long Island Sound. The i-Tree analysis only considers precipitation intercepted by leaves, with Athletics trees such as the 173 white pine (*Pinus strobus*), 138 red oak (*Quercus rubra*), and 79 red maple (*Acer rubrum*) able to capture the most cubic feet of avoided runoff. This is the result of having a higher-quantity species population, as well as the size and scale of the plant, resulting in larger mass of leaves and branches (i-Tree, Yale Analysis 2020). The avoided stormwater runoff also reduces the extent of surface erosion and soil lost.

Climate Resilience

Athletics Campus has certain components and conditions that put stress on its ability to be resilient in the face of current climate conditions. Drought, higher temperatures, severe weather and wind events, and invasive pests and plants add considerable challenges to a plant's vitality. The large, level area of open lawn and field open space allows water to permeate into the ground. It is unknown how much of the managed lawn is irrigated, though at times of severe drought, it is not practical to provide enough irrigation for the numerous roots.

Athletics has a couple of groups of monoculture plantings consisting of white pine (*Pinus strobus*) and red oak (*Quercus rubra*) planted in rows and groups.

One of these species is currently under treatment for the invasive insect pest emerald ash borer (ash) and Dutch elm disease (elms). The remaining sugar maples are susceptible to the invasive insect Asian longhorned beetle. Though there are no trees currently identified as undergoing an IPM program, there is a population of American elm trees that is susceptible to disease. Ideally tree plantings are more diverse in species to reduce the vulnerabilities of pests, pathogens, and adverse reaction to increasing climate extremes. This current scenario exposes the trees to potential pests and disease while increasing preventative maintenance costs.

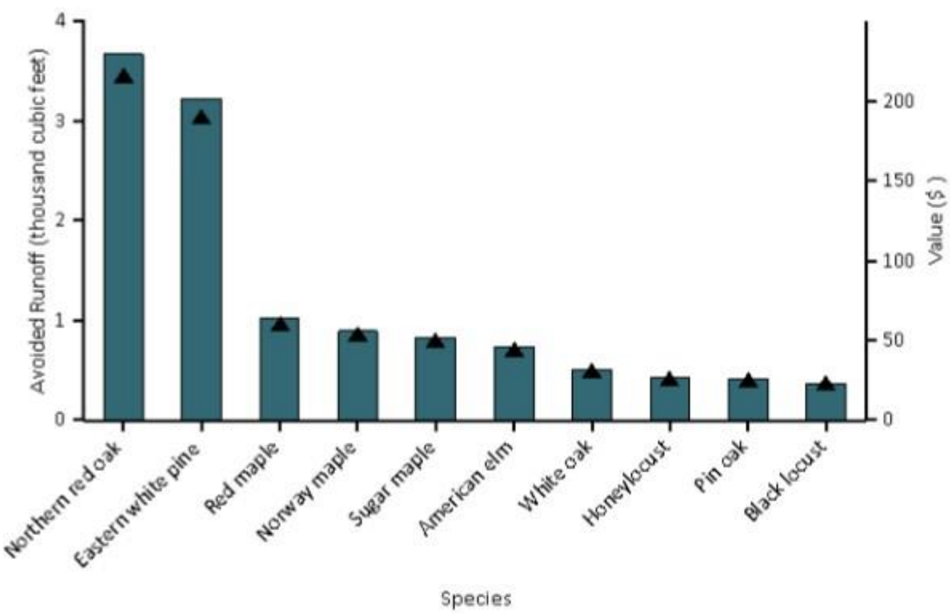

Figure 57 Avoided Runoff and Value, Athletics,(i-Tree, 2020)

Oxygen Production

Athletics Campus trees contribute to oxygen production released into the atmosphere. More importantly, the oxygen count is tied to the amount of carbon dioxide uptake and retention during photosynthesis. When carbon dioxide uptake surpasses the amount of carbon dioxide released through the process of respiration, it shows that the tree retains more carbon than released. The atmosphere has substantial oxygen in its stores without the contribution of trees (Nowak, 2007).

Athletics Campus's top producer of oxygen, according to the i-Tree Analysis, is northern red oak (*Quercus rubra*) at a count of 138 trees at 6,283.47 pounds. The next highest producer of oxygen is white pine (*Pinus strobus*) at 2,551.41 pounds, followed by white oak at 1,362.10 with a population of only 20 trees.

Canopy and Air Pollution

A canopy is the tree's components such as leaves, branches, and stems that cover the ground beneath the tree. Athletics has two distinct canopy covers: managed and woodland.

The managed area canopy cover is relatively sparse in comparison to the woodland area. It is defined by individual trees, due to the open ground area between trees, while the woodland area tends to be a contiguous canopy providing overlapping branch cover between adjacent trees.

The woodland area canopy cover provides more contiguous cover from heavy rains by breaking the fall of precipitation. It also offers cover from the solar rays that would otherwise heat open ground contributing evaporation and water loss.

Pollution particulates are also captured by individual leaves. The amount of pollutants removed in the managed area, according to the i-Tree Analysis, is 248 pounds in a year, with ozone the largest portion of removed pollutants (out of carbon dioxide, nitrogen dioxide, and other lesser count pollutants). (i-Tree Analysis, Athletics Campus, 2020). This does not include the predominantly deciduous forest area in the woodland. It is safe to assume that the benefits pertaining to air pollutant removal would be increased. Most of the air pollutants removed are linked to health problems (Hirabayashi, Nowak, 2016).

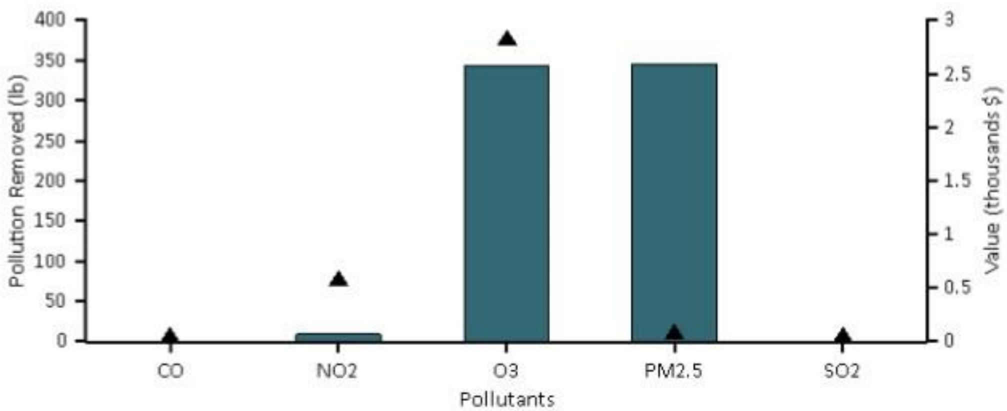

Figure 58 Athletics Pollutants Avoided and Value

Athletics Tree Valuation

The Athletics Campus valuation total for the inventoried tree population is $3,944,193. The figure was calculated from a total of 785 trees inventoried using the cost approach explained below. (See Tree Inventory Valuation Calculation, Appendix 2).

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

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The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with trunks of a diameter of four inches or greater be assessed in managed areas. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables that increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. (See Appendix 2, Tree Inventory Valuation Calculation.)

Trees that might have sentimental value due to their large stature, historical relevance and uniqueness need to be considered individually. Industry standards described above use accepted systems to determine value, though do not have specific consideration for such trees and associated "added value".

Treble values could be used for individual trees within specific parameters as dictated by the assignment taking into current tree condition and impact event (construction, vehicular accidents, or unanticipated occurrence). It is suggested that a determined bond value be set by the university when construction occurs within root protection areas. This will only provide incentive to protect the tree as actual tree replacement is not practical, reasonable, or feasible for such unique trees. The legal system often determines such specific cases on a case by case basis as there are no accepted industry standards in these cases.

INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) is a method of applying knowledge, prevention, and control to maintain tree health. There are four pillars of IPM: cultural, physical/mechanical, chemical, and biological. Used together, they follow the life cycle of the pest to effectively deal with the potential issues. The controls can be preventive or corrective and require passage of a certain time before efficacy is realized. Timing of any treatments should always consider and respect beneficial insect communities (such as pollinators).

1. Cultural controls make the pest less likely to establish on the given specimen(s). This may include simply changing irrigation frequency or adjusting mowing boundaries.
2. Physical/mechanical controls include placing barriers to entry around the plants of concern. Sticky traps for insects or fences for deer grazing are examples.
3. Biological control is the intentional cultivation or release of beneficial insects or pathogens that eat or infect the pest—plant or insect—in any stage of development.
4. Chemical controls are the most discussed treatment options. This may include synthetic or organic chemicals produced to target a single species or a broad spectrum.

Each pillar has its own benefits and shortcomings. Cultural and physical/mechanical can be costly because of the labor required, but they have the least unintended consequences. Biological is experimental and requires extensive monitoring but could be a cost-effective and less invasive approach. Chemical is usually the least expensive option, but frequently it affects more of the surrounding ecosystem than just the intended target pest.

To effectively apply IPM, four steps must be followed: set a threshold, monitor, and identify pests, prevent population development, and treat the specific pest. On Yale's campus, the threshold may vary depending on the specimen. A specimen tree on a main green may have a threshold of zero, while trees in forested plots may have a much higher pest threshold; if the tree does succumb to the pest it is less of a risk. The manager, in this case Yale University, establishes the tolerance level for the issue.

Wherever these priority specimen trees may be, they need to be monitored at regular intervals by qualified and/or trained arborists (Connecticut-licensed and/or International Society of Arboriculture certified arborists). The growing season (allowing a time buffer prior- and post-) mid-March through mid-November is the most critical period, requiring a monthly scouting for threats before they become a problem. A small population of pests may or may not present difficulties, depending on the pest and the manager's tolerance. Properly identifying pests is critical to effectively treating the issue. If the identified pest is considered a threat, the four pillars of IPM can be applied.

The consultants recommend monthly growing season scouting by an arborist of susceptible specimens (priority trees). Scouting requires observing all specimen trees from the ground up and noting potential threats to the trees' health, including tip dieback, developing cracks or cankers, mushroom growth, flying moths, hazardous deadwood, etc. The individual should be at least a certified arborist or ideally a Connecticut-licensed arborist to ensure that (s)he is aware of potential pests and risks that may affect both the tree and the human population. Any applied treatments need to be performed under the supervision of Connecticut-licensed arborists. IPM monitoring can be time consuming and depends on the ultimate number and location of identified specimens.

Yale University has directed the consultants to focus on "priority" trees to distinguish between trees currently on an Integrated Pest Management plan (Level I), trees that need to be on an integrated management plan (Level II), and campus trees that are noteworthy as either specimen, donated tree, milestone tree, culturally significant or having been identified as rare taxonomy (Level III).

IPM Level I Priority trees are distinguished from the general campus tree population as currently on an integrated pest management plan and shown as IPM Level I on the Yale University ArcGis platform. Level I trees are being treated for pests and disease and should be inspected at regular intervals between 30-45 days during the growing season usually considered between March and November for additional problems.

IPM Level II Priority trees are distinguished from the general campus tree population as not currently on an integrated pest management plan but should be on an integrated pest management plan in anticipation. These trees are currently shown as a Level II on the Yale University ArcGis platform.

IPM Level III Priority trees are considered as noteworthy trees. The trees have been identified as specimen, milestone, memorial, donated, culturally significant or of rare taxonomy. It is possible for trees to be considered for more than one priority designation, such as culturally significant and a specimen. It is also possible for them to be on an IPM program, depending on the tree.

IPM Level III Specimen trees have been identified as having exceptionally good or an unusual shape or size for the species as determined at the time of inventory or as advised by Yale representatives.

IPM Level III Milestone trees have been planted in recognition of Yale employees' milestone years of service. Often, more than one employee is associated with each tree.

IPM Level III Memorial trees are planted in memory of individuals who have been involved in various capacities with Yale University.

IPM Level III Donated trees have been donated by individuals involved with the university. They can be of varying size and species.

IPM Level III Culturally Significant trees have been identified as culturally or historically important trees. They might be associated with a Yale tradition, or noted individuals.

IPM Level III Rare Taxonomy trees have been identified by Yale staff as unusual or unique species that warrant recognition. Priority trees demand more attention on Yale's campus. There are also some trees of exceptional size (with a diameter at breast height greater than or equal to 40 inches) that we have noted to be considered in the maintenance plan. This excludes weedy or invasive trees.

While a wide variety of species is represented in the selected trees for monitoring, some species are more susceptible to pests than others. Those of greatest concern are ashes, beeches, oaks, elms, and maples. Numerous pests may affect the health of these species, but few will result in death. A trained arborist should be able to identify common pests, so only the most pressing are addressed here.

Species of Concern:	Common Pests:	Visual Cues:	Survey Method:
Ash *Fraxinus* White Ash *F. Americana* White Fringetree *Chionanthus C. virginicus*	Emerald Ash Borer	Bark blonding Crown dieback Flying adult beetles May 30- Aug 30 Woodpecker damage (indicates larva) "D" exit hole	Visual Inspection
Beech *Fagus* American Beech *F. grandifolia* European Beech *F. sylvatica*	Bleeding Canker Phytophthora Root Rot	Leaves wilt, dull, and yellow Bark around soil line appears dark Wood beneath bark is red-brown discolored	Visual inspection Visual inspection
Oak *Quercus* Black Oak *Q. velutina* Red Oak *Q. rubra* Pin Oak *Q. palustris* White Oak *Q. alba*	Armillaria Root Rot Phytophthora Root Rot	Leaves wilt, dull, and yellow Mycelial mats develop in infected tissue Honey colored mushroom develops at trunk base Or on surrounding roots Leaves wilt, dull, and yellow Bark around soil line appears dark Wood beneath bark is red-brown discolored	Visual inspection Visual inspection
Elm *Ulmus*	Elm Bark Beetle	Adult beetles May 1 - Sep 30	Visual Inspection Pheromone Traps

American Elm *U. americana* Slippery Elm *U. rubra* Elm Hybrids *Ulmus spp.*	Dutch Elm Disease	Sawdust in bark crevices or at base of tree Wilting crown Yellowing leaves Heavy defoliation	Visual Inspection
Maple *Acer* Sugar Maple *A. saccharum*	Decline Abiotic	Progressive dieback Thinning canopy Premature fall color	Visual Inspection

Table 22 Yale Species of Concern

The list above is hardly comprehensive, but for targeted pests, it is sufficient. There are some nontarget pests that have not yet become a problem in the New Haven area but should also be addressed. When a nontarget pest becomes prevalent, it becomes a problem for many tree and shrub species, which can drastically affect the campus canopy

Pests to Guard Against

Gypsy Moth (not usually a problem unless three dry springs)

Gypsy moth is an invasive problem in regions of Eastern and Northern Connecticut. The moth is the adult form, but the larva is the pest. Its favorite meal is oak (*Quercus),* but it will feed on beech (*Fagus)*, birch *(Betula),* tupelo (*Nyssa),* elm *(Ulmus),* fir (*Abies),* linden (*Tilia),* maple (*Acer),* pine *(Pinus),* hemlock *(Tsuga),* and spruce (*Picea)*. Those varieties make up 54 percent of the Yale campus canopy. The adults lay egg masses on the underside of large tree branches, which overwinter and hatch mid-May. The larva feed in the canopy of the tree for the first three instars (larval growth stages) of life.

During the fourth and fifth instars, the black and red fuzzy larvae migrate up the trunk during the day for feeding and down the trunk at night to remain safe from predators. These later instars cause the most damage to the trees' foliage. Around June 1, the larva turns pupae for two weeks. Adults emerge in late June and can persist into August. The adults are recognizable by their white wings. Trees can usually tolerate one to two aggressive seasons of defoliation, but a third year can be lethal. Treatment options can prevent later instar stages of development or future reproduction.

Figures 59 Gypsy Moth eggs on Bark, Gypsy Moth Laying Eggs, Close up of Eggs

Figures 60 Fungus maimaga and resulting dead gypsy moth caterpillars (U-Shaped)

Photo: Dead gypsy moth with maimaga funguus (u shape caterpillars) Gale Ridge, CAES CT Agricultural Extension Service 2020

Emerald Ash Borer (on campus)

The emerald ash borer is a small, green beetle that belongs to a large family of beetles known as the buprestidae, or metallic wood-boring beetles. The description is apt, as many of the adult buprestids are indeed glossy, appearing as if their wing covers are made of polished metal. The emerald ash borer, with its green, iridescent wing covers, fits right in. Adult EABs are relatively slender and between 0.3 to 0.55 inches in length—small by most standards but large compared to other buprestidae.

During its life cycle, EAB undergoes a complete metamorphosis. It starts as an egg, becomes a larva (alternatively called a grub), changes into a pupa, and then is an adult. The life cycle of an EAB takes either one or two years to complete. Adults begin emerging from within ash trees around the middle of June. Emergence continues for about five weeks. The female starts laying her eggs on the bark of ash trees about two weeks after she emerges. After seven to 10 days, the eggs hatch and the larvae move into the bark, to begin feeding on the phloem (inner bark) and cambium of the tree. Throughout each of its successive instars (larval growth stages), the larva continues to feed on the phloem and cambium of the tree. The larval stage may last for nearly two years. Before becoming an adult, the insect overwinters as a prepupal larva. It then pupates in the spring and emerges as an adult during the summer.

Figure 61 Emerald Ash Borer Underside


Figure 62 Emerald Ash Borer Topside


Figure 63 Emerald Ash Borer Exit Hole - note "D" shape

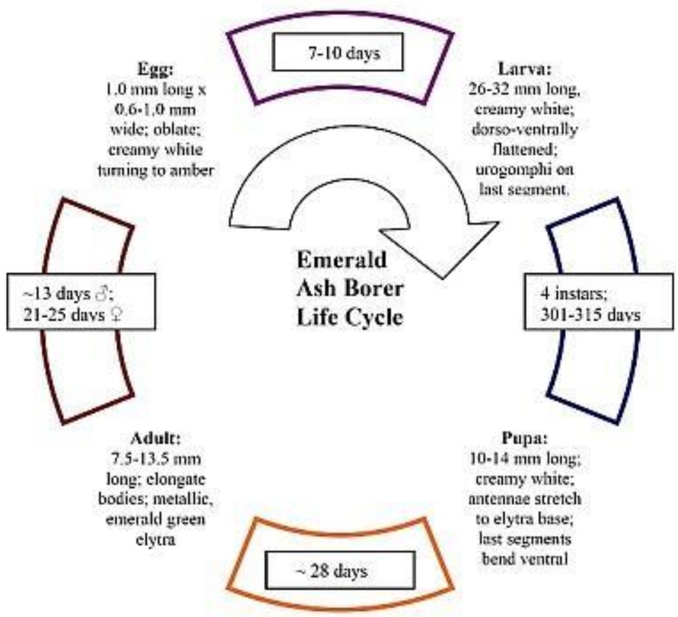

Figure 64Emerald Ash Borer Life Cycle

Figure 65 Emerald Ash Borer Pupa Source: USDA Emerald Ash Borer Program Manual

EAB feeds on ash trees almost exclusively. While the larvae feed on the phloem and cambium, the adults feed on leaves. In Connecticut, there are three species of ash trees—the white ash (*Fraxinus americana*), the green or red ash (*F. pennsylvanica*), and the black ash (*F. nigra*). Despite its common name, mountain ash (*Sorbus* spp.) is not a true ash and does not attract the EAB.

To date, the only non-ash genus EAB is known to feed on is *Chionanthus* (fringe tree). Yale has already identified and begun treatment of the ash population; however, the White Fringe tree (*Chionanthus virginicus*) population on North Campus is susceptible and should be addressed as well.

Asian Longhorned Beetle (not on campus but need to monitor for)

The Asian longhorned beetle (ALB) is another pest that has garnered a lot of publicity, primarily because there is no effective treatment option and it will eat nearly any kind of hardwood, though it prefers sugar maple. This means the infected trees must be removed and the wood destroyed to prevent further spread. The species has a shiny black-and-white spotted exoskeleton and long antennae. It has been found in New York and Massachusetts, but when a population is found, it has usually already been present for several years because it prefers treetops.

The adult female lays a single egg in the burrowed-out bark. She may do this up to 90 times a season. The larva hatches and burrows into the heartwood, where it overwinters. The larva pupates the following summer and will emerge as an adult in the fall. When they emerge, they leave ½-inch exit holes. The beetles are poor flyers, so they tend to re-infest the same tree year after year, which leaves pockmarks on the bark where the female bores into the wood.

The trees are usually slow to show symptoms of failing health. It is important to regularly check pruned branches for exit holes and pockmarks, as the infestation begins near the top of the tree. In nearly every instance where ALB was discovered in the United States, it was because a concerned citizen called it in. While there have been no cases in Connecticut up until this point, an infestation would be devastating.

Pictures of scaled (pictured with coin) Asian longhorned beetle here, exit holes:

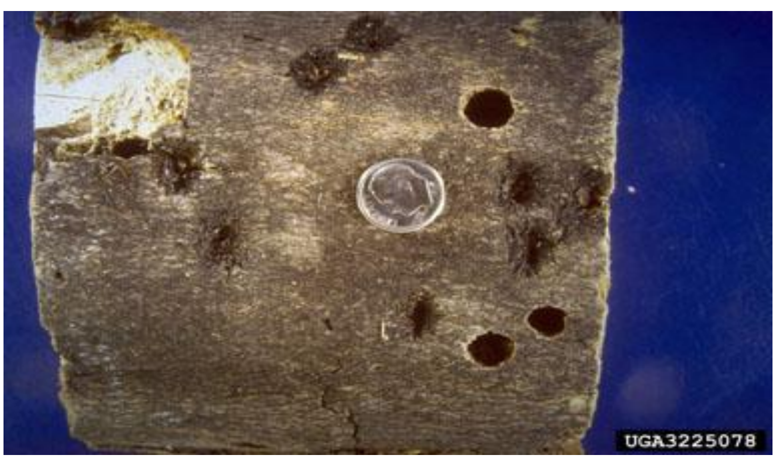

Figure 66 Asian Longhorned Beetle Exit Holes, Photo: E. Richard Hoebeke, Cornell University

The nearly perfect circles are fresh exit holes. The scarred circles near the top of the image are the previous season's exit holes, while the vertical ovals are previous seasons egg deposits.

Figure 67 Adult Asian Longhorned Beetle, Photo: Joe Boggs, Ohio State University

Spotted Lanternfly (not on campus but need to monitor for)

The spotted lanternfly is another pest that should be considered during monthly inspections, despite not having reported cases in Connecticut. Like ALB, the lanternfly does not have a host plant and there are no known treatment options yet. It is a major concern for Connecticut because 47 percent of Connecticut's forests are susceptible to the pest. The nymphs and flies suck the sugary sap from the trees, which depletes the plants' resources. It also leaves plants susceptible to sooty mold, as the sugar sap is a perfect opportunity for fungal growth. The mold is not life threatening, but it is unsightly anywhere, especially on campus trees. While more research is required, there is a suspicion that part of the reproductive cycle requires access to the invasive tree, tree-of-heaven (*Ailanthus altissima)*. By removing the plant population, the spread of the pest can be largely prevented. Additionally, if there is an outbreak, sticky bands placed four inches from the base of trees can prevent the pest from moving up and down.

Figure 68 Adult Spotted Lanternfly

Figure 69 Adult Spotted Lanternfly

Figure 70 Spotted Lanternfly Egg Casings, Photo: Lawrence Barringer, Pennsylvania Department of Agriculture

Figure 71 Adult Flies Feeding on Sap

Figure 72 Nymphs Feeding on Young Wood

Photos: Emilie Swackhamer, Penn State University

Dutch Elm Disease (on campus)

Dutch elm disease (*Ophiostoma ulmi* or *O. novo-ulmi*), a fungus, can occur on most elm trees and often on resistant varieties. The fungus is spread via elm bark beetles or by root grafts from adjacent trees. Symptoms develop quickly within a four- to five-week period, usually when the leaves have reached full size. The first visual symptom, usually observed within the crown of the tree, is referred to as "flagging." This occurs when one or more branches develop symptoms of wilting and/or yellowing of the leaves on an otherwise apparently healthy tree. Prior to this occurring, symptoms have developed internally and include the death of xylem cells, the loss of water-conducting ability, and the browning of the infected sapwood in narrow streaks that follow the wood grain channels. Dead branches begin to appear sporadically in parts of the crown. IPM scouting should also continue despite any fungicidal injections. Eradicative pruning can slow the spread if there is enough clear wood between the infected area and the cut (five to 10 inches) (Northeastern Area State & Private Forestry USDA Forest Service (2020)).

The Yale University community has successfully preserved numerous specimen elm trees despite most of the population being lost to Dutch elm disease and elm yellows. Preventative fungicidal injections have kept mortality to a minimum, although some researchers are concerned with repeated injection sites exposing the tree to decay.

Figure 74 Flagging on Elm (note discolored foliage)
Photo: Dr. Steve Katovich, USDA Forest Service

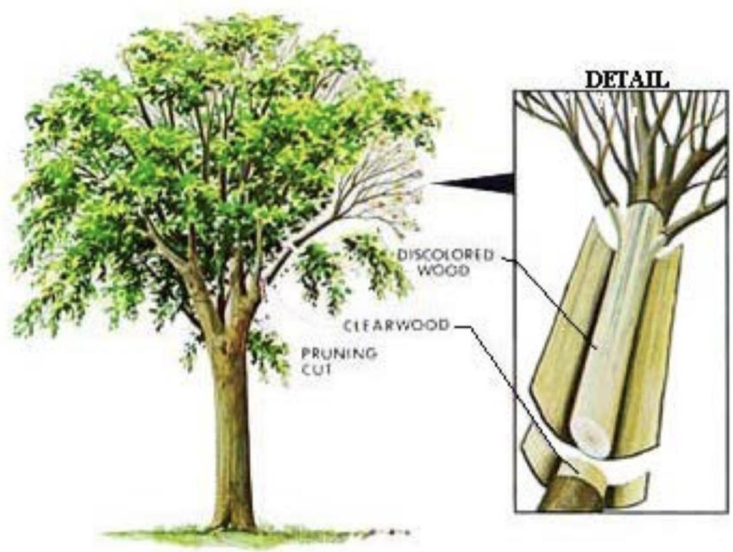

Figure 73 Elm Tree Interior Wood Signs

USDA Forest Service (2020)

Summary Table	
Causal Agent	Fungus
Disease Vector	Elm bark beetles (or via root grafts)
Damaging Stage of Vector	Adult
Overwintering Stage of Vector	Larva or adult
Number of Generations per Year	2-3
Time of Year when Damage Is Done	May-September
Major Symptoms	Flagging, wilting of foliage, browning of current or previous year's growth ring (sapwood)

Figure 75 Elm Tree Dutch Elm Disease Facts
Source: University of New Hampshire Cooperative Extension (2020)

Abiotic Factors (occurs on campus)

Abiotic factors also affect plant health. While pests are usually more easily recognizable, they are frequently only present on campus once a tree has been previously stressed by other factors: drought, severe winter cold, summer heat, soil compaction, constructional grade change, or mechanical damage. Being able to recognize these sorts of issues is critical for maintaining plant health.

Monitoring season	Abiotic concerns	What to recognize	Prevention and cures	Highly susceptible species
Winter	Winter desiccation	Tip dieback or complete necrosis of leaf margins	Regular watering in the fall to prevent winter dehydration and fertilize affected plants in early spring to encourage new growth.	Evergreens, especially soft tip, or broad-leaf evergreens (i.e., rhododendrons and pines)
	Frost cracks	Vertical cracks in bark caused by rapid drops in temperature	Mulch rings when planted to ensure no mechanical damage, encouraging stronger bark, and bracing existing cracks to prevent reopening in later seasons. Also monitor for disease or pests entering cracks	Species outside or on the edge of their natural range and those with soft bark - magnolias, cherries, red maples, beeches, crabapple, sycamore
	Winter sunscald	Discolored reddish/ brownish bark or bark peels Usually on the southern side of the plant	This occurs when the sun warms up the bark during the day and then the rapid cool of sunset causes the bark to split. For susceptible trees, tree wraps are available in the	Young trees or thin barked trees are most susceptible (see trees susceptible to frost cracks)

			fall and fertilizing to return vigor in the spring.	
	Snow and ice breakage	This is when the weight of snow or ice builds up too much and causes the branches to break	Regular pruning trees and shrubs keeps plant health during the growing season. When the plant is dormant, the weight of ice and snow can be more easily distributed. Additionally, when there is a severe storm, by pruning damaged branches as soon as possible, further damage to the plant is prevented.	Fully formed evergreens like yews and arborvitae are most susceptible because the snow and ice gets caught. Pines, spruce, and fir also struggle with the excess weight.
	Frost heaves	The ground cracks with the frost, leaving exposed roots to dry and freeze	Putting sufficient mulch rings around the base of new planting will create a barrier between the atmosphere and the soil layer. This protects roots. If the ground does heave, place new much in the cracks as soon as possible.	New plantings of any species are most susceptible
	Salt damage	Leaf yellowing and browning on edges and discolored roots	Preventatively plant salt tolerant trees near roads or use calcium chloride near sensitive trees	Forest species are sensitive to salt: maples, hickories,

			(compared to more common sodium chloride). Water drench salted ground around affected plants to flush salt out.	dogwoods, and oaks
Spring	Soil saturation	Water pooling around tree base		
Summer	Drought	Wilting leaves	Try to maintain regular water intake during spring compared to summer. If there is a lot of rain in the spring, limit irrigation, then water regularly in summer	
	Summer sunscald	Leaf or bark discoloration	Do not prune more than ¼ of the foliage at a time. This exposes excessive amounts of bark and can cause sunburn.	

Figure 76 Abiotic Factors
Source: i-Tree Ecosystem Analysis, Urban Forestry Effects and Values 2020

The following list is included in the Yale Campus 2020 i-Tree report and is presented here for easy reference. The investment and diligence required to monitor potential pest activity is significant. It is important to keep in mind that the upfront costs of IPM scouting (monitoring) are justified when environmental and ecological values as well as removal costs are factored in. The threat of these pests is always potentially present, nearby, or impending, and will most likely continue to increase in intensity, given the changing climate and broadening global economy, potentially introducing insect pest-contaminated shipping materials.

Tree valuation below is based on the "Income Approach".

Code	Scientific Name	Common Name	Trees at Risk (#)	Value ($ thousands)
AL	Phyllocnistis populiella	Aspen Leafminer	8	11.77
ALB	Anoplophora glabripennis	Asian Longhorned Beetle	1,437	2,105.09
BBD	Neonectria faginata	Beech Bark Disease	68	353.21
BC	Sirococcus clavigignenti juglandacearum	Butternut Canker	0	0.00
BWA	Adelges piceae	Balsam Woolly Adelgid	11	14.22
CB	Cryphonectria parasitica	Chestnut Blight	0	0.00
DA	Discula destructiva	Dogwood Anthracnose	538	260.81
DBSR	Leptographium wageneri var. pseudotsugae	Douglas-fir Black Stain Root Disease	4	7.02
DED	Ophiostoma novo-ulmi	Dutch Elm Disease	154	421.07
DFB	Dendroctonus pseudotsugae	Douglas-Fir Beetle	4	7.02
EAB	Agrilus planipennis	Emerald Ash Borer	55	60.40
FE	Scolytus ventralis	Fir Engraver	13	19.90
FR	Cronartium quercuum f. sp. Fusiforme	Fusiform Rust	1	2.40
GM	Lymantria dispar	Gypsy Moth	1,643	3,439.93
GSOB	Agrilus auroguttatus	Goldspotted Oak Borer	0	0.00
HWA	Adelges tsugae	Hemlock Woolly Adelgid	89	133.41
JPB	Dendroctonus jeffreyi	Jeffrey Pine Beetle	0	0.00
LAT	Choristoneura conflictana	Large Aspen Tortrix	168	168.84
LWD	Raffaelea lauricola	Laurel Wilt	24	15.11
MPB	Dendroctonus ponderosae	Mountain Pine Beetle	73	88.02
NSE	Ips perturbatus	Northern Spruce Engraver	17	19.06
OW	Ceratocystis fagacearum	Oak Wilt	851	2,746.03
PBSR	Leptographium wageneri var. ponderosum	Pine Black Stain Root Disease	0	0.00
POCRD	Phytophthora lateralis	Port-Orford-Cedar Root Disease	0	0.00
PSB	Tomicus piniperda	Pine Shoot Beetle	543	964.34
PSHB	Euwallacea nov. sp.	Polyphagous Shot Hole Borer	5	9.10
SB	Dendroctonus rufipennis	Spruce Beetle	104	121.50
SBW	Choristoneura fumiferana	Spruce Budworm	0	0.00
SOD	Phytophthora ramorum	Sudden Oak Death	660	2,099.66
SPB	Dendroctonus frontalis	Southern Pine Beetle	660	1,124.81
SW	Sirex noctilio	Sirex Wood Wasp	467	869.90
TCD	Geosmithia morbida	Thousand Canker Disease	30	53.93
WM	Operophtera brumata	Winter Moth	2,137	4,629.62
WPB	Dendroctonus brevicomis	Western Pine Beetle	0	0.00
WPBR	Cronartium ribicola	White Pine Blister Rust	390	798.63
WSB	Choristoneura occidentalis	Western Spruce Budworm	113	138.70

Figure 77 Potential Pest Threats to Yale Urban Forest, i-Tree 2020

IPM Recommendations

Timing is critical to proper IPM scouting for pests and can be combined with scouting for abiotic damage such as frost cracks, wind breakage, mechanical damage from vehicles such as mowers or construction equipment. The Yale IPM program is considering only trees that are already on a program as well as ones that might benefit from being on one such as unique plants, specimens, culturally significant trees.

Scouting for IPM is a matter of timing growing degree days with anticipated pest activity cycles. Most insect activity occurs in the early spring to late fall in New England. Growing degree days is an efficient way to predict pest activity:

- Choose a start date such as March 1
- Choose a threshold temperature like 50 degrees Fahrenheit
- Measure minimum and maximum temperatures
- Calculate an average temperature for each day, for example on March 1, minimum is 45F, maximum is 65F, average is 45 + 65/2 = 55
- Calculate the degree days above threshold for each day; for example, on March 1, the number of degree days is 55-50= 5-degree days.

IPM Levels I, II and III scouting should be an ongoing action during the growing season. An interval of 30-45 is acceptable and can vary depending on the weather conditions such as unusual temperature swings up or down, precipitation levels (also up or down), storms and unanticipated pest or disease conditions. Treatment costs can also vary depending on the same varying conditions.

Table 23 - Priority Trees by Campus						
Priority Levels	**Athletics Campus**	**Central North**	**Central South**	**Medical**	**West**	**Total**
Level I	0	26	51	18	43	138
Level II	0	38	1	0	0	39
Level III	0	170	55	43	14	282
Total	0	234	107	61	57	459

Table 23 IPM Levels I-III by Campus

IPM Level 1 estimated scouting (Table 9) and treatment costs (Table 9a):

Table 24 - Level 1 IPM Scouting Costs by Campus						
IPM Scouting	**Athletics Campus**	**Central North**	**Central South**	**Medical**	**West**	**Total**
Level 1 Tree Count	0	26	51	18	43	138
Level 1 Per Tree ($8.00) Scouting	0	$208.00	$408.00	$144.00	$344.00	$1,104.00
Annual Cost (45-day cycle IPM Scouting)	0	$3,687.11	$3,309.33	$1,168.00	$2,790.22	$8,954.67

Table 24 Level 1 IPM Estimated Scouting Cost by Campus

Table 25 - Level I IPM Estimated Annual Costs for Priority Trees by Campus						
	Athletics Campus	Central North	Central South	Medical	West	Total
Level I Tree Count	0	26	51	18	43	138
Organic supplement	0	$1,352.00	$2,652.00	$936.00	$2,236.00	$7,176.00
Treatments	0	$16,900.00	$33,150.00	$11,700.00	$21,500.00	$83,250.00
Total	0	$18,252	$35,802.00	$12,636.00	$23,736.00	$90,426.00

Table 25 Level 1 IPM Estimated Treatment Cost by Campus

IPM Level II estimated scouting (Table 10) and treatment costs (Table 10a):

Table 26 - Level II IPM Scouting by Campus						
IPM Scouting	Athletics Campus	Central North	Central South	Medical	West	Total
Level II Tree Count	0	38	1	0	0	39
Level II Per Scouting ($8.00) Per Tree	0	$304.00	$8.00	0	0	$312.00
Annual Cost (45-day cycle IPM Scouting)	0	$2,522.67	$66.39	0	0	$2,589.06

Table 26 Level II IPM Estimated Scouting Costs Per Campus

Table 27 - Level II IPM Estimated Annual Costs for Priority Trees by Campus						
	Athletics Campus	Central North	Central South	Medical	West	Total
Level II Tree	0	38	1	0	0	39
Organic supplement	0	$1,976.00	$52.00	0	0	$2,028.00
Treatments	0	$22,800.00	$750.00	0	0	$23,550.00
Total	0	$24,776.00	$802.00	0	0	$25,578.00

Table 27 Level 2 IPM Estimated Treatment Costs Per Campus

Level III IPM Scouting Costs by Campus						
IPM Scouting	Athletics Campus	Central North	Central South	Medical	West	Total
Level III Tree Count	0	170	55	43	14	282
Level III Per Scouting ($8.00) Per Tree Cost	0	$1,360.00	$440.00	$344.00	$112.00	$2256.00
Annual Cost (45-day cycle IPM Scouting)	0	$11,029.60	$3,568.40	$2,789.84	$908.32	$18296.16

Table 28 Level III IPM Scouting Costs by Campus

Level III IPM Estimated Annual Treatment Costs for Priority Trees by Campus						
	Athletics Campus	Central North	Central South	Medical	West	Total
Level III Tree	0	170	55	43	14	282
Organic supplement	0	$8,840.00	$2,860.00	$2,236.00	$728.00	$14,664.00
Total	0	$8,840.00	$2,860.00	$2,236.00	$728.00	$14,664.00

Table 29 Level III IPM Estimated Annual Treatment Costs

RECOMMENDATIONS

Tree Inspections

As noted, tree inspections provide the information to monitor and manage a tree population. Inspections served three primary vegetation management goals:

1. **Monitor** the tree population for short- and long-term risk issues. The former typically requires some form of mitigation which can range from deadwood pruning to whole tree removal. The latter concerns observable issues that are not of an imminent nature which is balanced with the benefits the tree provides.
2. **Assess** the tree for overall health and vigor. The most benefits to the university community are derived from trees that are healthy with expanding canopies. A scheduled inspection that includes assessing tree health allows staff to make choices that maximize these benefits.
3. **Demonstrate** due diligence by the university by applying a regular inspection process that is uniformly applied across the total tree population.

The following tree inspection recommendations are presented to enhance the university's overall vegetation management program.

Inspection Cycle. The consultants recommend a five-year cyclic inspection interval. This is a common inspection interval for a proactive urban forestry program in the United States. For the university, this translates to approximately 20 percent of the tree population on each campus being inspected annually. Table 30 below presents an approximation of the annual number of trees requiring inspection each year on a five-year cycle.

Inspection Type. The standard inspection should be the equivalent of an ISA Level 1–Limited Visual Inspection. This is based on the resources available and the size of the tree population requiring an inspection. A limited visual inspection should encompass a 360-degree view of the tree from the ground. If the tree presents elevated concerns to the inspector, a more advanced assessment may be required on individual trees.

Inspection Methodology. Each Level 1 inspection should include an assessment of the trunk, scaffold branches, and crown. Record keeping can consist of either working from a hard copy of an inventory-generated tree list or directly accessing the inventory via an electronic notebook. The primary issues to address are tree health and any short-term mitigation requirements. The inspector should update the tree's diameter, condition, maintenance needs, and inspection date. Basic hand tools to be used include a diameter tape, rubber mallet, and binoculars.

Inspection Scheduling. The optimum time for the inspection cycle to take place is during the summer when the trees have leaves and are fully leafed out. The optimum scheduling would have the trees that are scheduled for pruning during the forthcoming winter season be the trees scheduled for inspection during the prior summer. This would allow trees noted for removal to be mitigated before the pruning cycle begins. It also allows diameters to be updated to allow current diameter information to be used for contract specification and bidding purposes.

Table 30 - Annual Cyclic Inspection (ISA) By Campus						
Cyclic Inspection	Athletics Campus	Central North	Central South	Medica l	West	Total
20% of per Campus Tree Count	157	631	217	85	193	1,283
Per Tree ($10.00) Annual Inspection (ISA)	$1,570.00	$6,310.00	$2,170.00	$850.00	$1,930.00	$12,830.00

Table 30 Annual Cyclic Inspection Count Per Campus

Monitor Trees. Several hundred trees have been identified as requiring monitoring (see Table 31). These trees require annual inspection except as noted in the narrative in the next section. The "Monitor" trees had one or more issues associated with the tree. These could include large stature, high-target area, and/or a structural issue. At the time of the initial inventory assessment, the need for removal was not observed. Future, short-term removals may predominantly come from these trees.

Table 31 - Trees Identified to Monitor Annually and Cost by Campus						
Identified Monitoring	Athletics Campus	Central North	Central South	Medica l	West	Total
Campus Tree Count	17	149	19	11	192	388
Per Tree ($8.00) Annual Monitoring	$136.00	$1,192.00	$152.00	$88.00	$1,536.00	$3,104.00

Table 31Trees Identified to Monitor Annually by Campus

Campus-Specific Considerations. The recommendations noted above should be applied university-wide across all five campuses. Each individual campus, however, has nuances to its specific landscapes that warrant details specific to the campus.

Central North Campus – Central North Campus has the largest number and variety of trees. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice. Two considerations specific to the Central North Campus could affect the recommended inspection cycle.

- Number of Monitor Trees – The relatively large number of "Monitor" trees in this section (149) could be separated into a two-year inspection cycle rather than annually to reduce resource pressures.
- Several locations within Central North Campus have several significantly sized trees abutting areas of elevated use. These locations should be prioritized for inclusion in the initial inspection cycles. Some areas identified include the area along Prospect Avenue north of Edwards Street/Hillside Place, the west side of Prospect Avenue south of Hillside Place, and along the street boundaries of Prospect Gardens.

Central South Campus – Central South Campus has the highest density of structures adjacent to mature trees. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice. One consideration specific to South Campus could affect the recommended inspection cycle.

- Old Campus – the historical Old Campus is strongly associated with the identity of Yale. It is the location for many university events tied to the current university community and alumnus. Considering this high visibility and use, maintaining the annual inspection of the Old Campus trees is valid.

Yale School of Medicine Campus – Yale School of Medicine Campus is a relatively new campus and except for those in Amistad Park, the trees are relatively young. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice.

West Campus – Like Yale School of Medicine Campus, West Campus is relatively new, with young trees dominating. Most of the trees noted are of a size, location, and quality that a five-year cycle will suffice. One consideration specific to West Campus could affect the recommended inspection cycle.

- Woodland Site – The largest wooded tract of land at the university is found at West Campus. The meandering Oyster River bisects the woodland and a hard-surface path is in the woods. Because of this woodland size, the trees were not individually tagged and inventoried. An annual limited visual inspection along the trail and perimeter is recommended.

Athletics Campus –There are two considerations specific to the Athletics Campus that affect the recommended inspection cycle.

- Wooded Area Northwest of Yale Bowl – A few dozen mature, high-quality oaks were inventoried in the area identified as Lot H. The area is used in part for VIP parking and a picnic area. Additionally, some trees are adjacent to residential properties. Most of these trees require crown cleaning and heightened care because of the high ecosystem quality of the trees. As such, they should be included in the earliest inspection cycle if an inspection cycle is invoked.
- Wooded Area Around Connecticut Tennis Center – The wooded areas are bound by three major, high-use roads (Yale Avenue, Derby Avenue, and Chapel Street). These woodland areas have low maintenance and management policies associated with them. Several trees have been noted in the woodland area near the intersection of Yale Avenue and Derby Avenue. Because of the higher number of poor-conditioned trees and the high-target value offsite that can be affected by these trees, an annual inspection of the trees abutting the roads listed above should be invoked.

Environmental

Resilience

A resilient landscape is achieved through modifying best managed practices based on current research. Updating and sharing proven methods with other stakeholders is an ongoing process.

- Implement and track plant ratio minimums—10 percent of any one species, 20 percent of any one genus, or 30 percent of any one family for improved biodiversity.
- Use annual cyclic planting minimums to maintain future canopy cover.
- Use replacement planting for trees lost to damage, construction, or pests. Trunk area lost should be translated to trunk area replanting efforts. Larger trees will return environmental benefits sooner.
- Planting pits for trees should be larger and with ideal planting media like "Cornell Mix." (See .http://www.greenhouse.cornell.edu/crops/factsheets/peatlite.pdf)
- Implement Integrated Pest Management (IPM) program either in house or by contract, with the goal of reducing pesticide use. Staff training and support with programs such as International Society of Arboriculture certified arborist with continuing education requirements (CEUs) will assure long-term understanding of the campus and adoption of principles and methods.
- Encourage and support design programs that integrate bio-swale and stormwater capture on campus and adjacent city properties. These bring awareness to the community on the issue of cost and associated pollution of adjacent water courses.

- Encourage repurposing of wood products as the potential for lasting awareness and appreciation of campus trees such as current Yale Bowls project (yalebowls.com).
- Highlight environmental and economic benefits of individual trees by informational posting at tree. Adopt Sustainable Sites (http://www.sustainablesites.org/certification-guide) goals for the campus tree canopy as they relate to carbon sequestration, stormwater, and environmental benefits will also align with Yale's Sustainability Plan (http://www.sustainablesites.org/certification-guide, 2020).

Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are (Nowak 1995):

- Temperature reduction and other microclimate effects
- Air pollutant removal
- Volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC-emitting species, leads to reduced ozone concentrations in cities (Nowak 2000). Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include (Nowak 2000):

Strategy	Result
Increase the number of healthy trees	Increases pollution removal
Sustain existing tree cover	Maintains pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduces long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduces pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduces pollutant emissions
Plant trees in energy conserving locations	Reduces pollutant emissions from power plants
Plant trees to shade parked cars	Reduces vehicular VOC emissions
Supply ample water to vegetation	Enhances pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improves tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

Figure 78 Strategies to Improve Air Quality (Nowak, 2000)

Stormwater Retention

Existing trees can be enabled to capture stormwater runoff with mulched beds and beneficial grading. Mulch captures and slows water down, allowing it to percolate into most of the root system just beneath the surface (two to three feet). This capture removes water that otherwise would prone to eroding valuable topsoil.

- Species that are better at Rain Garden areas can utilize trees that favor moist conditions to acquire and hold runoff without an issue. Typically, these areas are established in areas with poor drainage or in an area that runoff velocity is being reduced. (red maple, Atlantic white cedar, and red twig dogwood)

- Existing areas and future construction sites could install stormwater capture areas adjacent to parking lots, gradients in the landscape, or low points in managed areas where water is slow to infiltrate soil zones due to saturation. Plant selection is site specific, although numerous small or even large trees can accommodate successful stormwater retention goals in conjunction with smaller plant selections such as shrubs and perennials.

Figure 79 Stormwater Retention Capture on New Haven Street

- Sustainability goals can also be met through stormwater retention projects. Trees and shrubs recommended for retention plantings can include: red maple (*Acer rubrum*), river birch (*Betula nigra*), American hornbeam (*Carpinus caroliniana*), hackberry (*Celtis occidentalis*), Eastern redbud (*Cercis canadensis*), and black gum (*Nyssa sylvatica*) (Uconn Plant Database, 2020).

Carbon Sequestration and Storage

The larger the tree, the greater the amount of carbon sequestered. The large trees can be invasive, native, or desirable but still have positive storage results. It is important to realize the benefits when evaluating environmental contributions of all trees. An important note in the chart below, Norway maple at 362 trees is the third largest contributor to carbon sequestration of carbon despite the negative connotations of being invasive. The 352 campus red oaks have the greatest ability to store carbon of all trees inventoried on campus according to the Yale University 2020, i-Tree Analysis.

When considering carbon sequestration and storage, the campus should acknowledge the significant red oak carbon benefits, though there is a need to increase its diversity with the tree population and consider planting larger quantities of smaller-sized trees in variety and increase diversity in larger tree species.

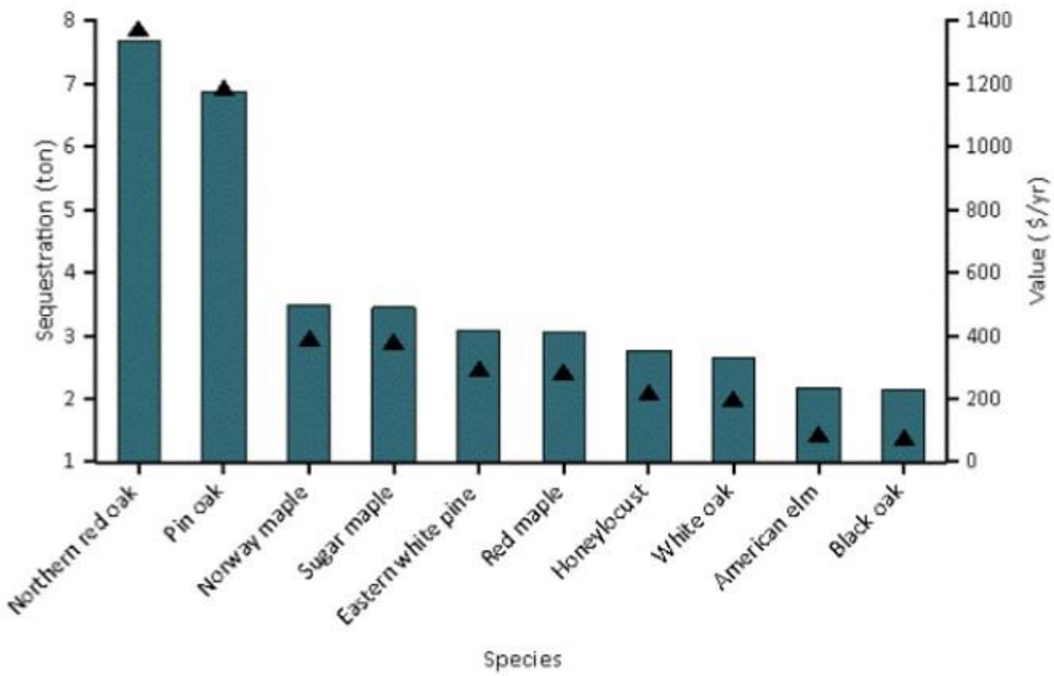

Figure 80 Yale University Carbon Sequestered and Value

Comprehensive Pruning

Comprehensive pruning refers to trees under a cyclic pruning cycle or any tree that may require corrective pruning due to storm, disease, or insect damage.

Pruning provides many benefits for a tree. First and foremost, it serves to maintain a tree in a healthy and safe state, while promoting longevity. From early structural pruning to maintenance pruning over a tree's mature life, the university can play a large role in increasing a tree's age and minimizing the reactive cost of future care such as storm damage. A regular pruning cycle is a critical component of an effective forestry program. Yale University will derive the following benefits from maintaining the cyclic maintenance program.

- Simply by pruning dead wood, the condition ratings will be upgraded for many of the university trees.
- Reactive requests and storm damage will be reduced.
- Cyclic maintenance guarantees that every tree on the university grounds will be regularly inspected by staff and/or contractors.
- The university can demonstrate that it is exhibiting "reasonable care" in maintaining its urban forest. The notion of "reasonable care" is the strongest defense Yale has in litigation due to a tree or tree part failure.
- Pruning specifications need to include manager notification by inspector/pruner of any additional observation of concern: decay, cracks, broken branches, etc.

In the United States, most system-level forestry programs try to implement a five- to eight-year pruning cycle. The consultants recommend a five-year pruning cycle for the university. If Yale cannot afford to contract services, a combination of options is available to meet this goal. For example, the trimming of trees with diameters over a certain size can be contracted out and trees with smaller diameters or heights (six inches or trees less than 25 feet in height) can be maintained by staff if under the supervision of a Connecticut licensed arborist or qualified consulting arborist. The overall objective is to achieve a cyclic pruning program within fiscal and human resource constraints.

All pruning activity should follow the American National Standard for Pruning (ANSI A300)—specifically for crown cleaning and raising. These pruning operations are best performed during winter months.

Crown Cleaning–The removal of defective limbs that are broken, diseased, dying, broken, structurally unstable and rubbing. This process improves tree health, reduces branch failures, and improves aesthetics.

Crown Thinning–The selective removal of branches to increase light penetration and air movement in the crown, or canopy, of a tree.

Crown Raising –The removal of lower branches. Crown raising is frequently done to allow foot or vehicle traffic or lawn mowers under the tree. Street trees require at least 16 feet of clearance for trucks. Lawn trees need eight feet of clearance for foot traffic. Trees used for screening or windbreak can be allowed to have branches near the ground.

Crown Reduction–The proper removal of upper branches when the tree has become too tall. When a tree is too tall, it is better to remove it. **Never top (removing large branches or/and trunks from treetops, leaving stubs, and not making proper pruning cuts) a shade tree to control its size**. Credit Below: BP Tree Services

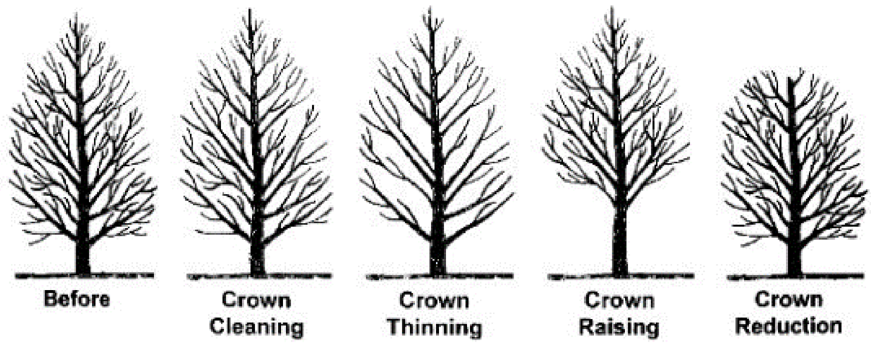

Figure 81 Examples of Types of Pruning

The number of trees requiring crown cleaning on the various university campuses is substantial. Some form of cyclic inspection and pruning program should be a primary maintenance goal for the university. A five-year cycle is the consultant's recommendation. Several approaches can be considered to meet this goal. The most efficacious approach will be informed by the following factors;

- Establish the degree that university representative or staff can carry out pruning. Staff should be able to prune trees under 12 feet and/or under 6-inch caliper if supervised by an onsite Connecticut licensed arborist. It is important to note that this is driven by Connecticut state law and should conform to those requirements (Ct Arborist Law Sections 23-61a through 23-61f of Ct State Statutes). This determination should consider current operational needs and staff ability to annually prune a portion of the 20 percent of the trees six inches or less in diameter in managed areas.
- Based on tree inventory data, the Yale campus has 1,730 trees that are six inches or less in diameter.

- The distribution of trees of this size class varies greatly between campuses. Athletics campus has 56 trees in this size class. North has 823 trees in this size class.
- Twenty percent of this size class for the Athletics campus is 11 trees and 165 trees for North.
- A larger-size diameter class could be considered for in-house pruning if capability is met: training and supervision under a Connecticut licensed arborist {otherwise, outside licensed contractors would also function as a pruning source).
- Some trees within the cycle may not require pruning, but inclusion in the pruning cycle guarantees that a regular inspection, as a minimum, occurs for the tree.
- Will require Yale representative/contractor or staff training in structural pruning.
- Will require Yale representative or staff training on maintaining pruning/inspection records.
- Contract pruning 20 percent of the balance of trees in managed areas and the perimeter of woodland sites on an annual basis.
- Pruning to A300 standards. Includes crown cleaning and crown raising during winter months.
- University representative or staff to identify the 20 percent to be inspected/pruned for that season. Selection should evenly distribute trees across size classes to guarantee uniform annual budget requirements.
- Inspection in the fall by university representative or staff of the 20 percent of trees to be pruned that season. The purpose of the inspection is to note any specific pruning requirements, update tree conditions, identify any removals, and identify any trees that do not require pruning.
- Provide a methodology and protocol for updating pruning/inspection records.

- Potentially create a field (in university ArcGis platform) in the tree inventory for assigning a tree to a cycle to allow an easily retrievable project list.
- Develop a tree inspection methodology for Yale representative or staff, based upon the ALARP model.

Develop pruning specifications to be used across campuses by both contractor and staff (reference A300 pruning standards).

- The current tree inventory GIS platform should be updated with regards to trees cyclically pruned and when by university staff or representative such as consulting arborist.
- Completed construction footprints, removals; all IPM priority tree actions and plantings should also be recorded and inventoried and updated by the consulting arborist.

Pruning, Cabling, and Removals

Table 13 below shows the count of recommended maintenance action by campus. Of all actions, the identified 158 tree removals should be considered first for action. The trees can be dead, in poor condition, or a healthy tree in fair or good condition with a structural defect leading to potential instability. Trees that are in woodland areas or forested areas away from foot or vehicular traffic are not usually recommended for removal. Trees that are near roads, sidewalks, or paths and have been identified as hazardous should be removed after evaluation and discussion with the Yale Office of Facilities. Removals are not considered part of a pruning cycle.

The pruning action count is for totals by campus. These are considered part of the recommended pruning cycle and should ideally be considered first over other trees during operational planning.

Tree counts for cabling maintenance or installation are also identified in the table below. Often, they can be combined with scheduled cyclic pruning operations leading to increased efficiency.

Table 32 - Recommended Maintenance Actions by Campus					
Action	**Athletic Campus**	**Central North**	**Central South**	**Medical**	**West**
Cable	0	5	5	0	2
Grind Stump	8	12	6	4	7
Prune: Crown Clean	130	526	76	110	78
Prune: Clearance	0	13	6	0	6
Prune: Reduction	2	45	4	5	2
Prune: Structural	1	4	1	0	0
Remove	43	74	15	18	8

Table 32 Recommended Maintenance Action by Campus

Stump grinding may or may not be a priority to be completed after tree removal based on site use, accessibility, and aesthetics and should be evaluated on a case by case basis as determined by the YR.

Pruning and Cabling

A significant number of trees require A300 crown cleaning. The amount of deadwood identified correlates with this action being assigned. A crown cleaning is the removal of all dead, diseased, and crossing limbs above a specified diameter size. It is not uncommon after a system-level tree inventory to have the number of removals range from 1.5 to 2 percent of the population.

Cabling or cable inspections are noted on ArcGis records as "cable." These trees have cables installed or should have them installed. The cabling operations can often be combined with pruning operations. A minimum number of 12 trees was identified for cabling throughout the campus.

Estimated costs for cabling and pruning operations are in Tables 14 below. The crown cleaning can be incorporated into cyclic pruning operations with a priority for pruning of dead wood and broken or hanging branches in areas of higher traffic prioritized for work first.

Table 33 – Action Costs				
Action	**Central North**	**Budget**	**Central South Tree Count**	**Budget**
Cable	5	2,250	5	2,250
Prune: Crown	526	552,300	76	79,800
Prune: Clearance	13	6,435	6	2,970
Prune: Reduction	45	29,700	4	2,640
Prune: Structural	4	2,640	1	660
Total		$593,325		$88,320

Table 33 Action Costs North South Campus

Table 34 – Action Costs Medical and West				
Action	Medical Tree Count	Budget	West Tree Count	Budget
Cable	0	0	2	900
Prune: Crown	110	115,500	78	23,400
Prune: Clearance	0	0	6	2,970
Prune: Reduction	5	1,650	2	1,200
Prune: Structural	0	0	0	0
Total		$117,150		$28,470

Table 34 Action Costs Medical and West Campus

Table 35 – Action Costs Medical Campus		
Action	Athletics Tree Count	Budget
Cable	0	0
Prune: Crown	130	113,750
Prune: Clearance	0	0
Prune: Reduction	2	1,200
Prune: Structural	1	660
Total		$115,650

Table 35 Action Costs Athletics

Removals

It is not uncommon after a system-level tree inventory to have the number of removals range from 1.3 to 2 percent of the population. The number of trees identified for removal on the Yale campuses is just above this norm. Removals should be prioritized and budgeted separately from cyclic pruning operations. It is recommended that trees that are dead or in extremely poor condition all be removed no later than the first two years of notification.

Yale staff may have the capability to remove the 21 smaller class 1- to 6-inch diameter trees and leave the remainder for an outside contractor. The greatest removal tree count of 127 is in the 7- 30-inch diameter range.

The following tables provide further detail on the campus removals. Table 36 presents the diameter distribution of trees noted for removal by campus. Table 37 presents the estimated cost distribution of trees noted for removal by campus. The relevance of the latter table is that it may inform what removals could be conducted by University staff and those requiring a contractor.

Table 36 - Diameter Distribution of Removals by Campus

Diameter Class	Athletic Campus	Central North	Central South	Medical	West	Total
1 - 6”	1	13	1	4	2	21
7 – 12”	10	28	4	7	2	51
13 - 18”	13	11	3	4	3	37
19 – 24”	7	14	3	0	1	25
25 - 30”	8	3	3	0	0	14
31 - 36”	1	3	0	0	0	4
37 – 42”	1	0	1	0	0	2
43” +	2	2	0	0	0	4
Total	43	74	15	18	8	158

Table 36 Diameter Distribution Removals by Campus

Table 37 – Diameter Distribution of Estimated Removals Cost by Campus						
Diameter Class and cost per tree	Athletics Campus	Central North	Central South	Medical	West	Total
1 - 6"	Yale Staff	Yale Staff	Yale Staff	Yale Staff	Yale Staff	Yale Staff
7 – 12" $850	$8,500	$23,800	$3,400	$5,950	$1,700	$43,350
13 - 18" $1500	$19,500	$16,500	$4,500	$6,000	$4,500	$51,000
19 – 24" $2000	$14,000	$28,000	$6,000	0	$2,000	$50,000
25 - 30" $2500	$20,000	$7500	$7,500	0	0	$35,000
31 - 36" $3500	$3500	$10,500	0	0	0	$14,000
37 – 42" $5000	$5,000	0	$5,000	0	0	$10,000
43" + $1500	$30,000	$30,000	0	0	0	$60,000
Total	$100,500	$116,300	$26,400	$11,950	$8,200	$263,350

Table 37 Diameter Distribution and Estimated Costs by Campus

Table 38 provides a comparison to initial costs of removals and pruning to the campus values. Central South has a relative lower figure of costs to value most likely because of a higher past degree of care, while West has a relatively newer campus planting and smaller trees overall. Yale School of Medicine Campus has higher initial pruning care needs as evident by 14.3 percent of total value.

Table 38 - Removal and Pruning Costs as a Percent of Campus Tree Value						
Removal/Prune Values	Athletic Campus	Central North	Central South	Medical	West	Total
Valuation	$3,944,193	$ 12,842,549	$3,398,650	$872,561	$2,047,522	$23,105,475
Remove/Prune Costs	$216,150	$709,625	$114,720	$129,050	$36,670	$1,206,215
Percentage of Value	5.4%	5.5%	3.4%	14.7%	1.8%	5.2%

Table 38 Removal and Pruning Costs as a Percent of Value

Plantings

To guarantee the long-term health and perpetuation of the urban forest, a good program must continue to plant trees on regular basis. An important element of a planting program is species diversification. The emerald ash borer is an example of how disaster can destroy poorly diversified urban forests.

Current plant vulnerabilities exist due to increases in seasonal temperature. The temperatures then increase the likelihood of drought conditions due to increased evaporation. This puts additional stress on the tree increasing its susceptibility to pests and pathogens. Not all species will most likely thrive, however, and a broader selection of species with varying degrees of resistance to climate swings will increase the depth of an urban forest.

As with any ecosystem, species diversity within the university insures against a single disease or blight destroying large sections of the urban forest. The number of different high-quality species should be greatly increased and perpetuated to maximize benefits and minimize hazards. The following guidelines provide direction for developing a diverse, healthy, low-maintenance, and aesthetically improved urban forest:

- Long-term (i.e., 20-year) population targets for high-quality species should hover around 5 percent of the current tree population. The trees should be distributed over time: planted in small numbers on a regular basis. Adjustments to tree size such as selecting a smaller size and planting by in house crews will lower costs. It is important to be aware that often, even with ideal initial years care, trees may be lost to unanticipated pests, disease, drought, storm damage and vandalism. It is critical to the urban forest to have a steady stream of new plantings to maintain the benefits the trees provide lower-quality species should have targets of less than 5 percent.

- The urban forest like Yale often has a need for numerous smaller trees like that take up less space than larger ideal trees like the white oak. The trees occupy less space and contribute less overall to tree value and benefit given their considerably smaller canopy. Planting quantities can be adjusted on a case by case basis though an established minimum tree fund is always recommended.

Table 39 – Planting by Campus			
Campus	**Quantity**	**2" – 2.5" cal. Tree Budget**	**Specimen 4" – 5" cal. Tree Budget**
Central North Campus	125	43,750	137,500
Central South Campus	41	14,350	45,100
Medical Campus	22	7,700	24,200
West Campus	32	11,200	35,200
Athletic Camus	30	10,500	33,000
Total	250	$87,500	$275,000

Table 39 Recommended Planting Quantities By Campus

- Trees should be chosen based on their moisture, soil, and light requirements and their growth rate.
- Inspect nursery stock before planting and avoid any trees with damaged trunks, poor form, or girdled roots. Explore on-campus growing possibilities.

- Planting sites should always be selected that maximize tree growth and health and minimize long-term infrastructure conflicts. Soil content, climate, and site size, and surrounding obstacles should be taken into consideration.
- Several species should be avoided when selecting street trees because they may have a high maintenance cost, short life expectancy, high storm damage potential, and/or a high hazard potential.
- If a uniform visual appearance is desired, choose different species that have similar forms. When selecting trees for their visual effect, consider the tree's size, texture, form, and coloring.
- Species concentrations should be monitored both at the overall university and campus levels.
- Watering at time of planting is three gallons per trunk-inch caliper.
- Basic rule of initial planting care is one year per one-inch caliper DBH.
- Maintain soil moisture during the growing season the first year or two, depending on size and soil conditions. This may be every day or once a week, depending on moisture level in the planting medium.
- Usually fertilizer and other additives (bio-stimulants, anti-transpirants are not recommended unless analysis determines otherwise,
- Mulch covering over the root ball area is recommended at two to three inches with nothing adjacent or against the trunk.

After a certain age, all trees decline and require greater maintenance. When large numbers of trees are planted within a short time, they become expensive and difficult to manage all at once. Multiple-aged stands are more desirable because they will disperse maintenance costs.

Slower-growing, longer-living trees minimize maintenance costs. Planting trees that live three times as long means spending approximately one third as much in removal costs over the same number of years. In general, the same slower-growing trees are higher quality and demand less pruning over their lifetime.

Finally, most urban trees have little utilization potential after their removal. Some underused species, such as swamp white oak, provide an opportunity to divert wood from the waste stream when the tree is removed. There are growing opportunities for converting resilient hardwood trees into high-quality firewood or low- and medium-grade lumber for the large secondary-wood industry in the Connecticut area. This activity also introduces a possibility of generating revenue.

The following plants are listed as invasive and should not be planted. That being said, the benefits of a large, existing invasive tree producing environmental benefits such as cooling, pollution capture, oxygen production, stormwater capture, and carbon storage and sequestration, can outweigh the negative aspect of invasive plants, including their having a competitive advantage over desirable trees, and often too self-propagating.

Connecticut Invasive Tree List

Amur maple (*Acer ginnala*)
Norway maple (*Acer platanoides*)
Sycamore maple (*Acer pseudoplatanus*)
Tree-of-Heaven (*Ailanthus altissima*)
Princess tree (*Paulownia tomentosa*)
White poplar (*Populus alba*)
Black locust (*Robinia pseudoacacia*)

Yale University Inventoried Areas Invasive Tree Count

Norway maple	(*Acer platanoides*)	455 trees
Amur maple	(*Acer ginnala*)	3
Sycamore maple	(*Acer pseudoplatanus*)	20
Tree of heaven	(*Ailanthus altissima*)	31
Poplar species	(*Populus species*)	6
Black locust	(*Robinia pseudoacacia*)	120
Total Invasive Tree Population		**635**

Yale University would benefit from a balanced list of nonnative as well as native planting options. Recommended planting suggestions vary from source to source and depend on existing population diversity, present pest problems, and degree of varying climatic conditions. The consultants recommended a broader range of species for increased biodiversity as identified by University of Massachusetts in their 2019 publication, *Planting for Resilience: Selecting Urban Trees in Massachusetts,* by Ashley M. McElhinney and Richard Harper.

The list identifies trees as native, utility compatible, urban adaptability and candidacy for assisted migration. The merits of assisted migration are often debated, due to the introduction of non-native species within a region where native species are found. Native species are, however, also subject to eradication by pests and disease such as elms with Dutch elm disease and emerald ash borer with ash. Assisted migration is the introduction of new species to overcome the effects of global warming and temperature-driven plant zones moving in a northerly direction. The result of considering plants from the list is opportunity of a broader plant selection (outside of the native-only criterion) that can also adapt to a southern New England region such as New Haven, Connecticut. The purpose of providing this list is to present a broad and reasonable suggestion for plant species for consideration (see Appendix 7).

Regular, annually scheduled tree plantings with target goals will assist in maintaining healthy canopy conditions for the future. Unforeseen events like storms, pathogens, and insect infestations can devastate an existing urban forest. A broad, diverse, and healthy planting will offer some insurance against such events. There is often flexibility in size of trees at time of planting, giving some leeway on budgetary options. First-year care is critical and should provide and maintain watering options such as Gator bags with regular fillings. A target number for new annual campus-wide plantings would be 250.

GLOSSARY

10-20-30 guideline for planting a diverse urban forest wherein a single species should make up no more than 10 percent of the tree population, a single genus no more than 20 percent, and a single family no more than 30 percent (Santamour, 1990)

abiotic disorder – plant malady caused by nonliving, environmental, or fabricated agents. (ISA, 2010).

absorbing roots – fine, fibrous roots that take up water and minerals. Most absorbing roots are within the top 12 inches (30cm) of soil. (ISA, 2010).

acceptable risk – a degree of risk that is within the tolerance or threshold of the owner, manager, or controlling authority. (ISA, 2011).

access route – defined entrance and exit route for a property during construction, tree work, or landscape operations. (ISA, 2010).

action threshold – pest population or plant damage level that requires action to prevent irreversible or unacceptable physiological and/or aesthetic harm. (ISA, 2010).

acute – disorder or disease that occurs suddenly or over a short period of time. Contrast with *chronic*. (ISA, 2010).

adaptability – genetic ability of plants and other living organisms to adjust or acclimate to different environments. (ISA, 2010).

air excavation device, air excavator – device that directs a jet of highly compressed air to excavate soil. Used within the root zone of trees to avoid or minimize damage to the roots, or near underground structures such as pipes and wires to avoid or minimize damage to them. (ISA, 2010).

anaerobic – without oxygen. Process that occurs in the absence of oxygen. (ISA, 2010).

ANSI A300 – in the United States, industry-developed, national consensus standards of practice for tree care. (ISA, 2010).

ANSI Z133.1 – in the United States, industry-developed, national consensus standards of practice for tree care. (ISA, 2010).

approved – in the contest of guidelines, standards, and specifications, that which is acceptable to federal, state, provincial, or local enforcement authorities or is an accepted industry practice. (ISA, 2010).

arboriculture – practice and study of the care of trees and other woody plants in the landscape. (ISA, 2010).

available water – water remaining in the soil after gravitational water has drained and before the permanent wilting point has been reached. Compare to *field capacity*, *gravitational water*, and *permanent wilting point*. (ISA, 2010).

balled and burlapped (B&B) – tree or other plant dug and removed from the ground for replanting, with the roots and soil wrapped in burlap or a burlap -like fabric. Contrast with *bare root*, *container grown*, and *containerized*. (ISA, 2010).

basic assessment (Level 2) - detailed visual inspection of a tree and surrounding site that may include the use of simple tools. It requires that the assessor inspect completely around the tree trunk looking at the visible aboveground roots, trunk, branches, and site.

best management practices (BMPs) – best-available, industry-recognized courses of action, in consideration of the benefits and limitations, based on scientific research and current knowledge. (ISA, 2010).

biological control – method of managing plant pests using natural predators, parasites, or pathogens. (ISA, 2010).

biorational control product – (1) control product or pesticide formulated from naturally occurring plant extracts, microbes, or microbial by-products that poses exceptionally low risk to nontarget organisms. (2) control product or pesticide that has limited environmental persistence and poses an exceptionally low risk to nontarget organisms. (ISA, 2010).

biotic disorder – disorder caused by an infectious living agent. (ISA, 2010).

botanical pesticide – pesticide derived from plants. (ISA, 2010).

buttress roots – roots at the trunk base that help support the tree and equalize mechanical stress. (ISA, 2010).

cambium – thin layer(s) of meristematic cells that give rise (outward) to the phloem and (inward) to the xylem, increasing stem and root diameter. (ISA, 2010).

canker – localized disease area on stems, roots, and branches. Often shrunken and discolored. (ISA, 2010).

carbon sequestration – capturing and long-term storage of carbon. Most often used about the capturing of atmospheric carbon dioxide through biological, chemical, or physical processes. Trees sequester carbon through photosynthesis. (ISA, 2010).

cavity – open or closed hollow within a tree stem, usually associated with decay. (ISA, 2010).

chronic – disorder or disease occurring over a long period of time. Contrast to *acute*. (ISA, 2010).

CODIT – acronym for Compartmentalization Of Decay In Trees. See *compartmentalization*. (ISA, 2010).

codominant stems – forked stems nearly the same size in diameter, arising from a common junction and lacking a normal branch union. (ISA, 2010).

compaction – see *soil compaction*. (ISA, 2010).

compartmentalization (compartmentalisation, in British English) – natural defense process in trees by which chemical and physical boundaries are created that act to limit the spread of disease and decay organisms. See *CODIT*. (ISA, 2010).

composting – subjecting organic matter to decay and decomposition processes. (ISA, 2010).

conk – fruiting body or nonfruiting body (sterile conk) of a fungus. Often associated with decay. (ISA, 2010).

consequences – outcome of an event affecting objectives (ISO, 2018). Effects or outcome of an event. In tree risk assessment, consequences include personal injury, property damage, or disruption of activities or services due to the event (ISA, 2011).

containerized – field grown plant placed into a container for a time and then sold as a potted plant. Term does not include a plant initially grown in a container. Contrast with *balled and burlapped, bare root.* (ISA, 2010).

Council of Tree and Landscape Appraiser (CTLA) – group of representatives of several tree care and landscape associations that works to research and compile the *Guide for Plant Appraisal.* (ISA, 2010).

crown cleaning – in pruning, the selective removal of dead, dying, diseased, and broken branches from the crown. (ISA, 2010).

data – facts and statistics collected for reference or analysis
data point – an identifiable element in a data set

diameter at breast height (dbh) – a U.S. custom means of expressing a diameter of a tree, as measured 4.5 feet (or 1.37 m) above the ground. (ISA 2019).

diameter tape – a diameter tape (D-tape) is used by foresters to measure the diameter of a tree. Since trees are swelled at the base, measurements are made 4.5 feet above the ground to give an average diameter estimate.

decay – (1) (*noun*) an area of wood that is undergoing decomposition. (2) (*verb*) decomposition of organic tissues by fungi or bacteria. (ISA, 2010).

deciduous – tree or other plant that sheds all its leaves according to a genetically scheduled cycle as impacted by climate factors (usually during the cold season in temperate zones). Contrast with *evergreen*. (ISA, 2010).

defoliation – loss of leaves from a tree or other plant by biological or mechanical means. (ISA, 2010).

degree day – difference between the daily average temperature and a given temperature base. (ISA, 2010).

dieback – condition in which the branches in the tree crown die from the tips toward the center. (ISA, 2010).

drought– A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term (see Box 3-3), therefore any discussion in terms of precipitation deficit must refer to the precipitation-related activity that is under discussion. For example, shortage of precipitation during the growing season impinges on crop production or ecosystem function in general (due to soil moisture)

duty of care – legal obligation that requires an individual to use a reasonable standard of care when performing tasks that may potentially harm others. (ISA, 2010).

ecosystem – complex system of living organisms and their abiotic environment. (ISA, 2010).

emergency response – predetermined set of procedures by which emergency situations are assessed and handled. (ISA, 2010).

eradication – total removal of a species from a area. May refer to pathogens, insect pests, or unwanted plants. (ISA, 2010).

evapotranspiration (ET) – loss of water by evaporation from the soil surface and transpiration by plants. (ISA ,2010).

event – occurrence of a set of circumstances (ISA, 2018).

failure potential – in tree risk assessment, the professional assessment of the likelihood for a tree to fail within a defined period. (ISA, 2010).

fertilizer (fertiliser, in British English) analysis – percentage of primary elements (nitrogen (N), phosphorus (P), and potassium (K) in a fertilizer. (ISA, 2010).

field capacity – maximum soil moisture content following the drainage of water due to the force of gravity. Compare to *available water*, *gravitational water*, and *permanent wilting point*). (ISA, 2010).

foliage – leaves of a plant. (ISA, 2010).

frass – fecal material and/or wood shavings produced by insects. (ISA, 2010).

frost crack – vertical split in the wood of the tree, generally near the base of the bole, caused by internal stresses and low temperatures. Radial shake. (ISA, 2010).

fruiting body – reproductive structure of a fungus. The presence of certain species may indicate decay in a tree. See *conk*. (ISA, 2010).

fungicide – chemical compound that is toxic to fungi. (ISA, 2010).

gall – abnormal swelling of plant tissues caused by gall wasps, mites, nematodes, and various insects and less commonly by fungi or bacteria. (ISA, 2010).

genus – taxonomic group, composed of species having similar fundamental traits. Botanical classification under the family level and above the specific epithet level. (ISA, 2010).

geographic information system (GIS) – computer application used to store, view, and analyze geographic information typically maps. (ISA, 2010).

girdling roots – root that encircles all or part of the trunk of a tree or other roots and constricts the vascular tissue and inhibits secondary growth and the movement of water and photosynthates. (ISA, 2010).

greenhouse effect – rise in temperature that the Earth experiences because certain gases in the atmosphere trap energy from the sun. (ISA, 2010).

growth rate – speed at which something grows. (ISA, 2010).

habit – characteristic form or manner of growth. (ISA, 2010).

hardiness – genetically determined ability of a plant to survive low temperatures. (ISA, 2010).

hardscape – constructed inanimate elements of a landscape, such as walls, pathways, and seats made of wood, stone, and/or other materials. (ISA, 2010).

hazard – a situation or condition that is likely to lead to a loss, personal injury, property damage, or disruption of activities or services; a likely source of harm. In relation to trees, a hazard is the tree part(s) identified as a likely source of harm (ISA, 2011).

hazard tree – a tree, or tree part, identified as a likely source of significant harm (ISA, 2011).

herbicide – chemical compound that kills vegetation. (ISA, 2010).

horizon – layer of soil within the soil profile. (ISA, 2010).

hybrid – plant resulting from a cross between two or more other plants that are alike. (ISA, 2010).

inspection interval – time between inspections (ISA, 2011).

i- Tree – suite of software products and management tools that allows the user to inventory the urban forest and analyze its costs, benefits, and management needs. (ISA, 2010).

included bark – bark that becomes embedded in a crotch (union) between branch and trunk or between codominant stems. Causes a weak structure. (ISA, 2010).

infectious – capable of being spread to plants from other plants or organisms. (ISA, 2010).

injection – method of putting liquid fertilizer or pesticide directly into the soil or a plant's tissues. (ISA, 2010).

integrated pest management (IPM) – method of controlling plant pests by combining biological, cultural, mechanical, physical, and/or chemical management strategies. (ISA, 2010).

job briefing – brief meeting of a tree crew at the start of every job to communicate the work plan, responsibilities and requirements, and any potential hazards. (ISA, 2010).

Leadership in Energy and Environmental Design (LEED) – green building rating system developed by the U.S. Green Building Council (USGBC) to provide standards for environmentally sustainable construction and building management practices. (ISA, 2010).

leaf spot – patches of disease or other damage on plant foliage. (ISA, 2010).

liability – something for which one is responsible. Legal responsibility. (ISA, 2010).

likelihood – chance of something happening (ISO, 2018). Within the ISO narrative, the word "likelihood" is used "to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically." The term "probability" while often having a narrower definition in English is considered an equivalent term for the purposes of the ISO narrative.

limited visual assessment (Level 1) – a visual assessment from a specified perspective such as foot, vehicle, or aerial patrol of an individual tree or a population of trees near specified targets to identify conditions or obvious defects of concern (ISA, 2017).

lion tailing (lion's tailing) – poor pruning practice in which an excessive number of branches are thinned from the inside and lower part of specific limbs or a tree crown, leaving mostly terminal foliage. Results in poor branch taper, poor wind load distribution, and a higher risk of branch failure. (ISA, 2010).

load – (1) general term used to indicate the magnitude of a force, bending movement, torque, pressure, etc. applied to a substance or material. (2) cargo; weight to be borne or conveyed. (ISA, 2010).

macronutrient – essential element that is required by plants in relatively large quantities. Contrast with *micronutrients*. (ISA, 2010).

microinjection – trunk injection technique using a small-diameter trunk penetration to introduce chemicals directly to the xylem. Contrast with *implant*. (ISA, 2010).

micronutrient – essential element that is required by plants in relatively small quantities. Contrast to macronutrients. (ISA, 2010).

mitigation – in tree risk management, reducing, alleviating, or minimizing risk of harm (damage or injury). (ISA, 2010).

monitoring – keeping a close watch. Performing regular checks or inspections. (ISA, 2010).

monoculture – cultivation or planting of a single species on agricultural land, in a forest setting or within an urban landscape. (ISA, 2010).

native species – plants indigenous to a region. Naturally occurring and not introduced by man. (ISA, 2010).

negligence – failure to exercise due care. (ISA, 2010). (1) The failure to exercise the standard of care that a reasonably prudent person would have exercised in a similar situation (Black, 2009).

negligence, gross (Willful and Wanton) – (1) a lack of even slight diligence or care. (2) a conscious, voluntary act or omission in reckless disregard of a legal duty and of the consequences to another party.

notice – legal notification required by law or agreement or imparted by operation of law because of some fact (Black, 2009).

notice, actual – notice given directly to, or received personally by, a person (Black, 2009).

notice, constructive – notice arising by presumption of law from the existence of facts and circumstances that a party had a duty to take notice of (Black, 2009).

organic – in chemistry, a substance containing carbon. In an applied arboricultural context, a substance, especially a fertilizer or pesticide, of animal or vegetable origin. Contrast with *inorganic*. (ISA, 2010).

organic layer – layer of organic matter at the soil surface. (ISA, 2010).

parasite – organism living in or on another living organism (host) from which it derives nourishment to the detriment of the host, sometimes killing the host. (ISA, 2010).

pathogen – causal agent of disease. Usually refers to microorganisms. (ISA, 2010).

permit – written order granting permission to do something. (ISA, 2010).

pest resistance – in plants, the tendency to withstand or to not develop certain pest problems. (ISA, 2010).

pesticide – any chemical used to control or kill unwanted pests such as weeds, insects, or fungi. (ISA, 2010).

phloem – plant vascular tissue that transports photosynthates and growth regulators. Situated on the inside of the bark, just outside the cambium. Is bidirectional (transports up and down). Contrast with *xylem*. (ISA, 2010).

photosynthate – general term for the sugars and other carbohydrates produced during photosynthesis. (ISA, 2010).

photosynthesis – process in green plants (and in algae and some bacteria) by which light energy is used to form glucose (chemical energy) from water and carbon dioxide. (ISA, 2010).

Plant Health Care (PHC) – comprehensive program to manage the health, structure, and appearance of plants in the landscape. (ISA, 2010).

prevention – proactive process intended to guard against adverse impact by avoiding or reducing the risk of its occurrence. (ISA, 2010).

raising – selective pruning to provide vertical clearance. (ISA, 2010).

reduction – pruning to decrease height and/or spread of a branch or crown. (ISA, 2010).

reduction cut – pruning cut that reduces the length of a branch or stem back to a lateral branch large enough to assume apical dominance. (ISA, 2010).

replacement cost – method to appraise the monetary value of trees considered replaceable with nursery- or field-grown stock. Based on the cost of replacement with the same comparable species of the same size in the same place, subject to depreciation for various factors. Contrast with *trunk formula method.* (ISA, 2010).

restoration – (1) pruning to improve the structure, form, and appearance of trees that have been improperly trimmed, vandalized, or damaged. (2) management and planting to restore altered or damaged ecosystems or landscapes. (ISA, 2010).

risk – (1) The uncertainty of a result, happening, or loss; the chance of injury, damage, or loss (Black, 2009). - effect of uncertainty on objectives (ISO, 2018).
The ISO provides several relevant considerations to this definition. These include: "An effect is a deviation from the expected. It can be positive, negative or both, and can address, create or result in opportunities and threats." And "risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood. the combination of the likelihood of an event and the severity of the potential consequences." (ISA, 2011).

risk, inherent – (2) A common risk that people bear whenever they decide to engage in a certain activity (Black, 2009).

risk analysis – the systematic use of information to identify sources and to estimate risk exposure (ISA, 2011).

risk assessment – process of evaluating what unexpected things could happen, how likely they are to happen, and what the likely outcomes are. In tree management, the systematic process to determine the level of risk posed by a tree, tree part, or group of trees. (ISA, 2010) and/or the process of risk identification, analysis, and evaluation (ISA, 2011).

risk evaluation – the process of comparing the assessed risk against given risk criteria to determine the significance of the risk (ISA, 2011).

risk management – coordinate activities to direct and control an organization about risk (ISO, 2018). The application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate risk (ISA, 2011).

root ball – soil containing all (e.g. containerized) or a portion (e.g., B&B) of the roots that are moved with a plant when it is planted or transplanted. (ISA, 2010).

root collar/root crown excavation – process of removing soil to expose and assess the root collar (root crown) of a tree. (ISA, 2010).

root crown – area where the main roots join the plant stem, usually at or near ground level. Root collar. (ISA, 2010).

runoff – that part of precipitation that does not evaporate and is not transpired but flows through the ground or over the ground surface and returns to bodies of water.

rust – disease caused by a certain group of fungi and characterized by reddish brown spots on the foliage and/or the formation of stem galls. (ISA, 2010)

sapwood – outer wood (xylem) is active in longitudinal transport of water and minerals. (ISA, 2010).

scaffold branches – permanent or structural branches that form the scaffold architecture or structure of a tree. (ISA, 2010).

shall – word that designates a mandatory requirement within the ANSI standards or contract documents. Contrast with *should*. (ISA, 2010).

should – word that designates an advisory recommendation in the ANSI standards or contract documents. Contrast with *shall*. (ISA, 2010).

sign – physical evidence of a causal agent (e.g. insect eggs, borer hole, frass). Contrast with *symptoms*. (ISA, 2010).

site considerations – factors that must be considered when assessing a site for planting, tree conservation, or preservation or any operation. (ISA, 2010).

soil analysis – analysis of soil to determine pH, mineral composition, structure, salinity, and other characteristics. (ISA, 2010).

soil compaction – compression of the soil, often because of vehicle or heavy-equipment traffic, that breaks down soil aggregates and reduces soil volume and total pore space, especially macropore space. (ISA, 2010).

soil moisture - water stored in or at the land surface and available for evapotranspiration. (ISA, 2010)

soil profile – vertical section through the soil and all the soil horizons. (ISA, 2010).

species – taxonomic group of organisms composed of individuals of the same genus that can reproduce among themselves and have similar offspring. (ISA, 2010).

species diversity – measure of the number and variety of different species found in each area. (ISA, 2010).

specifications – detailed plans, requirements, and statements of procedures and/or standards used to define and guide work. (ISA, 2010).

stakeholder – person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity (ISO, 2018).

standard of care – in the law of negligence, the degree of care that a reasonable person should exercise (Black, 2009).

stormwater runoff – water originating from precipitation (rain or melting snow and ice) that flows above ground rather than infiltrating into the soil. May occur if soils are frozen or saturated or if the rate at which precipitation falls is greater than the infiltration rate of a soil. (ISA, 2010).

structural defects – any naturally occurring or secondary conditions such as cavities, poor branch attachments, cracks, or decayed wood in the trunk, crown, or roots of a tree root growth. (ISA, 2010).

structural pruning – pruning to establish a strong arrangement or system of scaffold branches. (ISA, 2010).

sustainability – the ability to maintain ecological, social, and economic benefits over time. (ISA, 2010).

symptom – plant reaction to disease or disorder (e.g. wilting, dieback). Contrast to *sign*. (ISA, 2010).

systemic – (1) substance that moves throughout an organism after it is absorbed. (2) any condition, disease, disorder, pest that affects the entire organism. (ISA, 2010).

systemic pesticide – pesticide that moves throughout a tree after it has been injected or absorbed (often by roots or foliage). (ISA, 2010).

taper – change in diameter over the length of trunks, branches, and roots. (ISA, 2010).

target – people, property, or activities or services that could be injured, damaged, or disrupted by a tree or tree part (ISA, 2011).

target zone – the area where a tree or tree part is likely to land if it were to fail (ISA, 2011).

thinning – in pruning, the selective removal of live branches to provide light or air penetration through the tree or to lighten the weight of the remaining branches. (ISA, 2010).

threshold – (1) in Integrated Pest Management, pest population levels requiring action. (2) in hazard assessment, risk assessment, and risk management, levels of risk requiring action. (ISA, 2010).

tomogram – image generated by tomography. Created by sending waves through an object; a computer then produces images of cross sections of the object by using information about how the waves change. (ISA, 2010).

topping – inappropriate pruning technique to reduce tree size. Cutting back a tree to predetermined crown limit, often at internodes. (ISA, 2010).

transpiration – water vapor loss through the stomata of leaves. (ISA, 2010).

tree inventory – record of each tree within a designated population; typically includes species, size, location, condition, and maintenance requirements. (ISA, 2010).

tree protection zone (TPZ) – defined area within which certain activities are prohibited or restricted to prevent or minimize potential injury to designated trees, especially during construction or development. (ISA, 2010).

tree risk assessment – a systematic, technical process used to identify, analyze, and evaluate the risk associated with a singular tree (ISA, 2011).

trenching – linear, open excavation, often used to install utilities or structural footings. Can cause tree root damage. (ISA, 2010).

trunk flare – transition zone from trunk to roots where the trunk expands into the buttress or structural roots. Root flare. (ISA, 2010).

trunk formula method – method to appraise the monetary value of trees considered too large to be replaced with nursery or field-grown stock. Based on developing a representative unit cost for replacement with the same or a comparable species of the same size and in the same place, subject to depreciation for various factors. Contrast to *replacement method*. (ISA, 2010).

urban forestry – management of naturally occurring and planted trees and associated plants in urban areas. (ISA, 2010).

urban heat island - the relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, the concrete jungle effects on heat retention, changes in surface albedo, changes in pollution and aerosols, and so on.

vigor – overall health. Capacity to grow and resist stress. Sometimes limited to reference to genetic capacity. (ISA, 2010).

visual tree assessment (VTA) – method of assessing the structural integrity of trees using external symptoms of mechanical stress (such as bulges, reactive growth, etc.) and defects (cracks, cavities, etc). (ISA, 2010).

vitality – overall health. Ability of a plant to deal effectively with stress. (ISA, 2010)

water sprout – upright, epicormic shoot arising from the trunk or branches of a plant above the root graft or soil line. Incorrectly called a sucker. (ISA, 2010).

xylem – main water- and mineral-conducting (unidirectional, up only) tissue in trees and other plants. Provides structural support. Arises (inward) from the cambium and becomes wood after lignifying. Contrast with *phloem*. (ISA, 2010).

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APPENDICES

APPENDIX 1. TREE INVENTORY CONDITION REPORT

Rating category	Condition components			Percent rating
	Health	Structure	Form	
Excellent	High vigor and nearly perfect health with little or no twig dieback, discoloration, or defoliation.	Nearly ideal and free of defects.	Nearly ideal for the species. Generally symmetric. Consistent with the intended use.	100%
Good	Vigor is normal for the species. No significant damage due to diseases or pests. Any twig dieback, defoliation, or discoloration is minor.	Well-developed structure. Defects are minor and can be corrected.	Minor asymmetries/deviations from species norm. Mostly consistent with the intended use. Function and aesthetics are not compromised.	61% to 80%
Fair	Reduced vigor. Damage due to insects or diseases may be significant and associated with defoliation but is not likely to be fatal. Twig dieback, defoliation, discoloration, and/or dead branches may comprise up to 50% of the crown.	A single defect of a significant nature or multiple moderate defects. Defects are not practical to correct or would require multiple treatments over several years.	Major asymmetries/deviations from species norm and/or intended use. Function and/or aesthetics are compromised.	41% to 60%
Poor	Unhealthy and declining in appearance. Poor vigor. Low foliage density and poor foliage color are present. Potentially fatal pest infestation. Extensive twig and/or branch dieback.	A single serious defect or multiple significant defects. Recent change in tree orientation. Observed structural problems cannot be corrected. Failure may occur at any time.	Largely asymmetric/abnormal. Detracts from intended use and/or aesthetics to a significant degree.	21% to 40%
Very poor	Poor vigor. Appears to be dying and in the last stages of life. Little live foliage.	Single or multiple severe defects. Failure is probable or imminent.	Visually unappealing. Provides little or no function in the landscape.	6% to 20%
Dead				0% to 5%

(Gooding, 2019)

APPENDIX 2. TREE INVENTORY VALUATION CALCULATION

A requirement of the inventory project was the calculation of an amenity value for each tree inventoried. The basis for this calculation was the International Society of Arboriculture's *Plant Appraisal Guide*, 10th Edition. An outcome of the process was the individual calculation of plant value and the creation of an algorithm for calculating value for use within the university's GIS. The following narrative provides an explanation of the processes described within the *Guide* and the calculations obtained.

There are several ways to calculate tree value. Two approaches were ultimately utilized for the Yale inventory project. The first is the income approach and the second was based on what is known as the cost approach.

The income approach provides a current dollar value from future benefits. The iTree analysis described elsewhere in this report provides this information by presenting environmental benefits both in volume and dollars. For example, the number of gallons of stormwater uptake from the tree population being managed and the commensurate dollar savings in reduced storm water treatment, equipment wear and meeting tree watering needs.

The cost approach, described here, uses several methods and techniques to reproduce the value of the subject tree either through a direct or extrapolated cost technique. The difference between the two techniques is typically a function of the size of the subject tree. The direct cost technique is used for trees whose size is small enough to be readily available from nurseries. The extrapolation technique is used for subject trees that are larger than what is easily obtainable from a nursery. The inventory specifications required that all trees in the project area with a diameter of four-inches or greater be assessed. As four inches is not a size that is readily available for the range of species the campus plants, the extrapolated cost technique was employed.

The cost calculations have a range of required variables which increases the complexity of the calculations. Out of necessity, several variables required a default number to simplify the programming required in the final data storage area. The following variables were utilized in the extrapolated cost technique:

A. Caliper and Cross-Sectional Area of the Largest Transplantable-Sized Tree Available. The largest transplantable sized tree for the area is a tree with a three-inch caliper. This size tree has a cross-sectional area of 7 in^2. These two numbers can be "fixed variables" in the calculations—that is, it is a number that can be established by contacting local nurseries. The number does not change until Yale determines that updated information is required.

B. Wholesale Purchase Price of the Largest Transplantable-Sized Tree Available The wholesale purchase price of a 3-inch caliper tree is $266. This number was established by contacting several nurseries in Connecticut. It is also a fixed variable. The number should be updated every few years to match current market prices.

C. Unit Cost. The unit cost is the cost per square inch of the Largest Transplantable-Sized Tree Available. This is determined by dividing B by the cross-sectional area in A. In our example: Unit Cost equals $266 (B)/7$in^2$ (A), or $38.00/$in^2$.

D. Diameter and Cross-Sectional Area of the Subject Tree. The diameter of the subject tree is required to determine the cross-sectional area of the subject tree. For example, a 15-inch diameter tree has a cross-sectional area of 177 in^2.

E. Base Price - The unit cost is used to extrapolate a base price for the subject tree being valued. For our example, the base price of the subject tree is extrapolated by multiplying the unit cost (\$38.00/ in^2) by the cross-sectional area of the subject tree (177 in^2), or \$6,726.

Note on base price: Unless a purchase price is derived for each species that Yale purchases, an average purchase price for all species purchased is typically used. If this is the case, then all subject trees with the same diameter will have the same base price, regardless of species.

F. Condition. Condition is the first of three depreciations applied to the base price that is specific to the subject tree. The condition assigned to the subject tree is assigned a representative percentage. The following condition percentages were used for the Yale calculations of amenity value and for the iTree analysis:

Excellent	90%
Good	80%
Fair	50%
Poor	30%
Very Poor	10%
Dead	0%

For the example, the subject tree was identified as in Good condition. Applying the condition depreciation to the base price results in the following:

Base Price (E) x Condition Depreciation (F), or $6,726 x 80%, or $5,380.80

G. Functional Limitations. This is the second of the three depreciations. It is the interaction between the tree and site that will limit growth, performance, or function? Unless assigned to each tree, in a large inventory an average functional limitation is assigned. This accounts for the fact that most species have at least one pathology issue and each tree in the landscape has some site placement issue. For example, the subject tree was assigned a functional limitation of 75 percent. Applying this depreciation to the already condition-depreciated base price results in the following:

Condition-Depreciated Base Price (F) x Functional Limitations Depreciation (G), or $5,380.80 x 75%, or $4,035.60

H. External Limitations. This is the third of the three depreciations. This depreciation is the factors that can affect the plant that are outside the control of the tree owner. For example, the subject tree was assigned an external limitation of 90 percent. Applying this depreciation to the already condition-depreciated and functional limitations-depreciated base price results in the following:

Condition-Depreciated and Functional Limitation Depreciated Base Price (G) x 90%, or $4,035.60 x 90%, or $3,632.04. This number is termed the **Depreciated Base Price**.

I. Installation Costs. After the depreciations are applied, the installation cost of the largest available sized tree is added to the depreciated base price to obtain a final appraisal number. For example, the average cost to install a 3-inch caliper tree is $725. Adding this installation cost to the depreciated base price results in the following:

Depreciated Base Price (H) + $725, or $3,632.04 + $525, or $4,157.04.

J. Assignment Cost. The number obtained in I is rounded to three significant figures to obtain the final appraisal number, or $4,160.

The algorithm for calculating the amenity appraisal number of Yale's trees is:

Assignment Outcome = Diameter^2(.7845) x Unit Cost ($38) x Condition x Functional Limitations (75%) x External Limitations (905) + Installation Costs ($750).

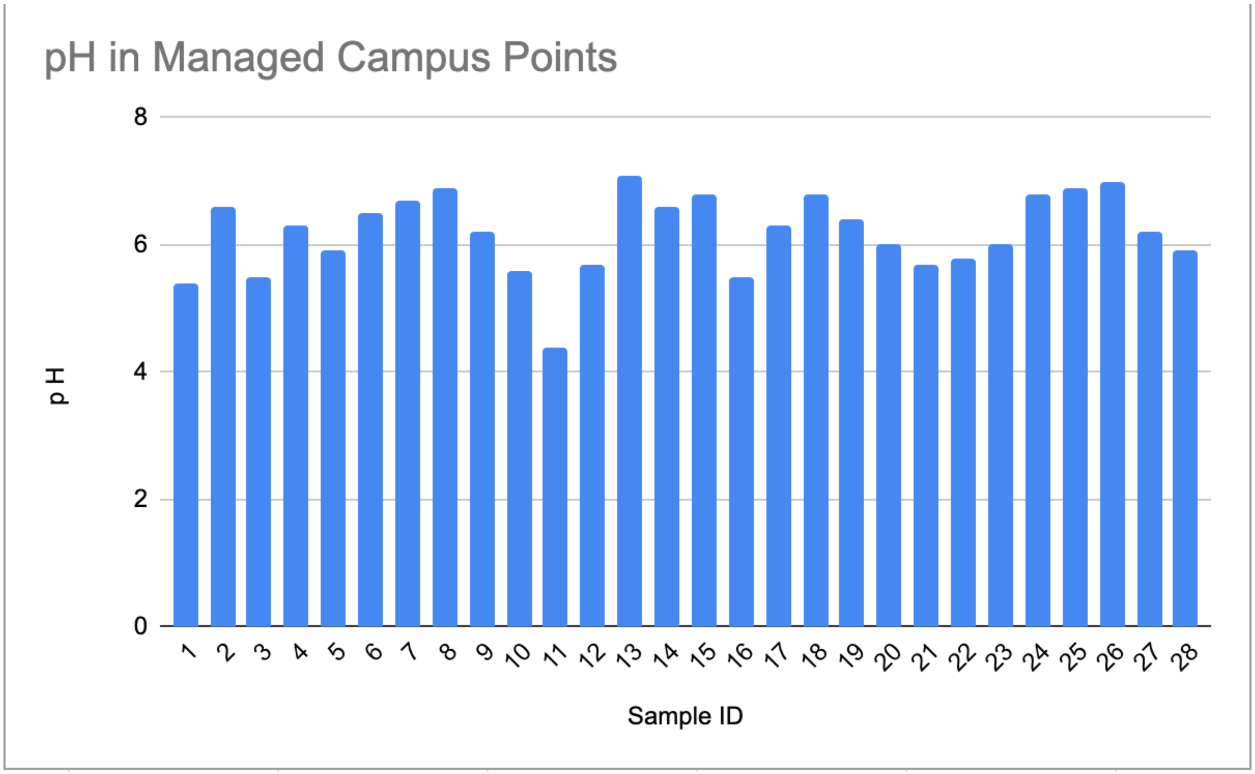
Where: Diameter and Condition are derived from the inventory;
Unit Cost and Installation Cost are derived from local nurseries and landscapers. These are variables that should be updated every year or every other year.
Functional Limitations and External Limitations were subjectively assigned. These are variables that in a more complex program could be applied to the tree or species level.

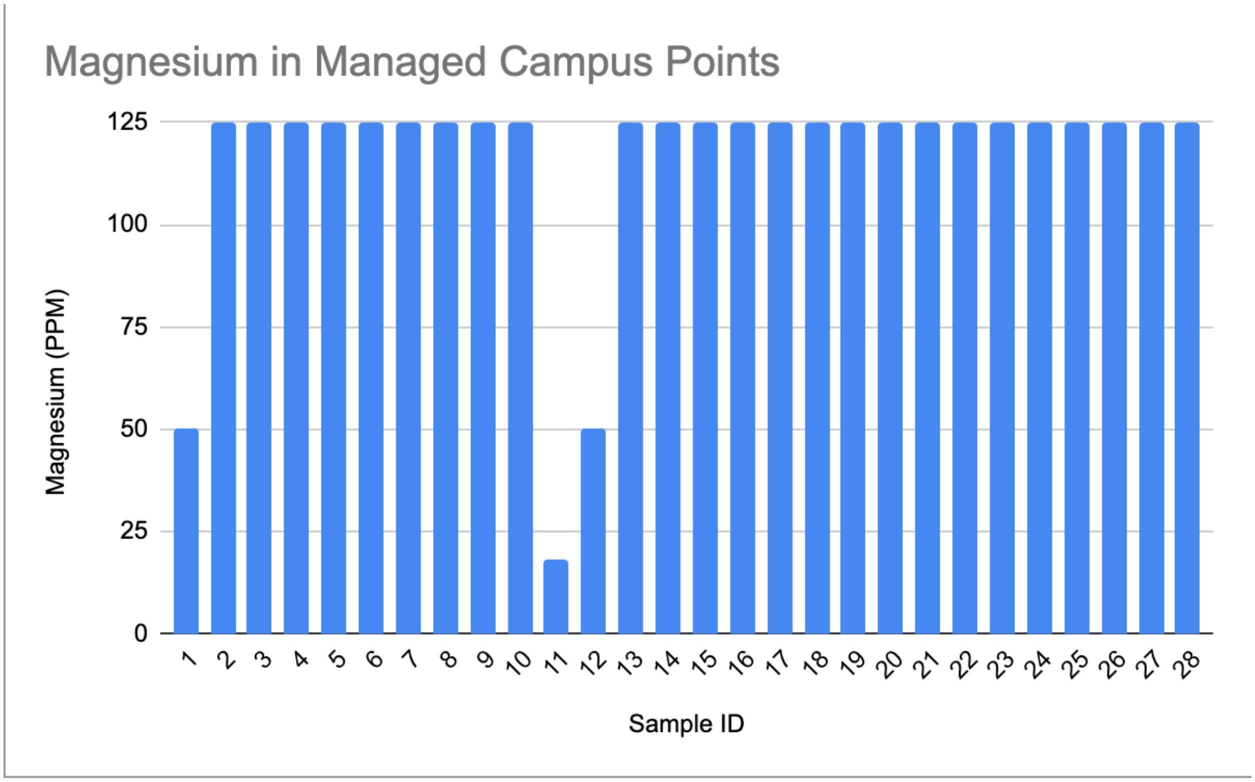
There are nuances for an individual tree that possibly cannot be captured in a programmed application for a large inventory. If an appraisal is required for insurance, bonding or litigation purposes, the authors suggest that an appraisal for the subject tree be conducted. Information that would provide a number that is different from the inventory calculated value include more current nursery purchase prices and depreciations that are more specific to the subject tree.

An additional note germane to the appraisal discussion is the value assigned to a dead tree. In the current calculations, dead trees are included. Because of the total depreciation for a condition of dead, the appraised value for dead trees is equal to the installed cost of $725. To include dead trees in the calculations is a policy decision. Some will view all trees, even dead ones, having some intrinsic value as a function of its location and purpose, such as a wildlife tree. Others would justifiably argue that dead trees have no amenity value. The algorithm calculated the 53 dead trees as $38,425, a nominal value considering the total value of $27 million. The final algorithm within Yale's GIS would have to be programmed to disallow dead trees if that is the policy the university desires.

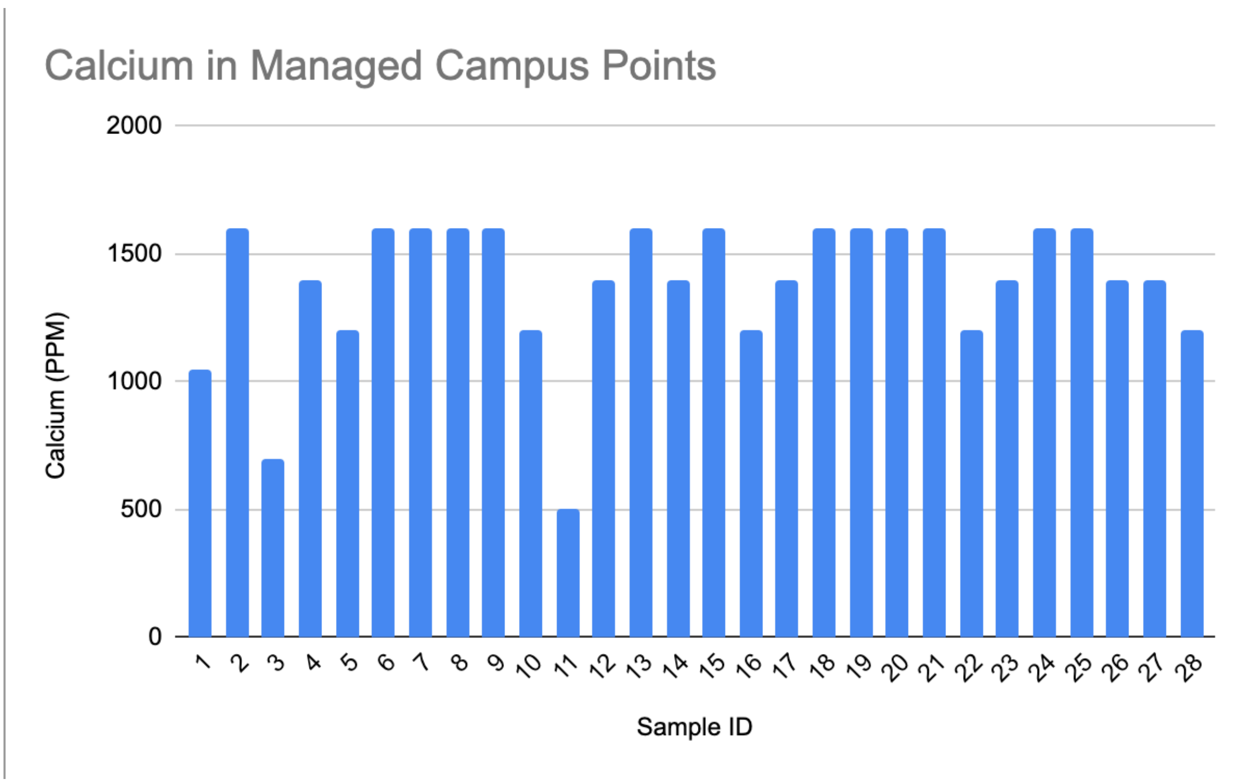
APPENDIX 3. SOIL TEST RESULTS

Appendix 3A. Managed Areas

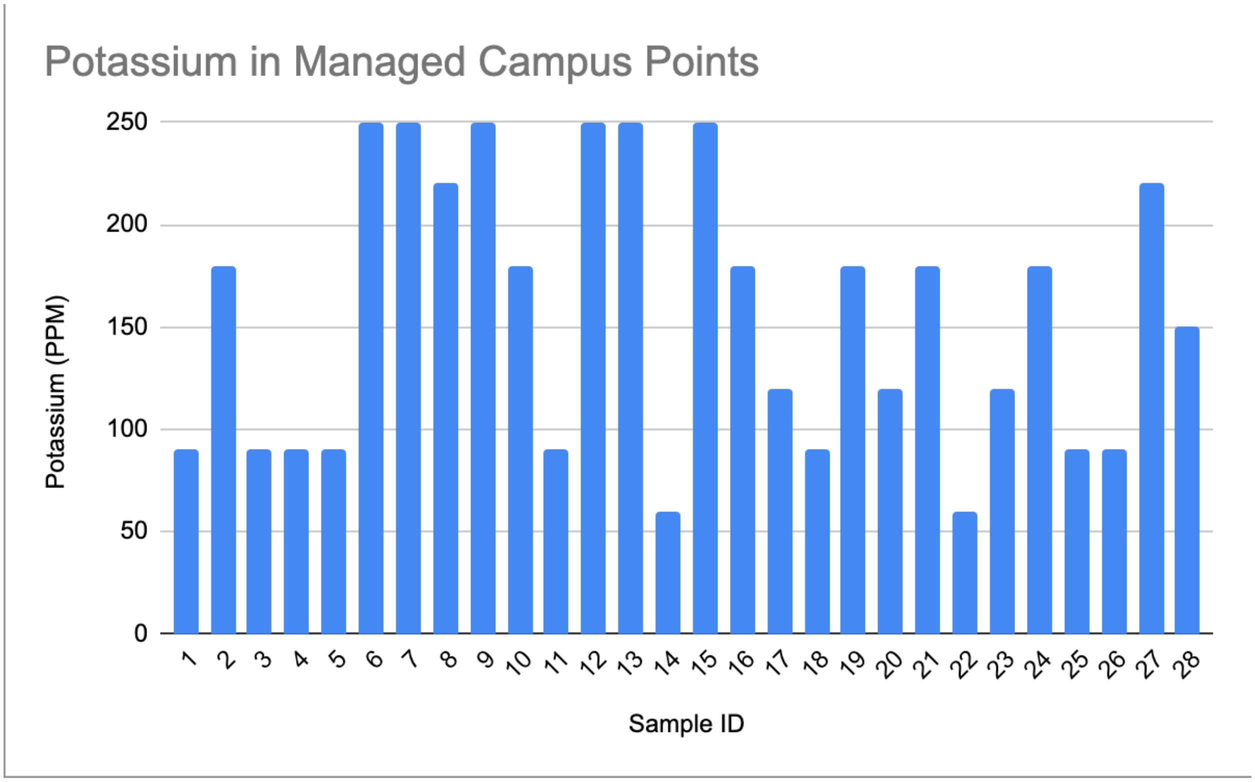




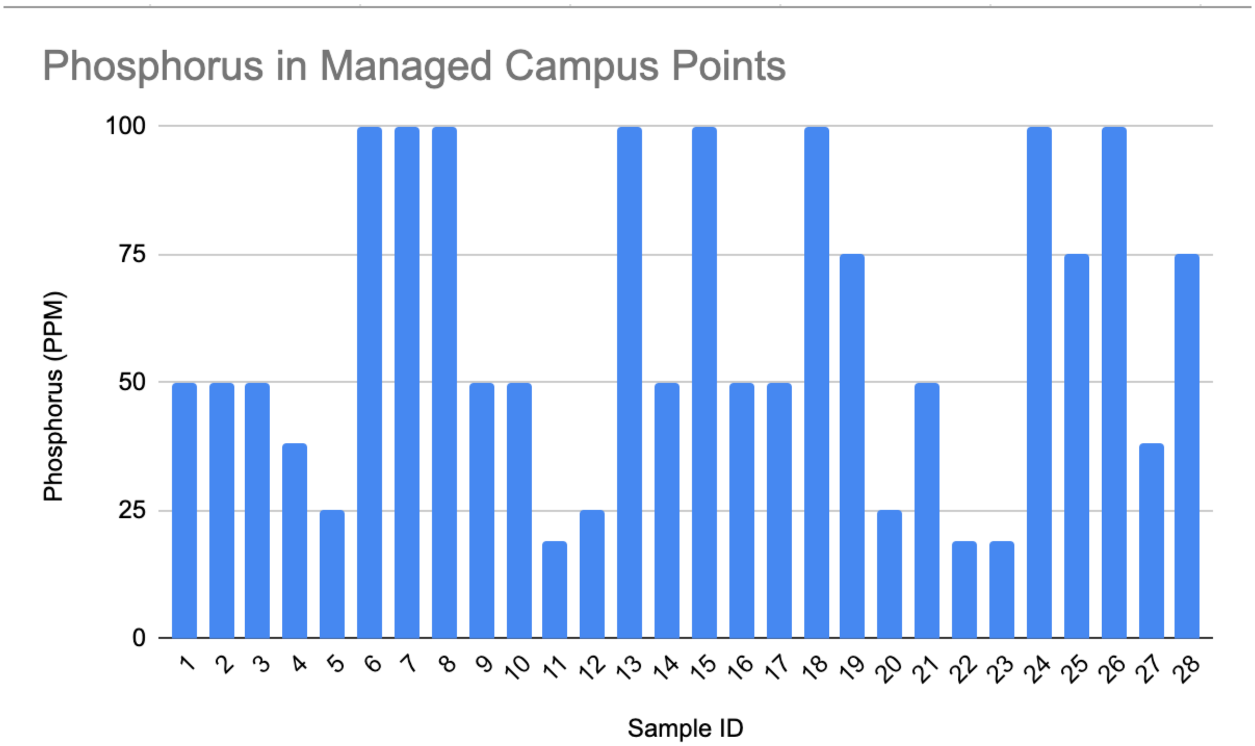
Magnesium in Managed Campus Points
Magnesium (PPM)
125
100
75
50
25
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID



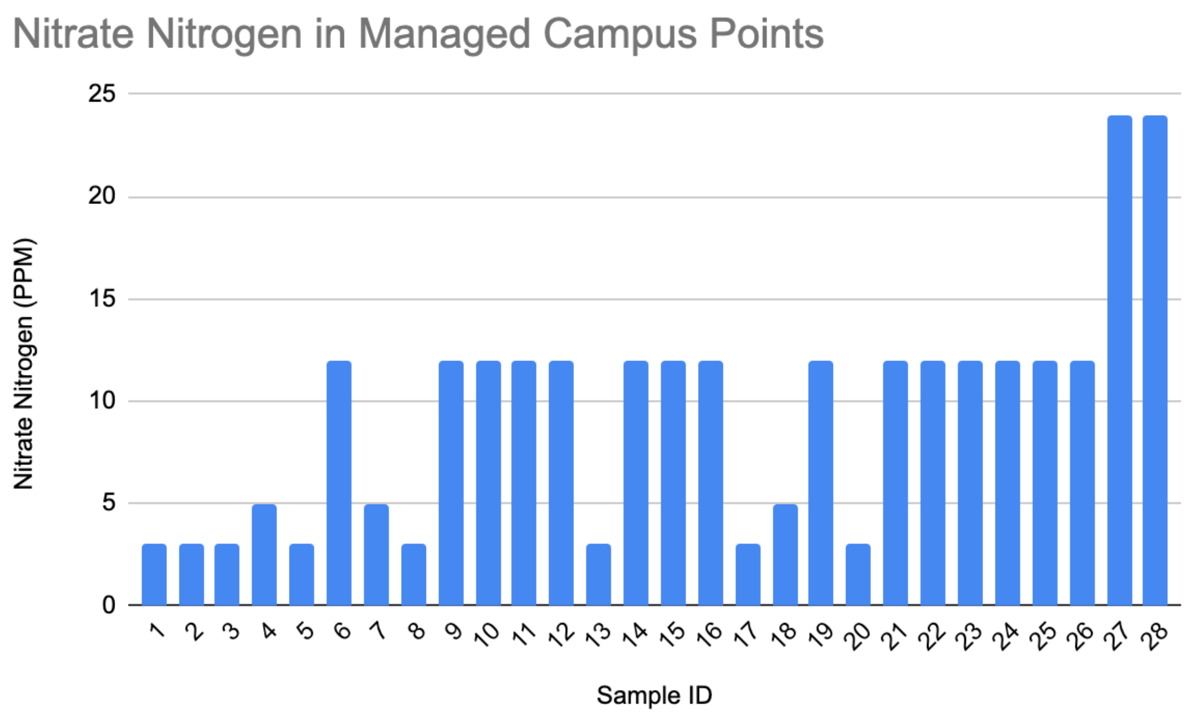
Calcium in Managed Campus Points
Calcium (PPM)
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID



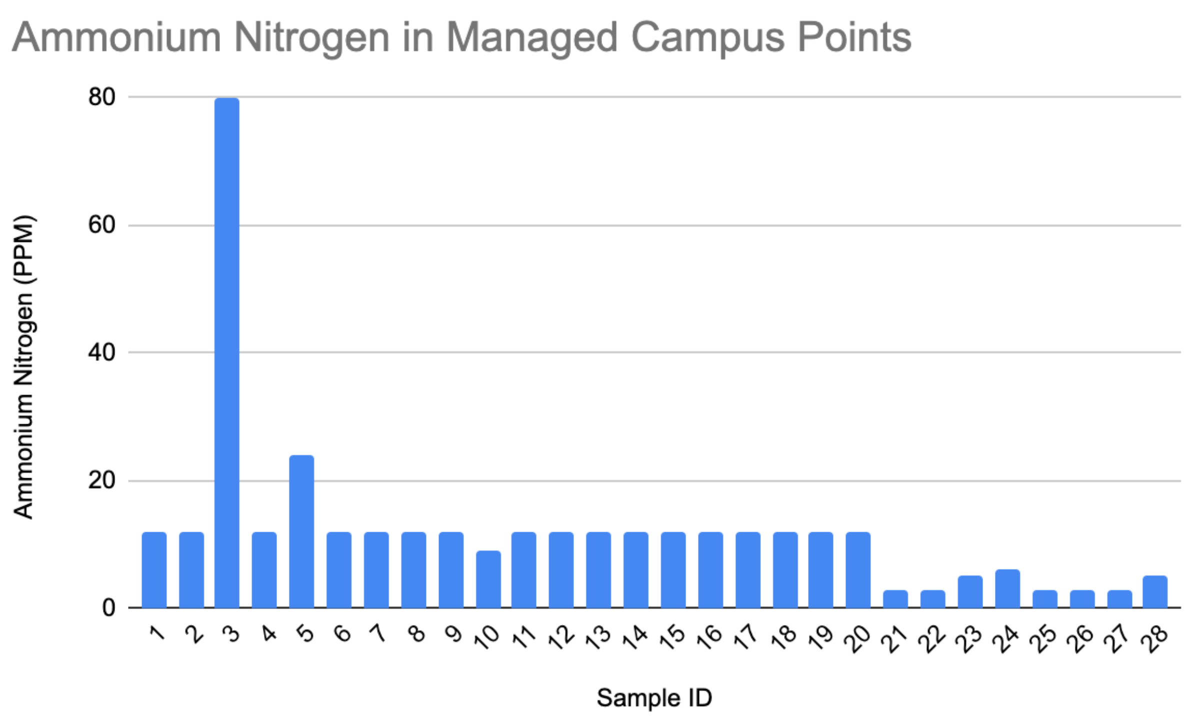
Potassium in Managed Campus Points
250
200
150
100
50
0
Potassium (PPM)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID



Phosphorus in Managed Campus Points
100
75
50
25
0
Phosphorus (PPM)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID

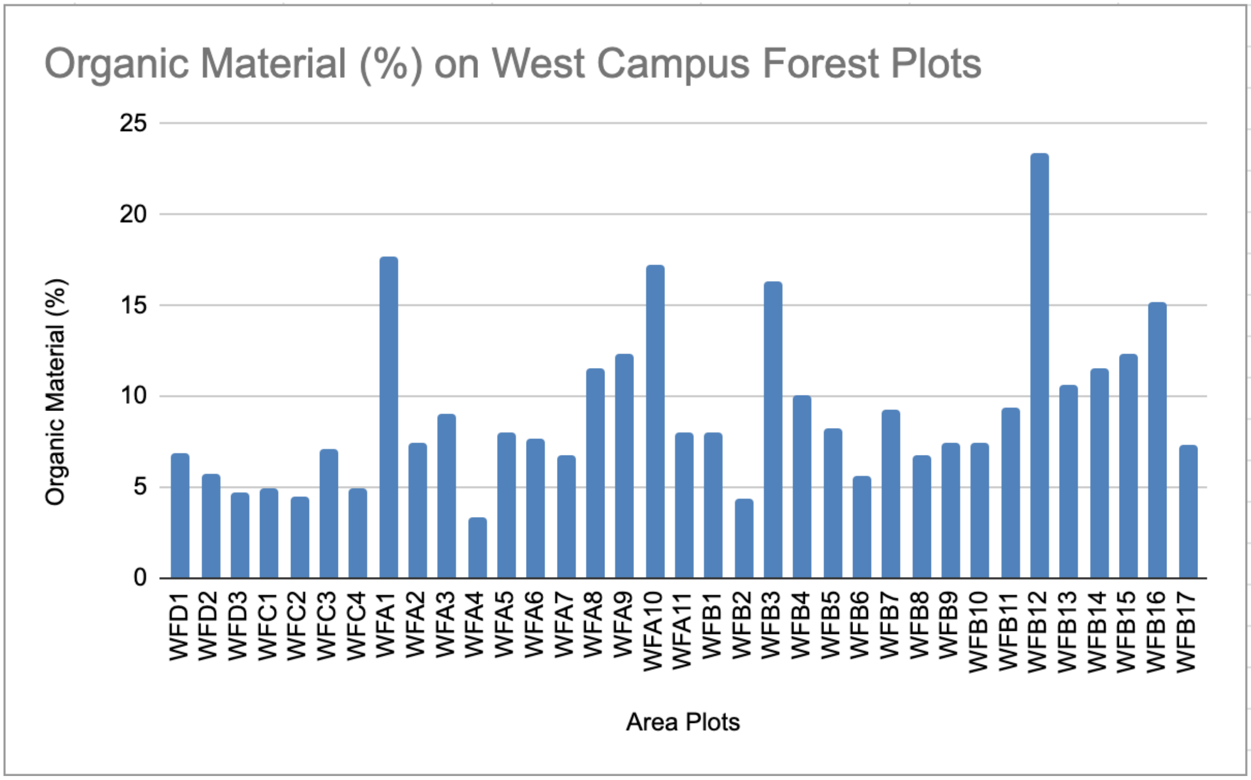


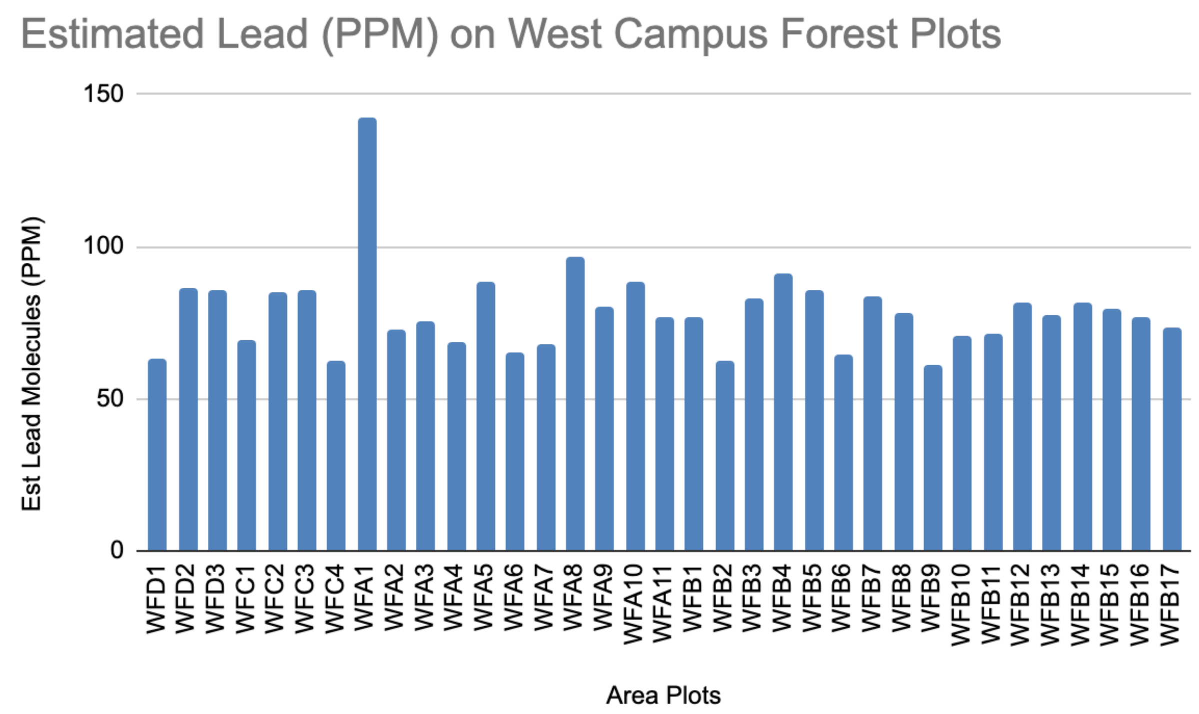
Nitrate Nitrogen in Managed Campus Points
Nitrate Nitrogen (PPM)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID



Ammonium Nitrogen in Managed Campus Points
Ammonium Nitrogen (PPM)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Sample ID

Appendix 3B. West Campus Forested Area Soil Test Results





Estimated Lead (PPM) on West Campus Forest Plots
150
100
50
0
Est Lead Molecules (PPM)
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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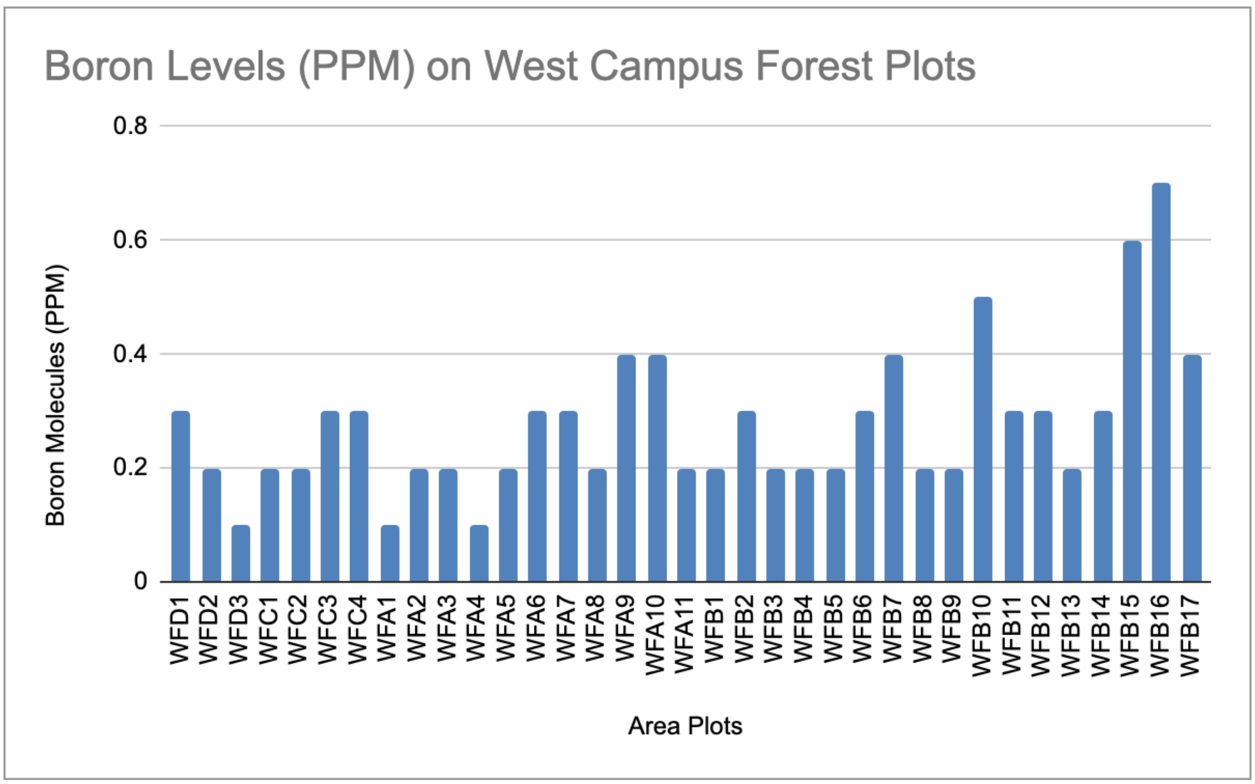
WFB16
WFB17
Area Plots



Boron Levels (PPM) on West Campus Forest Plots
0.8
0.6
0.4
0.2
0
Boron Molecules (PPM)
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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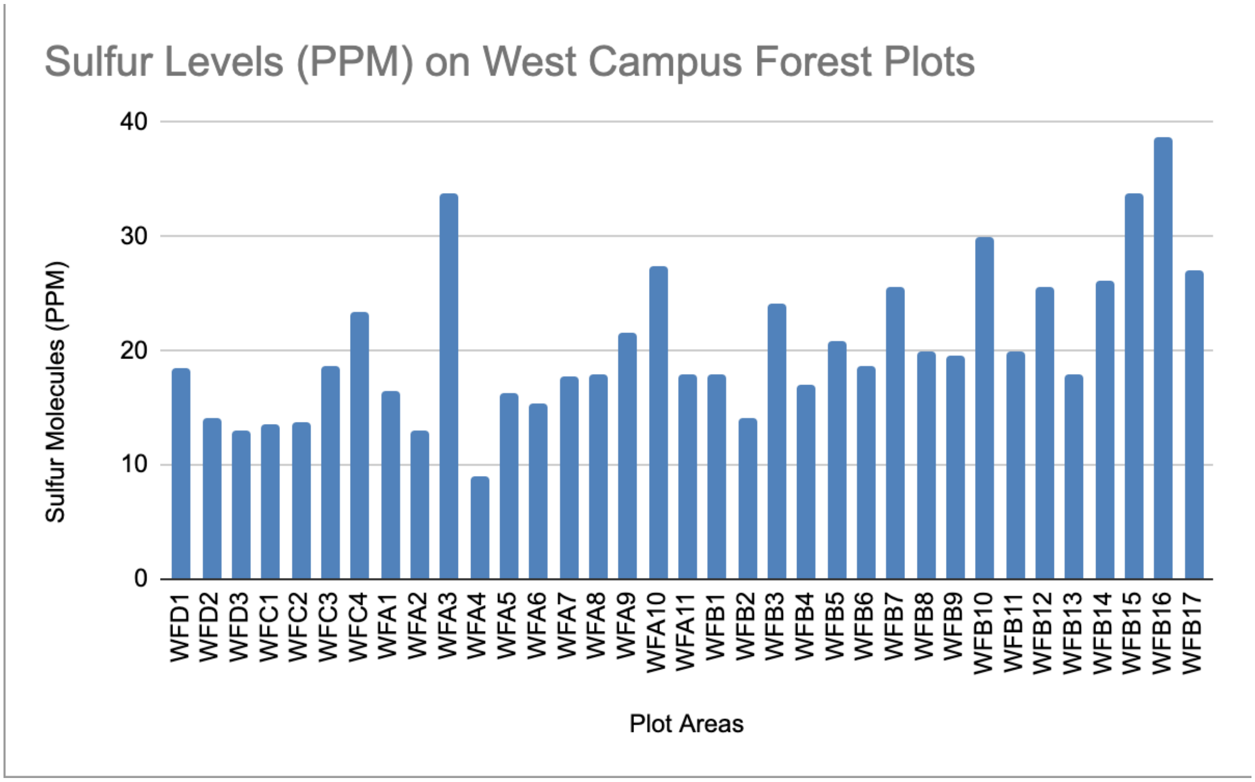
WFB16
WFB17
Area Plots



Sulfur Levels (PPM) on West Campus Forest Plots
Sulfur Molecules (PPM)
40
30
20
10
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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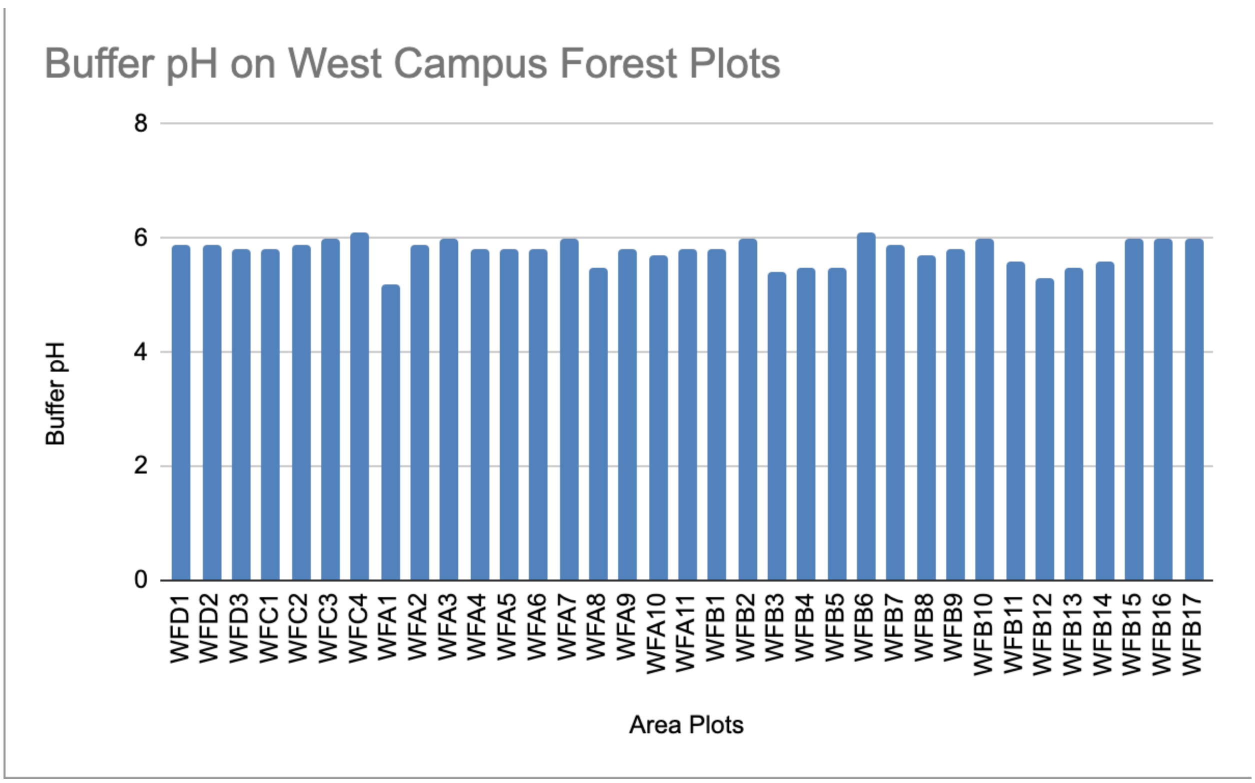
WFB15
WFB16
WFB17
Plot Areas



Buffer pH on West Campus Forest Plots
Buffer pH
8
6
4
2
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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WFB12
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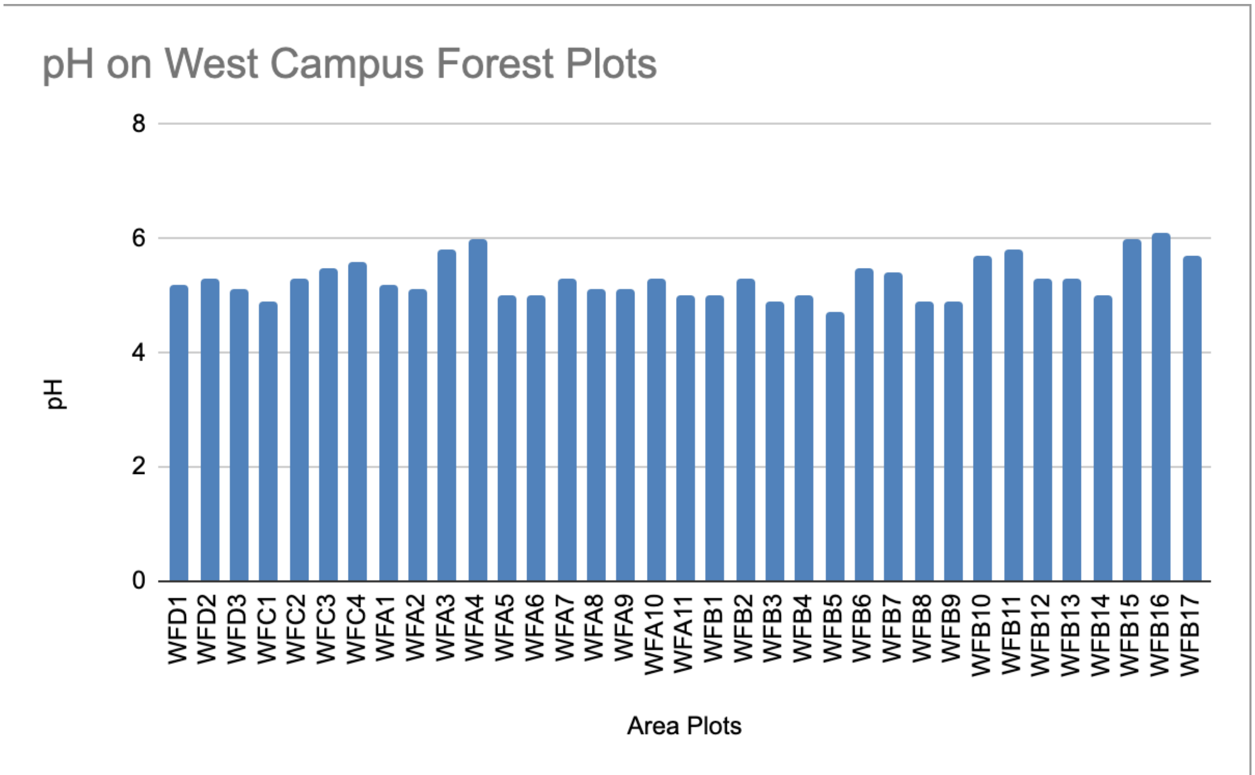
WFB15
WFB16
WFB17
Area Plots


pH on West Campus Forest Plots
8
6
4
2
0
pH
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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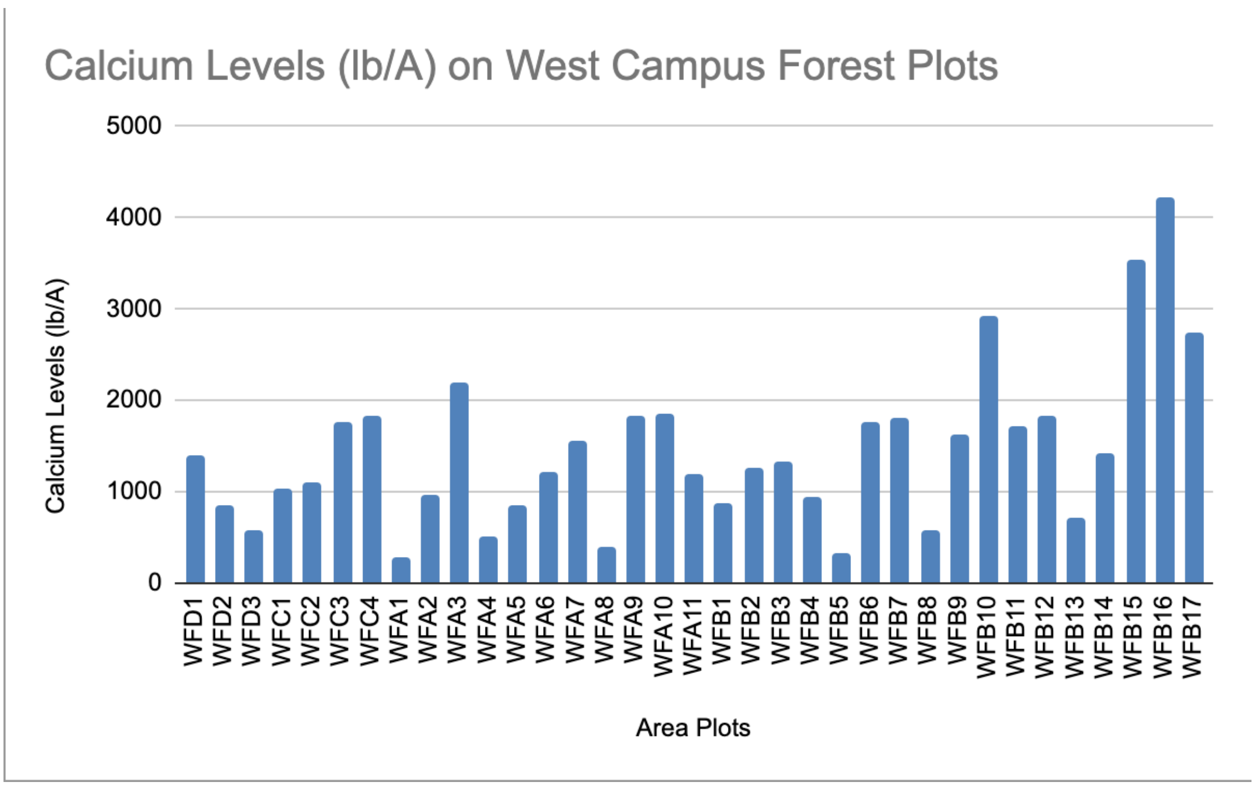
WFB16
WFB17
Area Plots


Calcium Levels (lb/A) on West Campus Forest Plots
5000
4000
3000
2000
1000
0
Calcium Levels (lb/A)
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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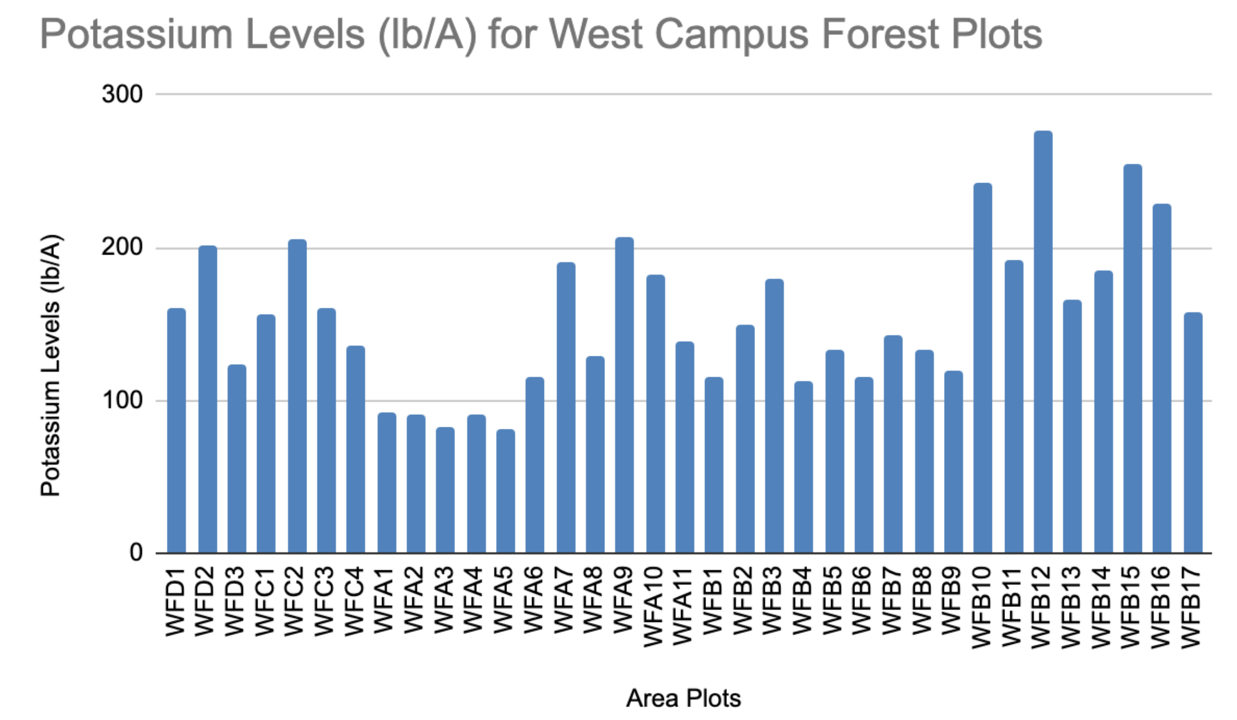
WFB16
WFB17
Area Plots


Potassium Levels (lb/A) for West Campus Forest Plots
Potassium Levels (lb/A)
300
200
100
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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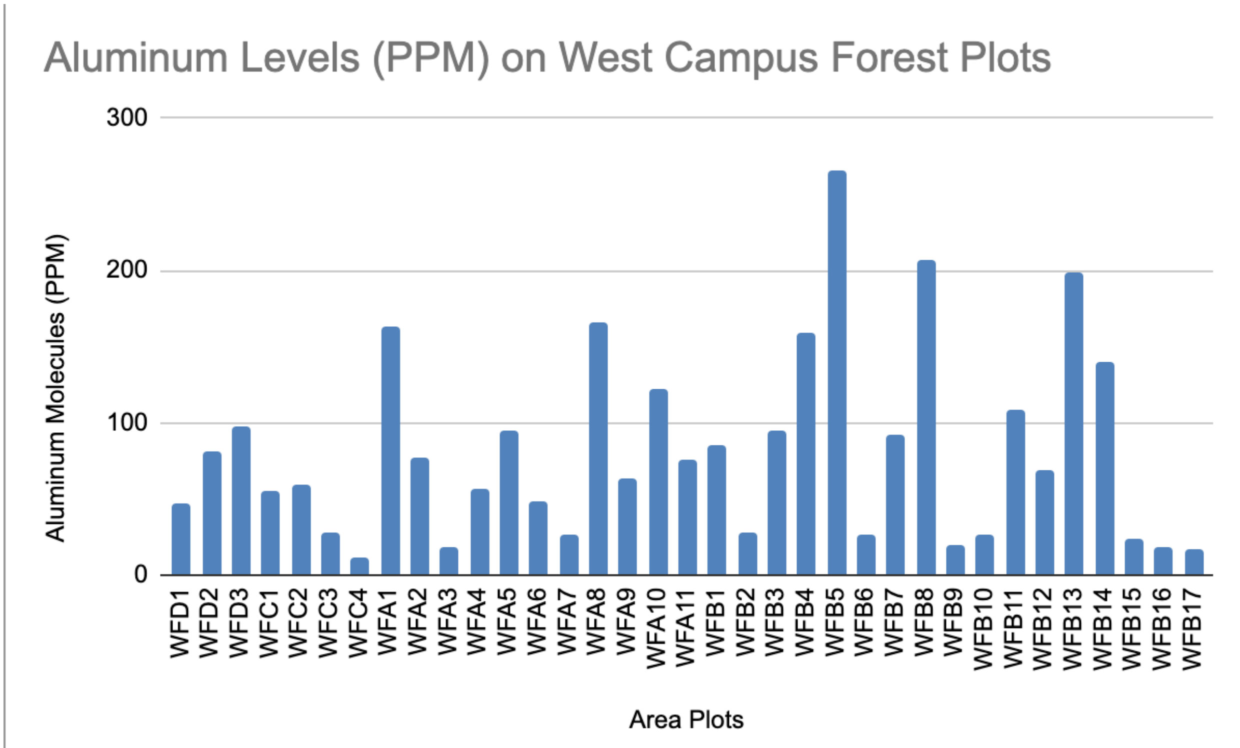
WFB16
WFB17
Area Plots


Aluminum Levels (PPM) on West Campus Forest Plots
Aluminum Molecules (PPM)
300
200
100
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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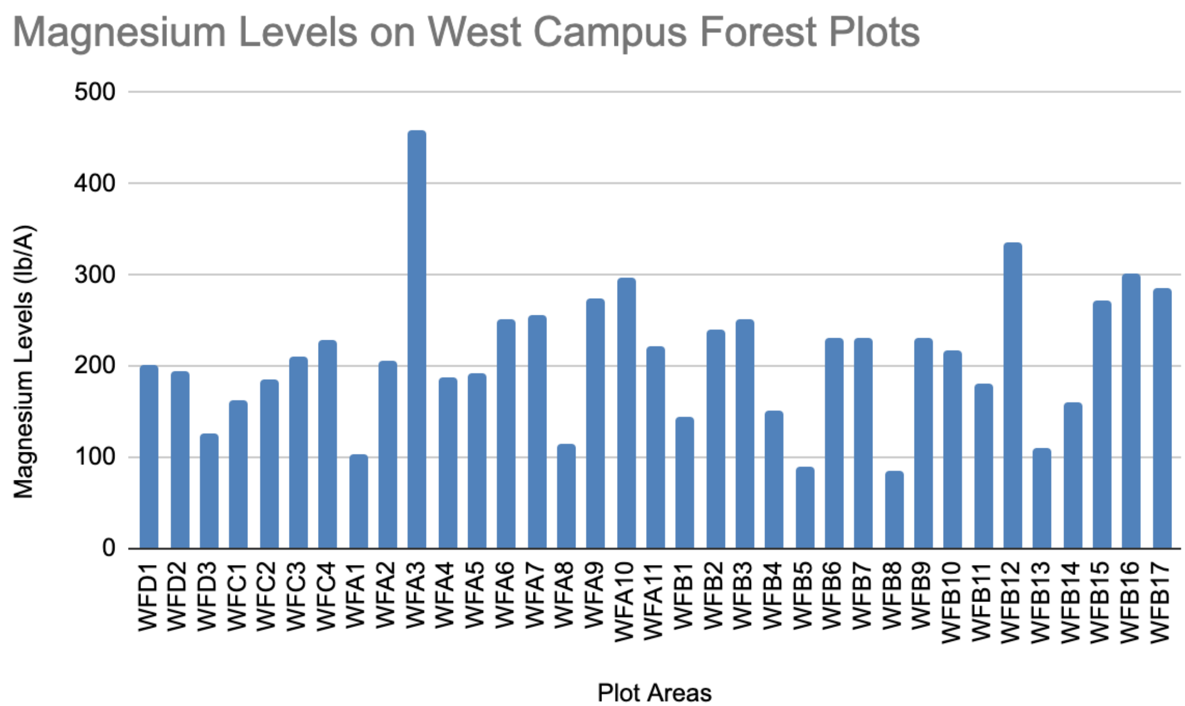
WFB16
WFB17
Area Plots


Magnesium Levels on West Campus Forest Plots
Magnesium Levels (lb/A)
500
400
300
200
100
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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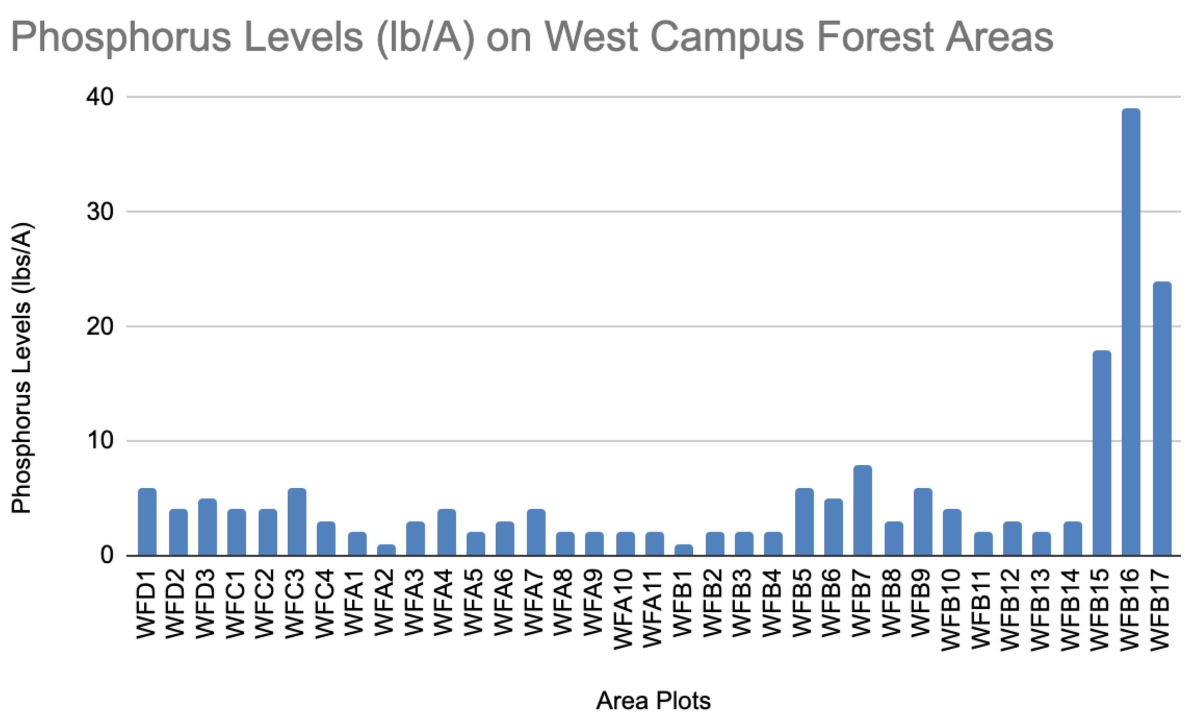
WFB16
WFB17
Plot Areas


Phosphorus Levels (lb/A) on West Campus Forest Areas
Phosphorus Levels (lbs/A)
40
30
20
10
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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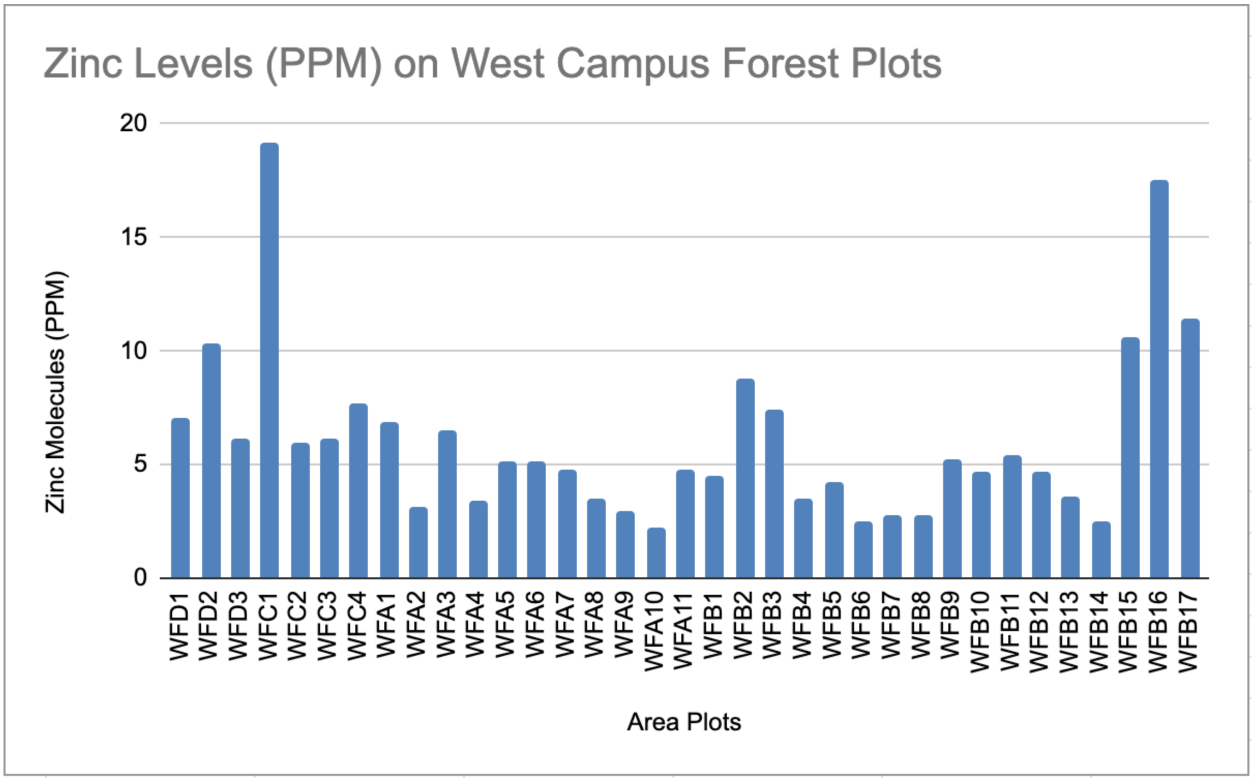
WFB16
WFB17
Area Plots


Zinc Levels (PPM) on West Campus Forest Plots
20
15
10
5
0
Zinc Molecules (PPM)
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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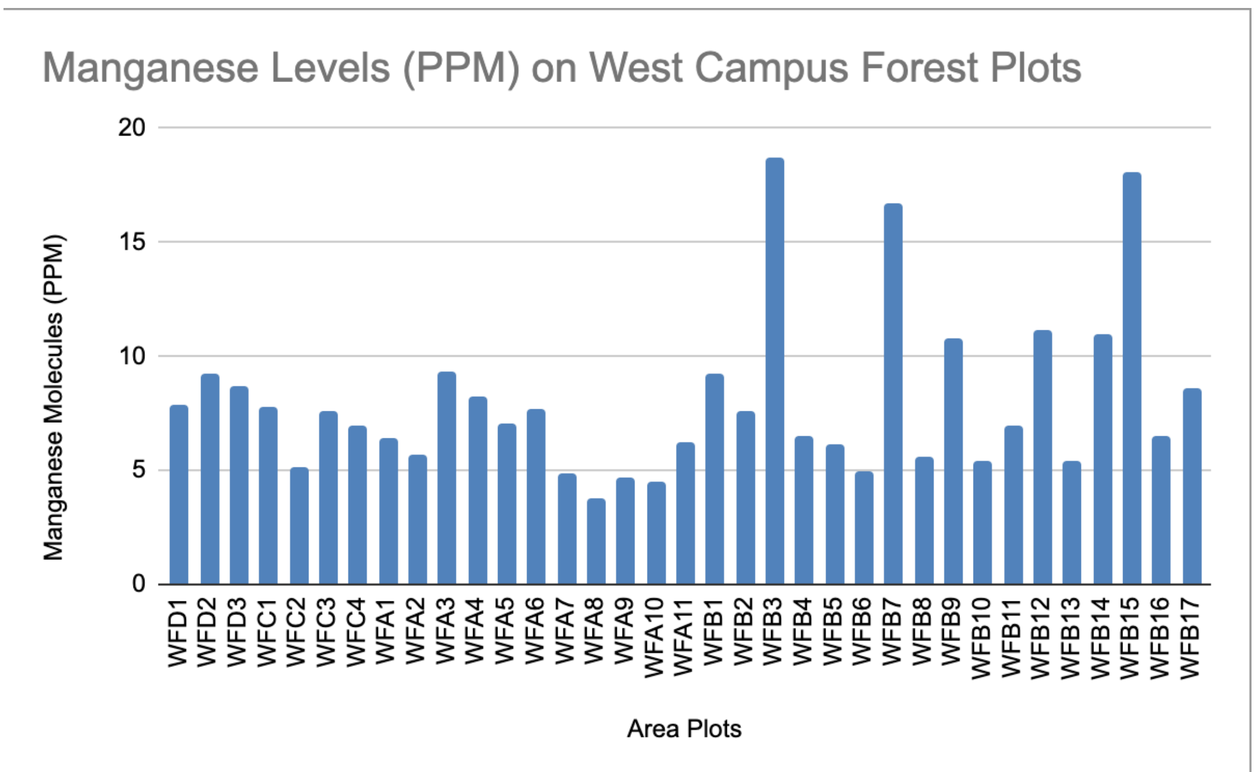
WFB16
WFB17
Area Plots


Manganese Levels (PPM) on West Campus Forest Plots
20
15
10
5
0
Manganese Molecules (PPM)
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
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WFB6
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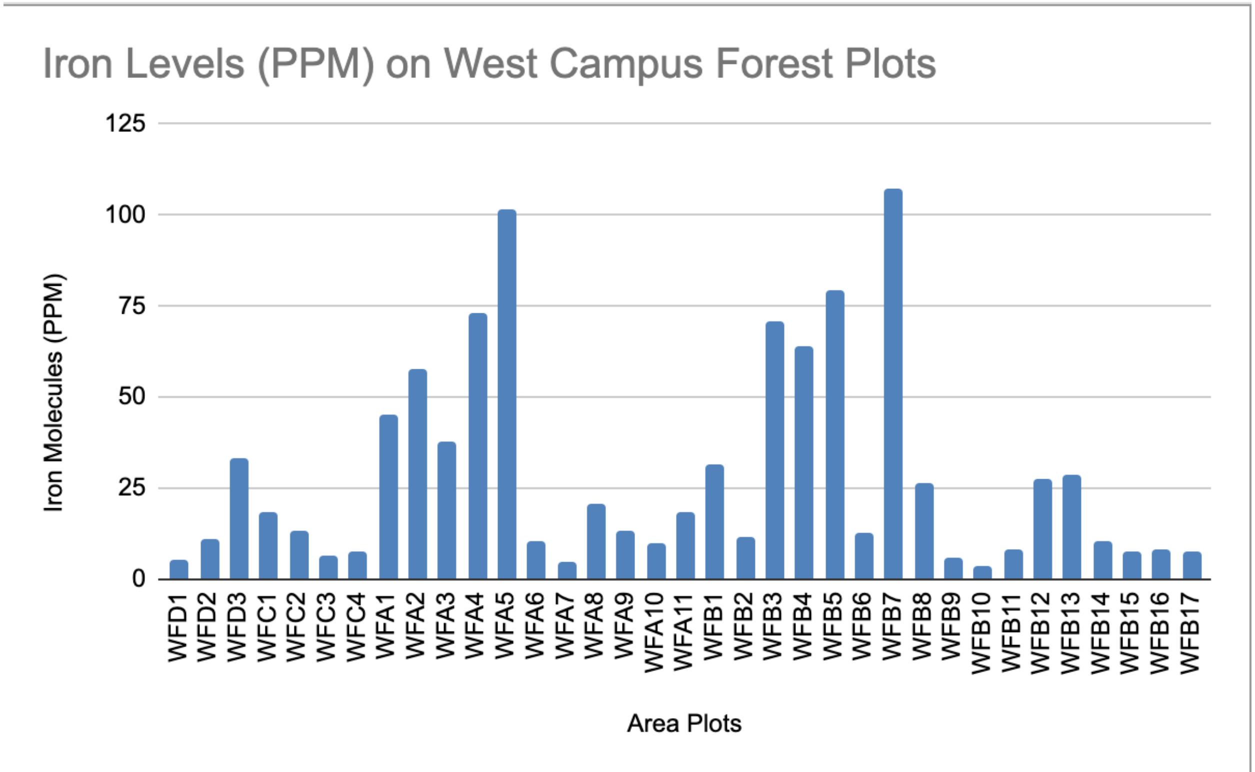
Area Plots


Iron Levels (PPM) on West Campus Forest Plots
Iron Molecules (PPM)
125
100
75
50
25
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
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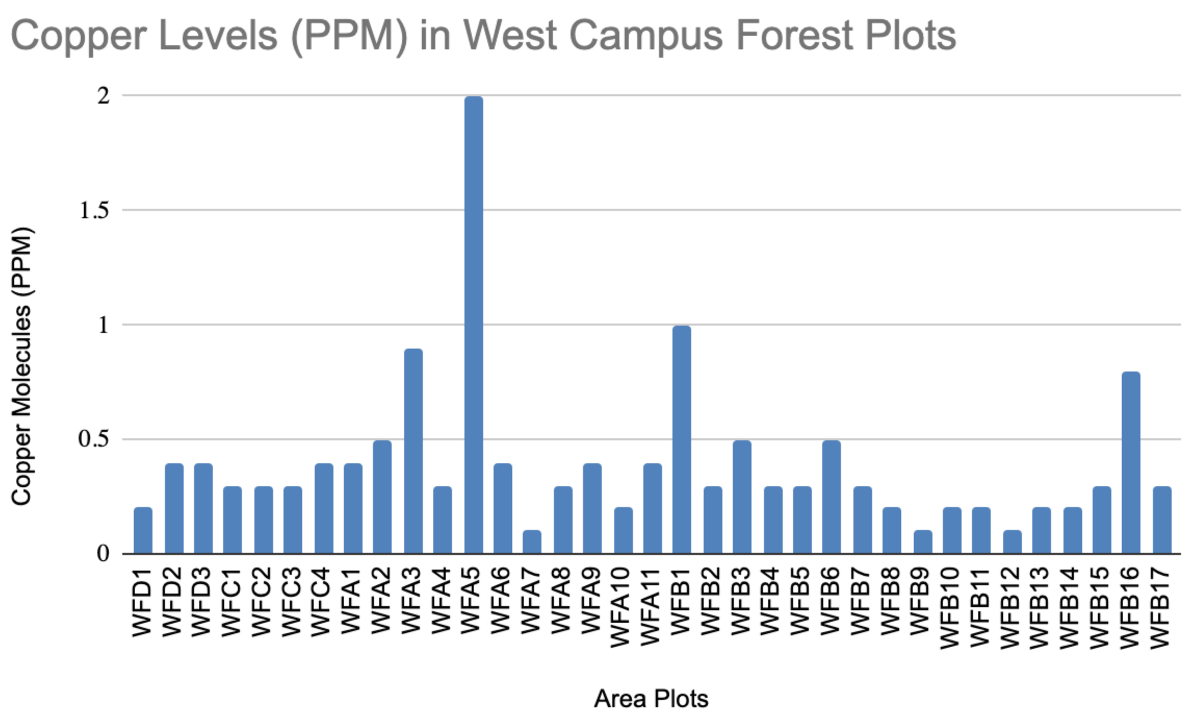
WFB16
WFB17
Area Plots


Copper Levels (PPM) in West Campus Forest Plots
Copper Molecules (PPM)
2
1.5
1
0.5
0
WFD1
WFD2
WFD3
WFC1
WFC2
WFC3
WFC4
WFA1
WFA2
WFA3
WFA4
WFA5
WFA6
WFA7
WFA8
WFA9
WFA10
WFA11
WFB1
WFB2
WFB3
WFB4
WFB5
WFB6
WFB7
WFB8
WFB9
WFB10
WFB11
WFB12
WFB13
WFB14
WFB15
WFB16
WFB17
Area Plots

APPENDIX 4. TREE RISK MANAGEMENT: A DETAILED OVERVIEW

Yale University Tree Management Statement

Yale University has a goal of managing its tree population to optimize the sustained benefits of those trees to the Yale community. This optimization is realized through actions invoked by staff to maintain a healthy and expanding tree canopy while managing the inherent risk of those trees to a level that is reasonable, practical, and proportionate. Yale staff defines the unique context of the campus and its operations from which these management choices are assessed and acted on.

Risk Management Plan Outline

The primary goal of a tree risk management plan is to present a document that articulates an organization's policies for managing tree risk. The document serves several purposes. These are:

1. Identifies the organization's current tree risk exposure.
2. Presents an analysis that establishes the organization's risk threshold.
3. Synthesizes all tree risk management policies into one document.
4. Provides guidance that allows uniform and consistent application of tree risk management policies across all staffing levels.
5. Provides a mechanism for reviewing program policies and tree-related events to refine risk management strategies.
6. In the rare case of tree-related litigation, the document forms the basis for demonstrating the organization's due diligence toward tree risk.

The structure of a tree risk management plan typically follows the general framework of the ISO's risk management process. It begins with a mission statement and is then followed by a process for identifying risk exposure, determining a risk threshold to manage to, developing a risk treatment strategy and outlining a process for reviewing the attainment of program goals.

1. The creation of a Tree Risk Management Group (TRMG) is the initial step in the development of a tree risk management policy. The TRMG is comprised of stakeholders who inform on policy development followed by annual meetings for program review. Stakeholders include staff involved with both planning, policy development and operations. Representatives from the university community additionally serve as stakeholders.

2. The initial task of the TRMG is to conduct a risk assessment of the campus. This is initially informed by an understanding of the current tree resource and an analysis of past tree-related events. This analysis results in an understanding of the University's current risk exposure. Once identified, the TRMG assesses strategies that can potentially reduce the identified risk exposure. Strategies can vary from enhanced staff training to more rigorous arboricultural practices and more thorough documentation processes to elevated mitigation response strategies. Each strategy should have an outcome that is quantifiable and allows the TRMG to gauge whether risk has been reduced. One outcome of the risk assessment may be that no additional strategies may be required.

3. Risk treatments based on the selected risk reduction strategies are devised and implemented. Treatments can include:

- Developing a staff training log.

- Enhancing staff skill sets to differentiate between low/moderate and high/extreme risk trees.
- Developing a risk mitigation response matrix.
- Incorporating risk assessment processes in contract specifications.
- Develop a tree-event reporting form.
- Develop an agenda for the annual program review meeting.

4. The second main task of the TRMG is to have an annual review of the program. The review focuses on assessing any previous year's tree-related events and their effect on the established risk exposure and threshold, whether program goals for the year were met, and whether any new information is available that could potentially refine the University's program.

5. The final task of the TRMG is to communicate with all stakeholders regarding the risk management policy process.

The ISO document on risk management and the ALARP model provide important guidance on managing tree risk at a system level. The five main goals that should form the basis of a reasonable and practical tree risk management strategy for Yale include:

1. Mitigating the tree-specific issues identified during the tree inventory phase.
2. Increasing staff capacity to identify trees with elevated risk (provide a price for an annual staff training program as described).
3. Developing an inspection program that is proportional to the risk.
4. Developing a process for ongoing stakeholder engagement.
5. Monitoring and analyzing tree-related events.

A Yale representative (YR) should inspect and confirm all trees recommended for removal for their respective campuses. Affirm the removals and initiate removal procedures. Trees affirmed for removal should paint an orange dot at the base of the tree to easily identify the tree for future removal operations. Table 14a delineates the number of trees identified for removal by size class and campus. The YR should identify the trees, typically by size, that the in-house crews can safely remove, and which trees are to be contracted for removal. If the removal results in a stump and the tree is not in a woodland area, removing or grinding the stump should be considered an element of the removal.

Table 14a – Diameter Distribution of Removals by Campus

Diameter Class	Athletic Campus	Central North	Central South	Medical	West	Total
1 - 6"	1	13	1	4	2	21
7 – 12"	10	28	4	7	2	51
13 - 18"	13	11	3	4	3	37
19 – 24"	7	14	3	0	1	25
25 - 30"	8	3	3	0	0	14
31 - 36"	1	3	0	0	0	4
37 – 42"	1	0	1	0	0	2
43" +	2	2	0	0	0	4
Total	43	74	15	18	8	158

Once the removal has been completed, the inventory needs to be updated with the removal date being entered and the Item Type changed from a "T" for a tree to an "R" for removed.

Each area supervisor (AS) should inspect and confirm all trees recommended for cabling for their respective campuses in coordination with the YR. If affirmed, complete the cabling mitigation and record in tree inventory. Most of the trees requiring pruning can be absorbed through the five-year pruning cycle with the initial emphasis on trees noted for pruning.

Linked with the inspection program would be an emphasis on trees that remain after the inventory-derived mitigations have occurred that have a condition rating of poor or worse. All the trees identified as extremely poor or dead on each campus should be removed within two years. An exception may be trees that have high wildlife or ecosystem value within the interior of woodland areas.

All university representative or operational staff should be trained in a Level 1 Limited Visual Inspection that focuses on target identification and structural defects. The purpose of this training would be to provide a formal, in-house, non-certificate training opportunity for the operational staff. The training emphasis would be placed on field exercises assessing trees with observable issues selected from the inventory. Outcomes would include more uniform and consistent application across staffing, campuses, and the university. Additionally, staff would be able to apply the ALARP model more effectively in prioritizing arboricultural needs on the trees they are responsible for managing.

In addition, a protocol for a Level one inspection must be developed that includes the field process, data management, and mitigation response strategy.

Those performing the inspections should track all significant tree-part failures. Information would include species, DBH, tree part, tree-part size, structural issues, contributing factors, weather at the time of the event, consequences, and financial cost of consequences. The number of annual tree part failures eventually will aid in quantifying the university's tree risk exposure. Recorded events would include those that produce no negative consequences along with those that may have caused property damage or physical harm.

APPENDIX 5. PEER UNIVERSITY TREE MANAGEMENT PROGRAMS COMPARISON

Yale University is a very distinct entity in a unique urban setting. It is quite helpful to align its unique characteristics with other higher educational institutions with similar fields. The extensive, shared urban setting with similar conditions, circumstances and social relationships exists with an extremely limited number of peer Ivy League universities.

The consultants were fortunate to be able to have had very helpful dialog (02/12/20) with representatives from two Ivy League universities: Robert Lundgren, of Facilities and chief landscape architect at University of Pennsylvania in Philadelphia, Pennsylvania, and Patrick Vetere, grounds superintendent at Brown University in Providence, Rhode Island.

Both universities also have sustainability plans that track tree environmental benefits such as canopy, carbon sequestration, stormwater, composting, etc.

The University of Pennsylvania

The University of Pennsylvania has more than 21,000 graduate and undergraduate students and more than 17,000 faculty and staff. Its campus covers over 300 acres of main campus area in an urban setting of Philadelphia.

The campus tree population is the responsibility of Facilities representative Robert Lundgren. He has been at the University of Pennsylvania for over 30 years, and as a landscape architect, works in operations and maintenance as well as design and facilities.

Lundgren credits the work of a previous University of Pennsylvania professor of landscape architecture, Ian McHarg, with bringing public awareness of ecological and urban planning to the UPenn setting during the seventies. Lundgren says the university acknowledges a rise in interest with an increase in canopy quantity and quality.

The university is also extremely fortunate to be affiliated with the University of Pennsylvania's Morris Arboretum, whose staff provide assessments of the entire 7,000 tree population on an annual basis.

The UPenn campus as well as the Morris Arboretum are recognized as an accredited ArbNet Level IV Arboretum, as well as with a Tree Campus USA (The Arbor Day Foundation) designation. The UPenn campus utilizes MB&G (Mason Bruce and Girard) mobile app for an interactive website linked to Penn's comprehensive tree inventory. App users have access to the UPenn tree collection classifications (donor, specimen) as located through campus.

The University of Pennsylvania campus is described as follows by ArbNet (http://arbnet.org 2020):
"The Penn Campus Arboretum at the University of Pennsylvania (Penn) curates and manages a diverse collection of trees, focused on preserving and sustaining the urban forest for the well-being of the community, environmental benefits, research, and educational opportunities. Penn's campus is an urban forest with over 6,500 trees in its collection, over 240 species of trees and shrubs, 10 specialty gardens, and five urban parks. Penn has dedicated resources and coordinated the care of a comprehensive tree management program over the course of many years, resulting in Tree Campus USA designation since 2009 and formal recognition as an accredited ArbNet Arboretum in 2017.

“The Penn Campus Arboretum at the University of Pennsylvania encompasses the entire campus, and is one of Penn’s two arboretums; the Morris Arboretum of the University of Pennsylvania is the official Arboretum of the Commonwealth of Pennsylvania, and is located in Chestnut Hill, a mature suburban community about 15 miles from Penn’s main West Philadelphia campus. The Morris Arboretum and Penn have a robust partnership promoting shared research, outreach and education programs highlighting the importance of trees”

Lundgren says the University of Pennsylvania has experienced positive results from the student and Philadelphia community, donors, and staff because of the entire campus being designated an ArbNet arboretum. The “Penn Plant Explorer” (https://www.facilities.upenn.edu/services/landscape/penn-plant-explorer 2020) is used to guide tours, research plant locations, and otherwise engage interested parties.

The tree inventory software is BG-Map and BG-Base (http://www.bg-map.com 2020) using ArcGis mapping. Capital project contractors have access to the map when considering tree locations and construction impacts.

The university grounds union staff perform mowing of approximately 120 acres, leaf cleanup, and planting of trees under 2-inch caliper size, as well as minimal pruning without the use of ladders or other person-elevated systems. The current size of the university work force and associated budget was not discussed.

The maintenance of the tree canopy has been successfully provided on a three-year contractual basis by Brightview, a large, national maintenance company with divisions focused on arboriculture. The approximate annual cost for these services is $200,000–$250,000 for pruning, removals, and treatments.

Lundgren also described a strong and healthy relationship with Philadelphia City Parks Department. The university can plant street trees within its campus network with city support as it sees fit. It also has sustainability goals, with concerns about tree canopy and tree waste on the forefront.

Brown University

Brown University has more than 6,752 undergraduates, 2,629 graduate students, and 585 medical students on its 146-acre campus located in an urban setting in Providence, Rhode Island.

The campus tree population is overseen by Patrick Vetere, grounds superintendent, who answers to the assistant director of facilities operations. He has been at Brown for decades, overseeing and coordinating tree care, maintenance, and planting.

The City of Providence (with which Brown University has a good relationship) has regulations that any tree over 20 inches DBH requires a permit prior to removal. Vetere and supportive Brown University administrators recognize the numerous benefits that the trees provide to their campus and are always looking for methods to save or preserve them before considering removal.

The university works in conjunction with the city through tree planting programs such as the Sharpe Tree Fund and other tree planting groups. The university loses approximately 1 percent of plant material a year through storm damage and demise. Approximately 450 trees a year are planted on and adjacent to the grounds (street trees).

Smaller (less than 20 inches DBH) campus-bordering Providence street trees are removed and replaced without permission/permits on Brown University representatives' direction.

Vetere said the grounds department has an employee who is a union International Society of Arboriculture (ISA) certified arborist. The employee has considerable campus knowledge, experience, and latitude in dealing with campus arboricultural issues. The arborist has limited access to the tree canopy but is able to utilize a smaller truck with boom to perform inspections if needed and accessible. A tree service contractor (Tree Tech, Inc., in Massachusetts) is contracted for all skilled tree work such as climbing, pruning, removal, and spraying. The contract budget was not divulged for Brown staff or contractors. It is also important to note that the campus has an exceptionally large population of elm trees like Yale University.

Brown University is not recognized as an ArbNet Arboretum nor a Tree Campus USA campus. Vetere acknowledged that the campus is predominantly tree focused and unilaterally supports tree preservation throughout its campus. New street construction installation often requires larger planting pits supplemented with Cornell University planting mix (Vetere 2/12/20).

Brown did have a partial tree inventory several years ago per Vetere, though updating the inventory with tree loss, maintenance, and new plantings became inefficient with present staff and was discontinued. The grounds department successfully uses physical maps to identify tree locations. This is most likely a direct result of the long-term familiarity the current staff has of tree locations, history, and future vulnerabilities such as pests, mechanical damage, and storm damage.

APPENDIX 6. UNIVERSITY CERTIFICATIONS

ArbNet

ArbNet created its Arboretum Accreditation Program to establish and share a widely recognized set of industry standards for the purpose of unifying the arboretum community. No other international program of accreditation exists that is specific to arboreta. Any arboretum or public garden with a substantial focus on woody plants may apply. Accreditation is based on self-assessment and documentation of an arboretum's level of achievement of accreditation standards, including planning, governance, number of species, staff or volunteer support, education and public programming, and tree science research and conservation. The entire program is free of charge.

Benefits of accreditation

- Be recognized for achievement of specified levels of professional practice.
- Work toward higher levels of professional standards once accredited.
- Identify other organizations at similar or higher levels of accreditation to provide comparative benchmarks and models for further achievement.
- Earn distinction in your community, university, college, or government agency.
- Exert leadership and influence by serving as a model to encourage professional development in other organizations.
- Identify opportunities for collaboration with other arboreta for scientific, collections, or conservation activities.

ArbNet Level 1

	LEVEL I
Arboretum plan	■
Organizational or governance group	■
Labeled tree and woody plant taxa	
25+	■
100+	
500+	
Staff or volunteer support	
Volunteer or paid	■

Level I is the most basic level of accreditation and requires achievement of the following standards:

1. An arboretum plan documentation of some sort, such as an organizational plan, strategic plan, master plan, or other, that defines the purpose of the arboretum, its audience(s), the types of plants that are to be grown to achieve that purpose and serve those audiences, provisions for the maintenance and care of the plants, and provisions for the continuing operation of the organization through time with a clear succession plan.

1. An arboretum organizational group of people or governing board or authority that is dedicated to the arboretum plan and its continuation beyond the efforts of a single individual. Such an organizational group can affirm fulfillment of standards and authorize participation as an accredited arboretum.

2. An arboretum collection with a minimum number of 25 species, varieties, or cultivars of trees or woody plants that have been planted and are growing in accordance with the arboretum plan. Plants in the arboretum collection must be labeled in some way as to identify them taxonomically, including scientific name and cultivar if applicable, and documented in some way so that

information on their acquisition (source or origin, date of acquisition, etc.) is available for access.

3. Arboretum staff or volunteers who ensure fulfillment of the arboretum plan and provide for the basic needs of the arboretum collection and functions of the arboretum.

4. An arboretum public dimension that includes some level of public access, and at least one public event or educational program each year focused on trees or arboretum purposes (for example, an Arbor Day observance).

ArbNet Level II

	LEVEL I	LEVEL II
Arboretum plan	■	■
Organizational or governance group	■	■
Labeled tree and woody plant taxa		
25+	■	
100+		■
500+		
Staff or volunteer support		
Volunteer or paid	■	
Paid management		■
Curator		
Scientific or conservation staff		
Public dimension		
Public access and at least one event per year	■	■
Enhanced public and educational programs		■
Substantial educational programming		
Collections policy		■

Level II-accredited arboreta have met the following enhanced levels of arboretum standards:

1. Satisfy all criteria for Level I accreditation.
2. Larger arboretum collection with a minimum number of 100 species, varieties, or cultivars of trees or woody plants.
3. Arboretum collections policy that describes the development and professional management of the plants in the arboretum collection, in accordance with standards developed in the public garden and museum

fields, with consideration given to the Saint Louis Declaration regarding invasive species. Such a policy and related practices includes a rationale for holding the collections of the arboretum, and collections inventory and record-keeping practices.

4.One or more arboretum employees who have job responsibilities that specifically include management or operation of the arboretum.

5.Enhanced educational and public programming beyond the base level required in Level I accreditation. Programs must be related to trees (e.g. tree identification, ecology, conservation, collections, or some other tree-focused aspect of the arboretum mission or master plan).

	LEVEL I	LEVEL II	LEVEL III
Arboretum plan	■	■	■
Organizational or governance group	■	■	■
Labeled tree and woody plant taxa			
25+	■		
100+		■	
500+			■
Staff or volunteer support			
Volunteer or paid	■		
Paid management		■	■
Curator			■
Scientific or conservation staff			
Public dimension			
Public access and at least one event per year	■	■	■
Enhanced public and educational programs		■	■
Substantial educational programming			■
Collections policy		■	■
Collaboration with other arboreta			■
Collections data sharing with networked collections			■
Agenda for tree science, planting, and conservation			■

ArbNet Level III

1. Satisfy all criteria for Level I and Level II accreditation.

2. A minimum number of 500 species, varieties or cultivars of trees or woody plants.

3. A dedicated curator, or curator-equivalent employee, who is focused on the care and development of the arboretum collection, in accordance with the arboretum plan and collections policy.

4. Professional capability to collaborate in some way with other arboreta relevant organizations (e.g. public gardens, universities, local government, NGOs, student groups, etc.) preferably with evidence of existing collaboration. Examples of collaborations may include plant evaluations, research projects, in situ or ex situ conservation projects, educational programs, exhibits, public events, interpretation, collecting expeditions, plant exchanges, professional meetings, and co-authoring scientific research papers.

5. Sharing of plant collections data with networked collections databases, such as the BGCI Plant Search Database (bgci.org/worldwide/plant upload).

6. An active agenda related to tree science, strategic planting, or conservation. This agenda should include direct research or the facilitation of scientific activities beyond public educational activities, in which data are acquired to solve problems in tree science or tree conservation. Examples include conducting plant trials, habitat

monitoring, detecting pests and diseases, hosting collections-based research projects, or conducting research in forest ecology, physiology, systematics, seed and tissue banking, horticulture, or tree care.

7. Substantial program of education related to trees, conservation, and other related topics.

ArbNet Level IV

	LEVEL I	LEVEL II
Arboretum plan	■	■
Organizational or governance group	■	■
Labeled tree and woody plant taxa		
25+	■	
100+		■
500+		
Staff or volunteer support		
Volunteer or paid	■	
Paid management		■
Curator		
Scientific or conservation staff		
Public dimension		
Public access and at least one event per year	■	■
Enhanced public and educational programs		■
Substantial educational programming		
Collections policy		■

1. Satisfy all criteria for Level I, Level II, and Level III accreditation.

2. A scientific and/or conservation staff and capability to collaborate in scientific or conservation activities with other arboreta or organizations related to trees.

3. Institutional capacity, stability, and commitment to hold and safeguard plants of collections or conservation value on behalf of the collective interests of the profession.

4. Specific participation in collaborative scientific or conservation activities related to trees, such as the North American Plant Collections Consortium or the Global Trees Campaign.

5. Specific consideration of a conservation role linked to the Global Trees Campaign (globaltrees.org) and complete the GTC addendum to the application.

6. A dedicated curator, or curator-equivalent employee, who is focused on the care and development of the arboretum collection, in accordance with the arboretum plan and collections policy.
7. Professional capability to collaborate in some way with other arboreta relevant organizations (e.g. public gardens, universities, local government, NGOs, student groups, etc.) preferably with evidence of existing collaboration. Examples of collaborations may include plant evaluations, research projects, in situ or ex situ conservation projects, educational programs, exhibits, public events, interpretation, collecting expeditions, plant exchanges, professional meetings, and co-authoring scientific research papers.
8. Sharing of plant collections data with networked collections databases, such as the BGCI Plant Search Database (bgci.org/worldwide/plant upload).
9. An active agenda related to tree science, strategic planting, or conservation. This agenda should include direct research or the facilitation of scientific activities beyond public educational activities, in which data are acquired to solve problems in tree science or tree conservation. Examples include conducting plant trials, habitat monitoring, detecting pests and diseases, hosting collections-based research projects, or conducting research in forest ecology, physiology, systematics, seed and tissue banking, horticulture, or tree care.
10. Substantial program of education related to trees, conservation, and other related topics.

Tree Campus USA

The second program that the consultants would recommend for Yale University to consider would be through certification by The Arbor Day Foundation. The process of engaging the Yale students and New Haven community through tree planting efforts by Yale's Urban Resource Initiative (URI) is already in place.

The program selection by Yale depends on their interest and level of commitment by stakeholders. The university meets most known requirements of Standard 1-5.

Both above programs would help consolidate support for the Yale Campus tree canopy. The programs provide a neutral and organized protocol reinforcing campus engagement and community support. Bob Lundgren, landscape architect at University of Pennsylvania, credits programs such as ArbNet with engaging many more participants in consciously acknowledging and appreciating the campus tree population (Lundgren 2/12/20).

SITES

SITES is a sustainability-focused program that allows tracking of environmental benefits for projects such as carbon storage, flood mitigation, and climate regulation. From the SITES website, "By providing performance measures rather than prescribing practices, SITES supports the unique conditions of each site, encouraging project teams to be flexible and creative as they develop beautiful, functional, and regenerative landscapes.

"SITES-certified landscapes help reduce water demand, filter and reduce stormwater runoff, provide wildlife habitat, reduce energy consumption, improve air quality, improve human health and increase outdoor recreation opportunities.

"SITES certification is based on a point system: the number of points that a project earns determines the certification level it receives. The SITES certification process allows projects to benchmark against performance criteria. The process is performed through SITES Online, which is a simplified tool designed to register a project, make payments and receive worksheets to aid in project documentation."

APPENDIX 7. RECOMMENDED PLANTINGS

Common Name	Scientific Name	Zone	Height (Ft)	Width (Ft)	Native	Utility Line Compatible	Notably Urban	Candidate for Assisted Migration	Page #
White Fir	*Abies concolor*	4A	30-50	15-30	✓				17
Trident Maple	*Acer buergerianum*	5B	20-30	15-25		✓	✓		18
Hedge Maple	*Acer campestre*	5A	25-35	25-35			✓		19
Paperbark Maple	*Acer griseum*	5A	20-30	20-30		✓			20
Miyabe Maple	*Acer miyabei*	4B	30-45	30-40					21
Red Maple	*Acer rubrum*	3B	40-60	30-70	✓		✓		22
Sugar Maple	*Acer sacharrum*	3B	60-75	35-50	✓				23
Purpleblow Maple	*Acer truncatum*	4B	25-30	25-30		✓	✓		24
Freeman Maple	*Acer* x *freemanii*	4A	40-75	Varies	✓				25
Red Horsechestnut	*Aesculus* x *carnea*	5A	30-50	30					26
Serviceberry	*Amelanchier* spp.	4A	15-25	15-30	✓	✓			27
River Birch	*Betula nigra*	4A	40-70	40-60	✓				28
Common Hornbeam	*Carpinus betulus*	5A	35-60	30-40					29
American Hornbeam	*Carpinus caroliniana*	3A	20-30	20-30	✓	✓			30
Northern Catalpa	*Catalpa speciosa*	4A	40-60	20-40	✓		✓		31
Sugar Hackberry	*Celtis laevigata*	5A	60-80	50	✓		✓	✓	32
Common Hackberry	*Celtis occidentalis*	3A	40-60	40-60	✓		✓	✓	33
Katsura Tree	*Cercidiphyllum japonicum*	4A	40-60	25-60					34
Eastern Redbud	*Cercis canadensis*	4A	20-30	25-35	✓	✓	✓	✓	35
Atlantic White Cedar	*Chamaecyparis thyoides*	4B	40-60	10-20	✓				36

White Fringetree	*Chionanthus virginicus*	5A	15-25	10-25	✓	✓	✓		37
Yellowwood	*Cladrastis kentukea*	4A	30-50	40-55	✓				38
Japanese Clethra	*Clethra barbinervis*	5B	10-20	10-20		✓			39
Kousa Dogwood	*Cornus kousa*	5A	15-30	15-30		✓			40
Corneliancherry Dogwood	*Cornus mas*	5A	15-25	15-20		✓			41
Dogwood Hybrids	*Cornus* x *rutgersensis*	5A	10-20	10-20		✓		✓	42

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Common Name	**Scientific Name**	**Zone**	**Height (Ft)**	**Width (Ft)**	**Native**	**Utility Line Compatible**	**Notably Urban**	**Candidate for Assisted Migration**	**Page #**
Turkish Filbert	*Corylus colurna*	4A	40-50	15-35			✓		43
American Smoketree	*Cotinus obovatus*	4A	20-30	15-30	✓	✓	✓		44
Thornless Cockspur	*Crataegus crusgalli* var. *inermis*	4A	20-30	20-35	✓	✓	✓		45
'Winter King' Hawthorn	*Crataegus virdis* 'Winter King'	4A	25	25	✓	✓	✓		46
Hardy Rubber Tree	*Eucommia ulmoides*	5A	40-60	40-60			✓		47
Gingko	*Gingko biloba*	4B	50-80	30-40			✓		48
Thornless Honeylocust	*Gleditsia triacanthos* var. *inermis*	4B	40-60	30-70	✓		✓		49
Kentucky Coffeetree	*Gymnocladus dioicus*	3A	50-75	40-50	✓		✓		50
Carolina Silverbell	*Halesia carolina*	5A	20-40	20-35	✓				51
Witchhazel	*Hamamelis virginiana*	4A	10-30	15-20	✓	✓			52
Eastern Red Cedar	*Juniperus virginiana*	3B	40-50	8-20	✓		✓	✓	53

Goldenraintree	*Koelreuteria paniculata*	5A	30-40	30-40			✓		54
American Sweetgum	*Liquidambar styraciflua*	5B	50-75	40-65	✓			✓	55
Tuliptree	*Liriodendron tulipifera*	5A	70-90	35-50	✓			✓	56
Amur Maackia	*Maackia amurensis*	4A	20-30	20-30		✓	✓		57
Thornless Osage Orange	*Maclura pomifera* var. *inermis*	5B	20-50	20-50	✓		✓	✓	58
Flowering Crabapple	*Malus* spp.	4B	10-25	10-25		✓			59
Dawn Redwood	*Metasequoia glyptostroboides*	5A	70-100	25-50					60
Black Gum	*Nyssa sylvatica*	4A	30-60	20-40	✓				61
American Hophornbeam	*Ostrya virginiana*	4A	25-40	20-40	✓				62
Persian Parrotia	*Parrotia persica*	5A	20-30	15-30		✓	✓		63
Serbian Spruce	*Picea omorika*	4B	50-60	20-25					64
Swiss Stone Pine	*Pinus cembra*	4A	30-40	15-25					65
London Planetree	*Platanus* x *acerifolia*	5A	70-100	65-80			✓		66
Accolade Cherry	*Prunus* 'Accolade'	5A	20-30	15-25		✓			67
Common Hoptree	*Ptelea trifoliata*	4A	15-20	15-20	✓	✓			68

Common Name	**Scientific Name**	**Zone**	**Height (Ft)**	**Width (Ft)**	**Native**	**Utility Line Compatible**	**Notably Urban**	**Candidate for Assisted Migration**	**Page #**
White Oak	*Quercus alba*	4A	45-80	45-80	✓			✓	69
Swamp White Oak	*Quercus bicolor*	4A	45-70	45-60	✓		✓		70
Scarlet Oak	*Quercus coccinea*	5A	60-75	40-50	✓			✓	71

Shingle Oak	*Quercus imbricaria*	4A	40-60	40-65	✓			✓	72
Bur Oak	*Quercus macrocarpa*	3A	60-80	60-90	✓		✓	✓	73
Chestnut Oak	*Quercus montana*	5A	60-70	60-70	✓			✓	74
Chinkapin Oak	*Quercus muehlenbergii*	4B	35-50	35-60	✓			✓	75
Pin Oak	*Quercus palustris*	4A	50-70	25-40	✓				76
Willow Oak	*Quercus phellos*	6A	40-60	40-60	✓		✓	✓	77
English Oak	*Quercus robur*	5A	40-60	40-60			✓		78
Northern Red Oak	*Quercus rubra*	4A	60-75	60-75	✓		✓		79
Shumard Oak	*Quercus shumardii*	5B	40-60	45-65	✓		✓		80
Common Sassafras	*Sassafras albidum*	4B	30-60	25-40	✓				81
Japanese Umbrella Pine	*Sciadopitys verticillata*	5B	20-30	15-20		✓			82
Japanese Pagodatree	*Styphnolobium japonicum*	5A	50-70	35-55			✓		83
Japanese Tree Lilac	*Syringa reticulata*	3A	20-30	15-25		✓	✓		84
Bald cypress	*Taxodium distichum*	5A	50-70	20-40	✓		✓	✓	85
Arbor vitae	*Thuja occidentalis*	3A	40-60	10-15	✓		✓		86
American Linden	*Tilia americana*	3A	60-80	20-40	✓				87
Littleleaf Linden	*Tilia cordata*	3B	50-70	30-50					88
Silver Linden	*Tilia tomentosa*	5A	50-70	25-55			✓		89
American Elm Cultivars	*Ulmus americana*	3B-5A	60-80	30-60	✓		✓		90
Lacebark Elm	*Ulmus parvifolia*	5B	40-75	30-75			✓		91
Elms Hybrids	*Ulmus* x spp.	3B-5A	50-70	40-60			✓		92

Siebold Viburnum	*Viburnum sieboldii*	4B	15-20	10-15		✓			93
Japanese Zelkova	*Zelkova serrata*	5A	50-80	40-60			✓		94

1.1 Tree species

A comprehensive, broad-based literature review was undertaken to decide which tree species would be included in Planting for Resilience: Selecting Urban Trees in Massachusetts. This began by determining which trees were recommended in other selection guides produced by university extension programs, state agencies, and the industry (i.e., nurseries). Once an initial list relevant to growing conditions in the Northeast was composed, characteristics and attributes of each tree (i.e., preferred environmental conditions, site adaptability, optimal growing conditions) were assessed. This information was gathered from not only the aforementioned selection guides, but tree identification books, encyclopedias, and online resources generated from various stakeholders (see pages 104-106).

Individual tree species were carefully scrutinized and eliminated based on invasive potential (i.e., *Robinia pseudoacacia*), pest susceptibility (i.e., *Fraxinus* spp., *Sorbus* spp.), management considerations (i.e., *Pyrus calleryana*) and overall compatibility to adverse urban environments (i.e., *Acer saccharinum, Pinus strobus*).Tree species' sensitivity and adaptability to common stress factors found in the urban environment (i.e., alkaline soil, drought, heat, salt, pollution, poorly drained soils, mechanical damage), were specifically considered; from there, current and future habitat suitability was analyzed in an attempt to ensure that remaining tree species would be well-adapted to future climate projections of the Northeast (see Methods 1.5).

1.2 Criteria

Tree species data is often anecdotal, based on observations of industry professionals, agency/university specialists and tree enthusiasts from the public. Discrepancies concerning tree attributes and characteristics often occurred between reference materials. Thus, consistency and agreement among sources was an important consideration relevant to determining the information that was deemed acceptable to include. Generally, information presented in this guide has been verified by at least two other references. Though no single claim or piece of information was casually dispensed with, a hierarchy of trust was established where isolated claims and observations in sole sources were not included to conservatively consider discrepancies. For example, the "highest" or most conservative hardiness zone rating found in the literature for each species was listed on their profile, if it could be verified by two or more sources. This was done so that a tree would not be planted in a zone that would be too cold, beyond what it could tolerate. A range was presented regarding each tree species' height and width, that generally included the smallest and largest values found in the literature.

1.3 Limitations

Urban forestry is a relatively new field of study, and unlike traditional forestry where trees have been studied and observed for many centuries, there is a dearth of data concerning the growth and response of trees in our expanding towns and cities. Climatic projections themselves also vary. Being such long-lived organisms, trees may not perform as predicted relative to their response to shifting habitat suitability, over extended periods of time.

1.4 Urban tree suitability

"Urban" tree species must be able to tolerate a host of difficult conditions including soils that often feature extreme pH, prolonged periods of dryness, salt, pollution, and poor drainage. Although not all species here are well-suited for tough, urban sites, we highlight species (using an icon in the top corner of its profile page) that are notably adaptable to these adverse conditions. Some references (Dirr, University of Connecticut, Cornell University) presented a list of species that were recommended to plant in tough, urban sites, which were considered.

APPROACH

1.5 Trees and assisted migration

This table displays our interpretation of data obtained from the US Forest Service10,20. This data set was specific to Massachusetts, and was divided into 1° latitude x 1° longitude sectors, which essentially coincide with what is considered western, central, and eastern Massachusetts. Species marked with * were not included in this data set. but were found in the US Forest Service's Climate Change Tree Atlas. Highlighted species are projected to gain habitat suitability, therefore were chosen as 'Candidates for assisted migration'.

Model reliability

1= most reliable, 3= least reliable.

Current abundance
Tree species abundance varies across the state, due to numerous factors. To determine each species' mean state-wide current abundance, we averaged the data from the three sectors of Massachusetts by assigning a value to each abundance class [0: absent; 1: rare; 2: common; 3: abundant].

Changes in habitat suitability
Possible change in habitat suitability by 2100 according to the ratios of future (2070-2099) suitable habitat for an average of 3 climate models to current (1981-2010) modeled habitat at RCP4.5 (low emissions) and RCP8.5 (high emissions) scenarios. This does not necessarily mean the species' *abundance* will change in the area by 2100, only that the habitat is expected to change in suitability for that species over time. Further, it is important to note that this data is not specific to urban environments, meaning these projections may differ in the urban forest. To determine each species' mean state- wide change in habitat suitability, we averaged data from the three sectors of Massachusetts by assigning a value to each change class [-3: extirpated; -2: large decrease; -1: small decrease; 0: no change, unknown; +1: small increase; +2: large increase; +3: new habitat].

Adaptability
This score is based on a literature review of 12 disturbance (i.e., disease, drought, pollution) and 9 biological characteristics (i.e., shade tolerance, seedling establishment, environmental habitat specificity) for each species. It aims to account for factors that may affect how a species will respond to climate change that the models do not take into consideration. Scores have been classified as High (5.2-9.0), Medium (3.4-5.1), and Low (0.1-3.3). However, these scores may differ based on specific location-based factors. (McElhinney, 2019)

APPENDIX 8. SAMPLE I-ECO META DATA REPORT

Metadata Report For:

Location: New Haven, New Haven, Connecticut, United States of America
Project: Yale University 2020, Series: 04032020, Year: 2020
Generated: 7/10/2020

i-Tree Eco

i-Tree Eco v6.0.19
Project created: 4/27/2020
Project location: C:\Users\18603\Desktop\April 2020 Components\i-Tree Analysis\Yale University 2020.ieco
Model HAS been run

Project Type: Complete Inventory

- Project: Yale University 2020
- Series: 04032020
- Year: 2020
- 6,159 trees

Project Info:

- Location: New Haven, New Haven, Connecticut, United States of America
  - Leaf on day (day of year, 1 - 365, when frost ends): 113
  - Leaf off day (day of year, 1 - 365, when frost begins): 297
  - Frost-free days: 210
  - Longitude: -72.9242720052
  - Latitude: 41.31041513
  - Elevation: 0.0 (ft)
- Area: Not configured (Strata check box must be checked in Data Collection Options and proper area entered in Project & Strata Area form)
- Population: 129,779
- Study area is treated as Urban: Yes
- Units: English

Pollution Details:

- Year: 2016

CO	O3	NO2	SO2	PM2.5	Location	Station ID
Yes	Yes	Yes	Yes	Yes	New Haven, Connecticut, United States of America	0027

Weather Station Details:

- Year: 2016
- USAF: 725045
- WBAN: 14758
- Name: N/A

* see avoided runoff report for annual precipitation total used for analysis

By Stratum (Unavailable for this project type or location)
Species Range
Native Status by Stratum
Condition
By Species
By Stratum and Species
Crown Health
By Species
By Stratum and Species
Leaf Area
By Stratum
By Stratum per Unit Area (Unavailable: "Strata/Area" not checked)
Leaf Area and Biomass
Of Shrubs by Stratum (Unavailable for this project type or location)
Of Trees and Shrubs by Stratum
Ground Cover Composition (Unavailable for this project type or location)

Page 2

Metadata Report For:

Location: New Haven, New Haven, Connecticut, United States of America
Project: Yale University 2020, Series: 04032020, Year: 2020
Generated: 7/10/2020

By Stratum (Unavailable for this project type or location)
Land Use Composition (Unavailable: "Land Use" not checked)
By Stratum (Unavailable: "Land Use" not checked)
Relative Performance Index
By Species
Maintenance (Unavailable: "" not checked)
Recommended (Unavailable: "Maintenance recommended" not checked)
Recommended by Species (Unavailable: "Maintenance recommended" not checked)
Recommended by Species and DBH (Unavailable: "Maintenance recommended" not checked)
Task (Unavailable: "Maintenance task" not checked)
Task by Species (Unavailable: "Maintenance task" not checked)
Task by Species and DBH (Unavailable: "Maintenance task" not checked)
Sidewalk Conflicts (Unavailable: "Sidewalk conflict" not checked)
Sidewalk Conflicts by Species (Unavailable: "Sidewalk conflict" not checked)
Sidewalk Conflicts by Species and DBH (Unavailable: "Sidewalk conflict" not checked)
Utility Conflicts (Unavailable: "Utility conflict" not checked)
Utility Conflicts by Species (Unavailable: "Utility conflict" not checked)
Utility Conflicts by Species and DBH (Unavailable: "Utility conflict" not checked)
Other (Unavailable: "Custom Field One name:", "Custom Field Two name:", "Custom Field Three name:" not checked)
Field One (Unavailable: "Custom Field One name:" not checked)
Field One by Species (Unavailable: "Custom Field One name:" not checked)
Field One by Species and DBH (Unavailable: "Custom Field One name:" not checked)
Field Two (Unavailable: "Custom Field Two name:" not checked)

Benefit Prices:

- Electricity $ (USD)/kWh: 0.22 (Eco default value: 0.22 for 2018)
- Fuels $ (USD)/Therm: 1.44 (Eco default value: 1.44 for 2018)
- Carbon $ (USD)/ton: 170.55 (Eco default value: 170.55 for 2020)
- Avoided Runoff $ (USD)/gallon: 0.0089 (Eco default value: 0.0089 for 2004)

Metadata Report For:

Location: New Haven, New Haven, Connecticut, United States of America
Project: Yale University 2020, Series: 04032020, Year: 2020
Generated: 7/10/2020

Models:

- Forecast v6.0.19
- UFORE-D v1.1.0

Processing History:

Date/Time	File Name	Retrieved
Friday, April 3, 2020 11:15 AM	_001_09_009_52070_Yale_University_2020.ieco.2020_4_3_40477.zip	Yes

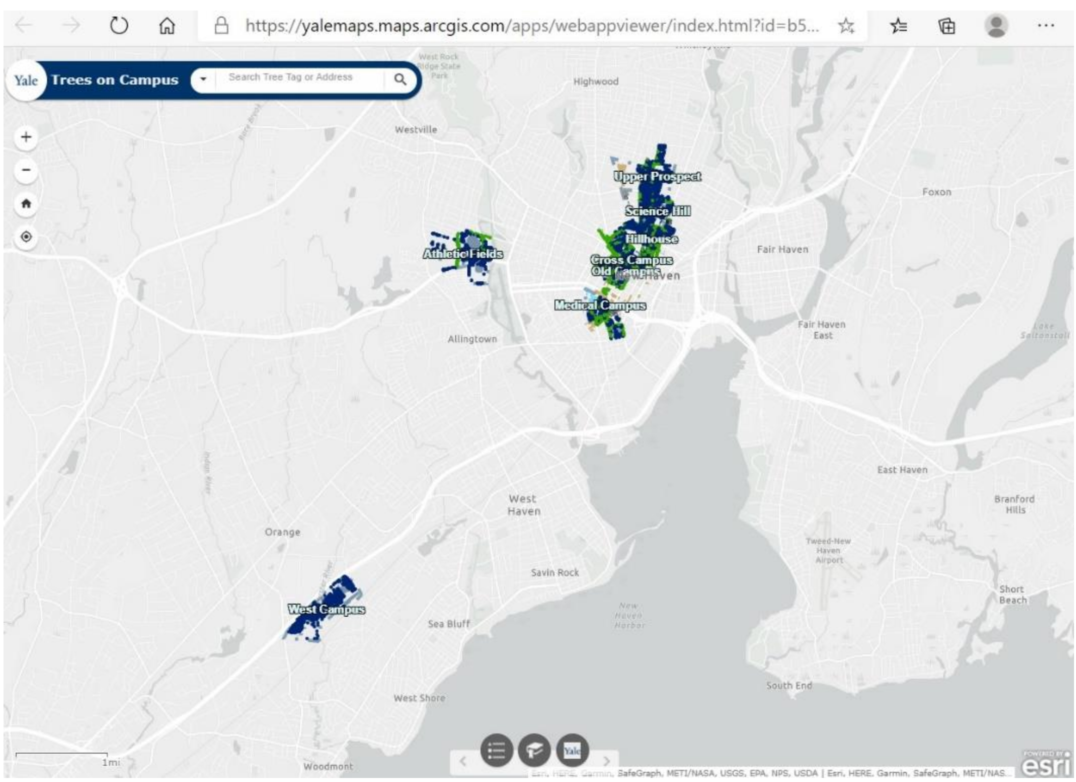
Report Availability

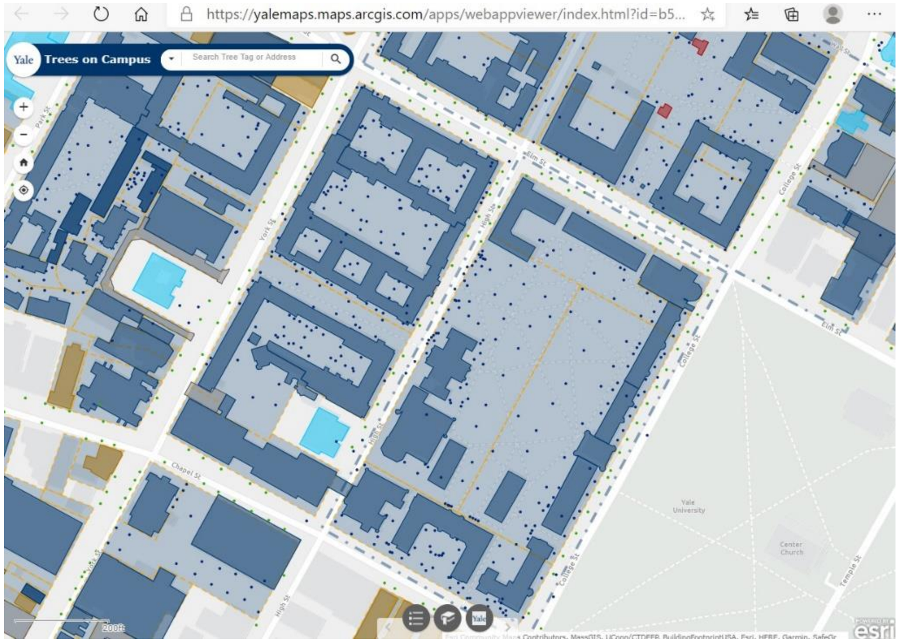
Formatted Reports
Written Report
Composition and Structure
Structure Summary
By Species
By Stratum and Species
Population Summary
By Species
By Stratum
By Stratum per Unit Area (Unavailable: "Strata/Area" not checked)
Public and Private by Stratum (Unavailable: "Public/private" not checked)
Street Trees by Stratum (Unavailable: "Street tree/non-street tree" not checked)
Species Distribution
By DBH Class (chart)
By DBH Class (vertical table)
By DBH Class (horizontal table)
By DBH Class and Stratum (vertical table)
By DBH Class and Stratum (horizontal table)
Importance Values
By Species
Diversity Indices (Unavailable for this project type or location)
By Stratum (Unavailable for this project type or location)
Species Range

APPENDIX 9. YALE "TREES ON CAMPUS" APP

Yale University has made available to the community a unique opportunity to access tree information from the recent tree inventory. A dedicated map platform was created to allow such access using smart phones that can scan a QR code (below) or laptops/desktops that enter the URL address (in blue below).

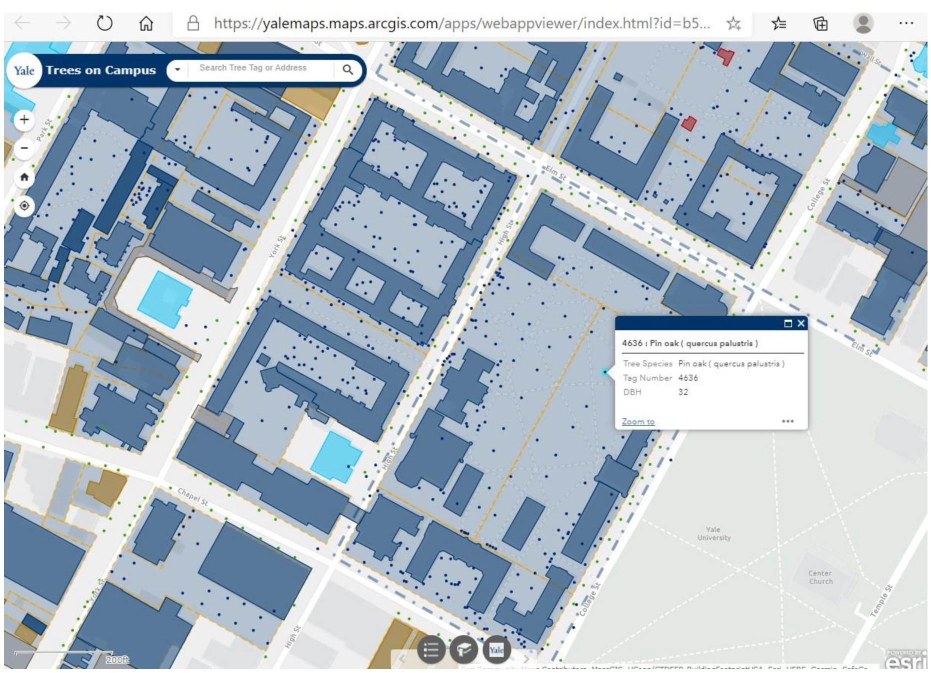
https://yalemaps.maps.arcgis.com/apps/webappviewer/index.html?id=b5b7fbc8898b4d18bffeefdc68f39ca0





Tree points can be touch tapped to generate information like tag number, botanical name, common name, and size.

A tree tag number can also be entered in the search query with the ability to field locate that tree.



APPENDIX 10. TOMOGRAPHY

SUMMARY

Tomography uses sound waves to measure decay in trees by measuring the differences in sound wave speed between sensors placed on the outside of a tree trunk. Images create a two dimensional "layer" which interprets the conditions within that "slice" of the tree. These images can be fused to create a 3-dimensional image if warranted. This information in combination with other observations is an advanced tree risk assessment.

The consultant, and registered consulting arborist John Wickes, performed tomography analysis on a select 5 campus trees as part of the Yale Tree Management Plan on November 5, 2020.

The recommendations are identified in Table 1 below. One tree, a European Beech tag # 4726, is recommended for removal. The other four are recommended for further testing due to either inconclusive results or additional findings warranting specific additional testing.

Tree Reference	Tag Number	Species	Location	Recommendation
1	# 4286	**Ginkgo** *(Ginkgo biloba)*	**Timothy Dwight**	**additional testing:** **tomography, resistance drill**
2	# 4726	**European beech** *(Fagus sylvatica)*	**Branford College**	**removal**
3	# 4723	**American elm** (*Ulmus americana*)	**Branford College**	**additional testing:** **pull test, root excavation, root tomography**
4	# 4825	**American elm** (*Ulmus americana*)	**University Theatre**	**additional testing:** **tomography, pull test, root excavation, resistance drill**
5	# 4885	**American elm** (*Ulmus americana*)	**Pierson College**	**additional testing:** **tomography, pruning and bracing**

Table 40 Recommendations for Scanned Trees

BACKGROUND

The consultant performed tomography to provide insight for campus tree diagnosis. Tomography is considered a Level III Advanced Assessment technique that produces additional information to interior tree conditions associated with decay.

A Level II Tree Risk Assessment was performed for each of the five trees prior to the tomography work. The tree rating for trunk, root and branch failure rating used International Society of Arboriculture (ISA) Tree Risk Assessment Qualified (TRAQ) standards. The recommended inspection time frame interval for these trees was one year.

Risk assessment interpretations are considered in combination with other results before making recommendations. Tomography, if available and warranted, is a tool to be considered along with other assessment methods such as removals. It can provide insight to the degree of decayed wood as well as sound wood and their location within the tree column. It is often the extent of sound wood and its location that can help determine tree strength despite decay or hollows.

Tomography is limited to above ground testing. One test layer can produce a 2 -dimensional result or multiple layers can produce a three-dimensional model (like multi-layer velocity model created for tree 1 and 2) depending on need, time and financial resources available. Additional testing for root system integrity like root excavation and resistance drilling should be considered prior to recommended historic iconic or mature tree removals.

METHODOLOGY

The consultant worked with an experienced independent registered consulting arborist, John Wickes, to perform the tomography scans on November 5, 2020. Five trees were selected from a list of seven trees provided by campus area supervisors in early November 2020 to be considered for tomography scanning:

1. A 55" dbh Ginkgo (*Ginkgo biloba*) tagged # 4286
2. A European beech (*Fagus sylvatica*) tagged # 4726
3. An American elm (*Ulmus americana*) tagged # 4723
4. An American elm (*Ulmus americana*) tagged # 4825
5. An American elm (*Ulmus americana*) tagged # 4885

Tomography uses sound waves generated from sensors on the trunk to detect interior conditions of trees: solid wood, decayed wood, or hollows that are not visible from exterior inspections. The technology can produce two, or three-dimensional images of the interior makeup or architecture of the tree providing additional information when interpreting the interior health of trees.

- Sensor number one was placed (inserted slightly into trunk) on the North side of the tree at various heights above grade depending on the area of focus.

- The remaining nine sensors were spaced evenly around the trunk.

- The sensors were tapped to create a sound wave and its rate of speed which was determined by the interior conditions creating a single horizontal color image layer.

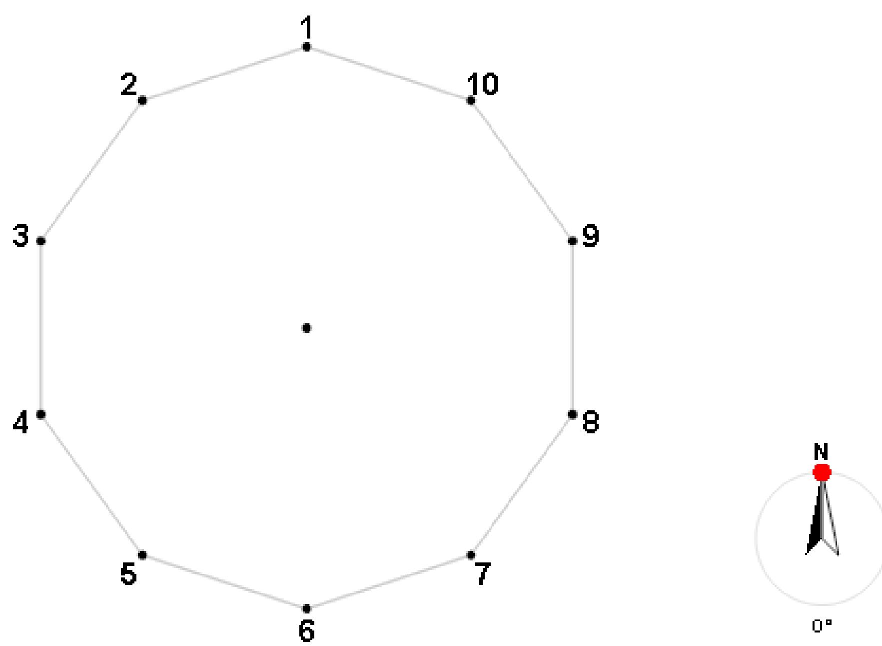


Figure 82 Sensor Number Placement and Orientation

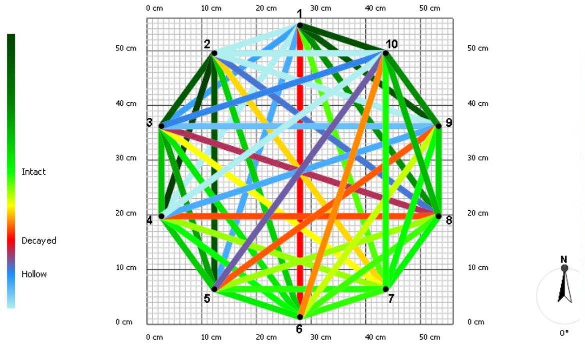


Figure 2 Tomography Layer - graph

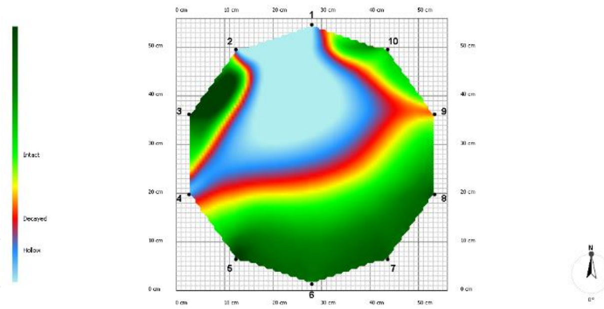


Figure 3 Created Layer

- Additional layers can be integrated to create a three-dimensional image.

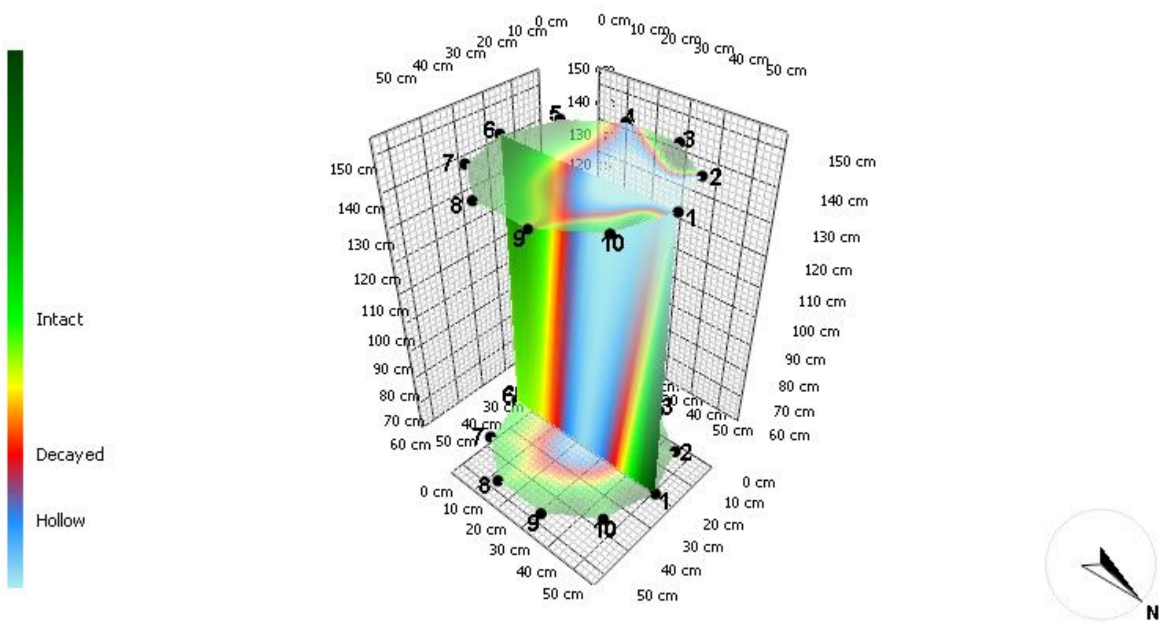


Figure 4 Multilayer - velocity

- The test layer is a structural assessment of the scan location only and not representative of conditions above and below unless multiple scan layers are used.
- Test results were interpreted along with location of cavities or decay, wind load, existing crown and tree architecture, species and maturity.

- Excessive bark thickness and associated tree response to decay and cracks can produce inconclusive results on some trees leading to a recommendation for additional testing.
- The consultant utilized a laptop, an iPhone, diameter tape, sounding hammer and ArborSonic tomograph.

FINDINGS

Tree number 1

The tree, a 55" dbh ginkgo (*Ginkgo biloba*) with a tag # 4286 is located off Temple Street and is the dominant tree in the Timothy Dwight open courtyard.

The tree was rated as a "moderate risk" after completing a Level II Risk Assessment prior to the tomography.

Figure 5 Technician Setting Sensors

Figure 6 Ginkgo in Courtyard

Tree 1 Scan Results

The ginkgo showed hollowed (area in shades of blue) and decayed (area in red/brown) portions at the tested height (85 centimeters above grade).

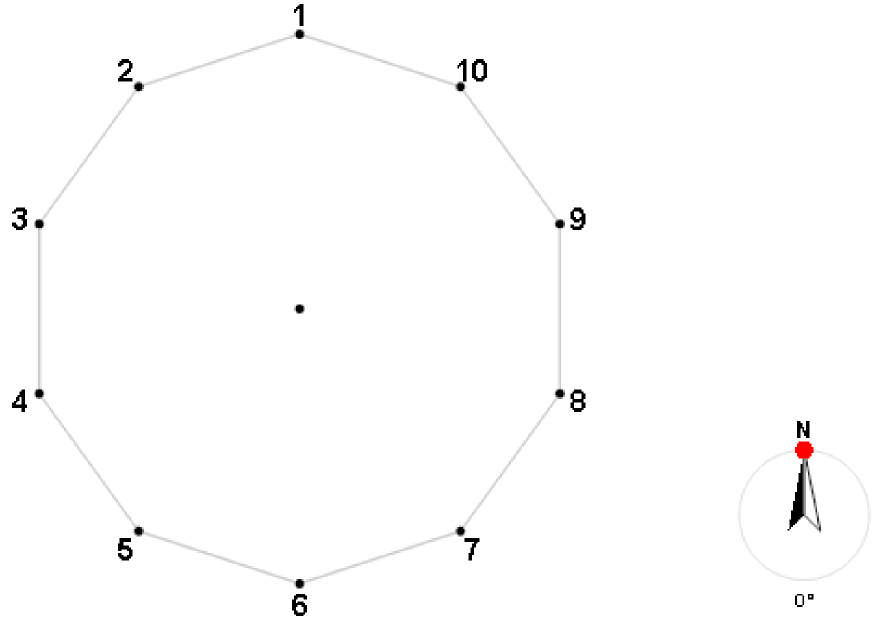


Figure 7 Ginkgo Sensor Geometry

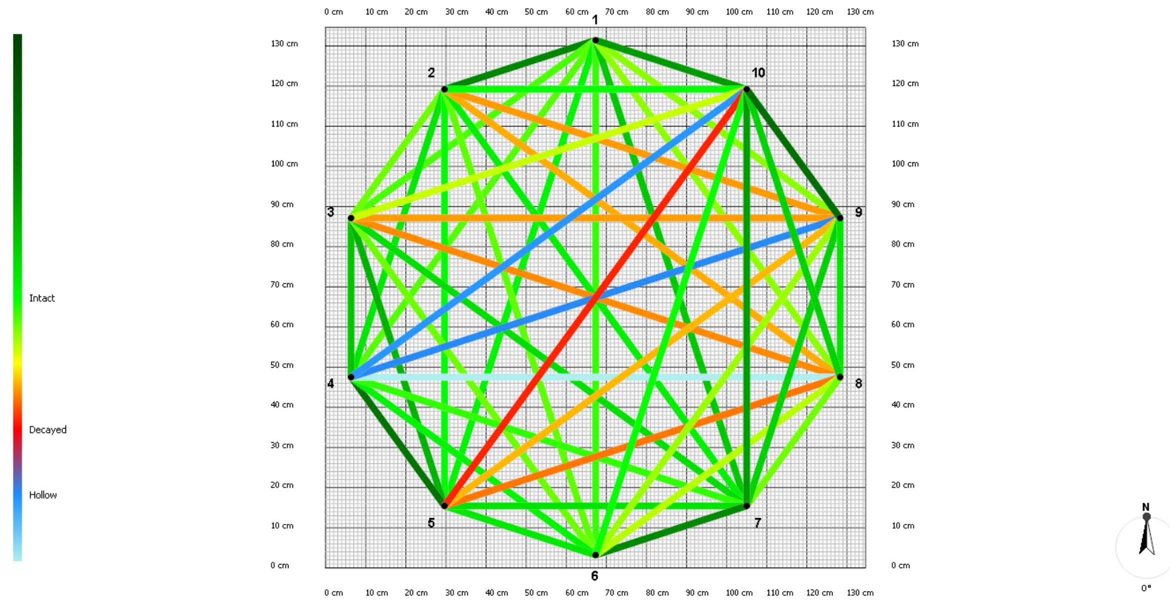


Figure 8 Ginkgo Layer Graph

The codominant structure and associated hollowed area align between point 4 and 8 and decayed area between point 4 and 10 on the single layer.

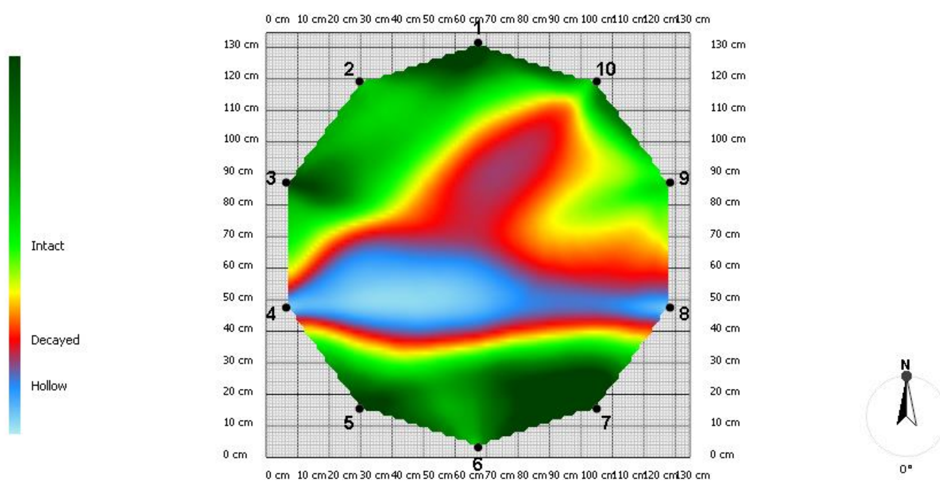


Figure 9 Ginkgo Layer 1 - 2d Map

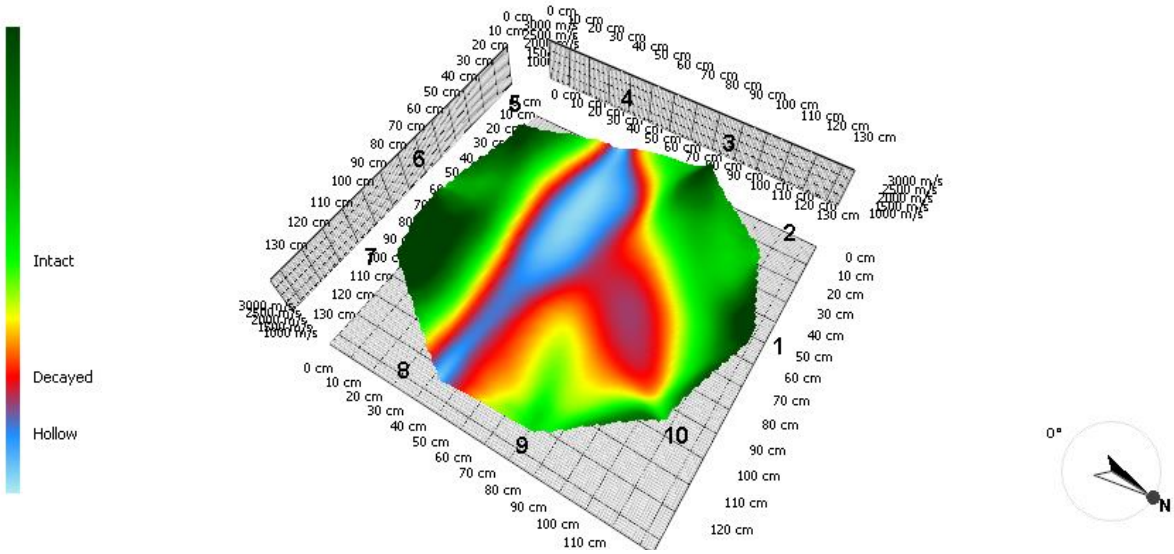


Figure 10 Ginkgo Layer 1 - 3d Map

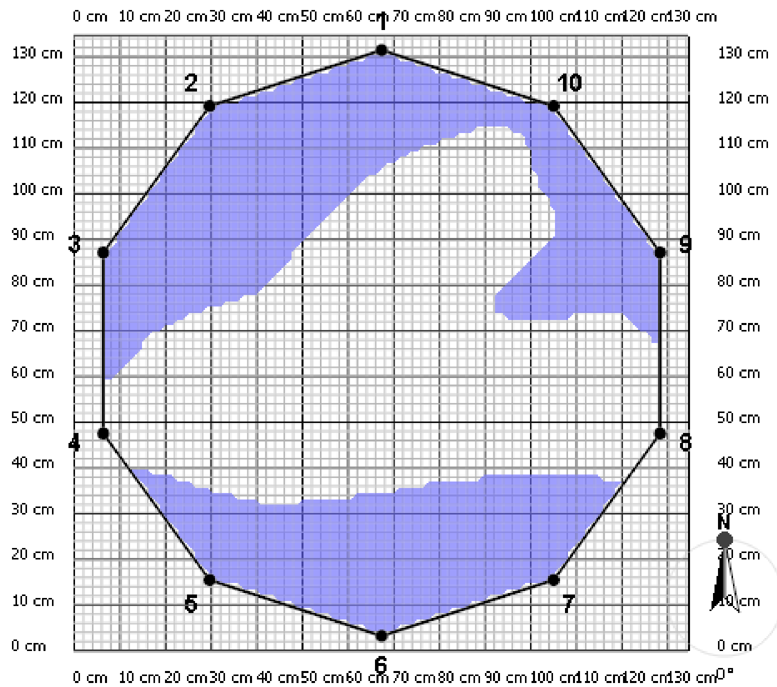


Figure 11 Ginkgo Area Map - no color is hollow/decay zone

Interpretation

The ArborSonic tomograph shows hollowing and decay across the base of the ginkgo where tested. The upper and lower extent of decay remains unknown but further testing is required. A weak point due to the codominant trunks branches is additionally confirmed with the extent of decay and hollow where tested.

Buttress roots are located predominantly lower than the tested area. It is very possible that decay extends into the buttress root zone and deeper.

Recommendations

The consultant recommends immediate additional tomographic testing above the current layer. Resistance drilling is also recommended to quantify tree wall thickness. This will provide more information as to the pattern of extent of decay.

It is also recommended 2 (minimum) additional bracing rods be installed between the codominant upper trunk with a safety check of the current cabling system. It might also be necessary to augment the current system with supplemental cabling pending the outcome of additional tomography results and cable conditions.

Tree number 2

The tree, a 23" dbh European beech (*Fagus sylvatica*) with a tag # 4726 is located off York street and is in Branford Courtyard.

Figure 12 European Beech in Branford College

The tree was rated as a "moderate risk" after completing a Level II Risk Assessment prior to the tomography.

Figure 13 Arborist setting Sensors

Tree 2 Scan Results

The beech showed a hollowed core (area in shades of blue) and adjacent decayed (area in red/brown) portions at the layer 1 tested height (60 centimeters above grade) and layer 2 (150 cm above grade). The decayed appearance of the trunk warranted two layers.

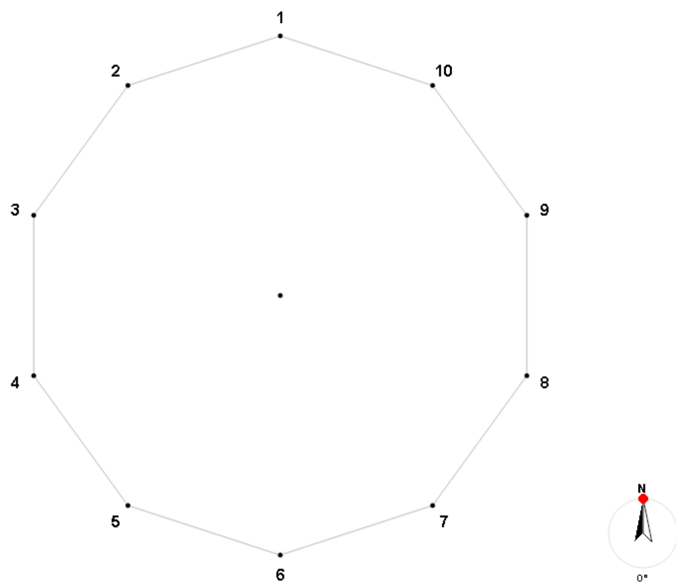


Figure 14 European Beech Sensor Orientation

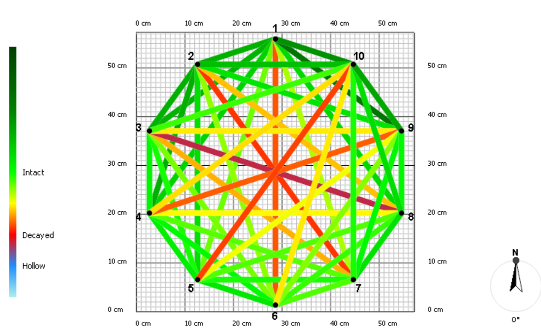


Figure 15 Beech Layer 1 - Graph

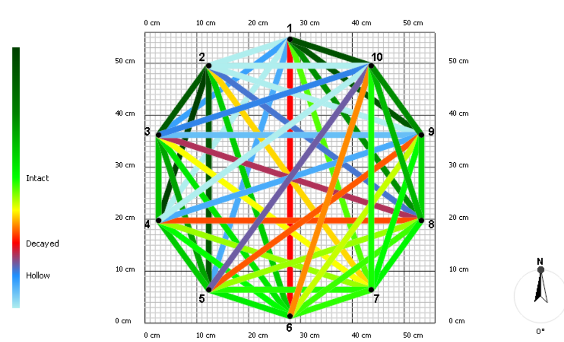


Figure 16 Beech Layer 2 – Graph

The trunk structure showed a hollowed decayed area that widened at the layer 2 between points 1 and 2 and extended to point 4. The interpretation of the space between layer 1 and 2 is shown below.

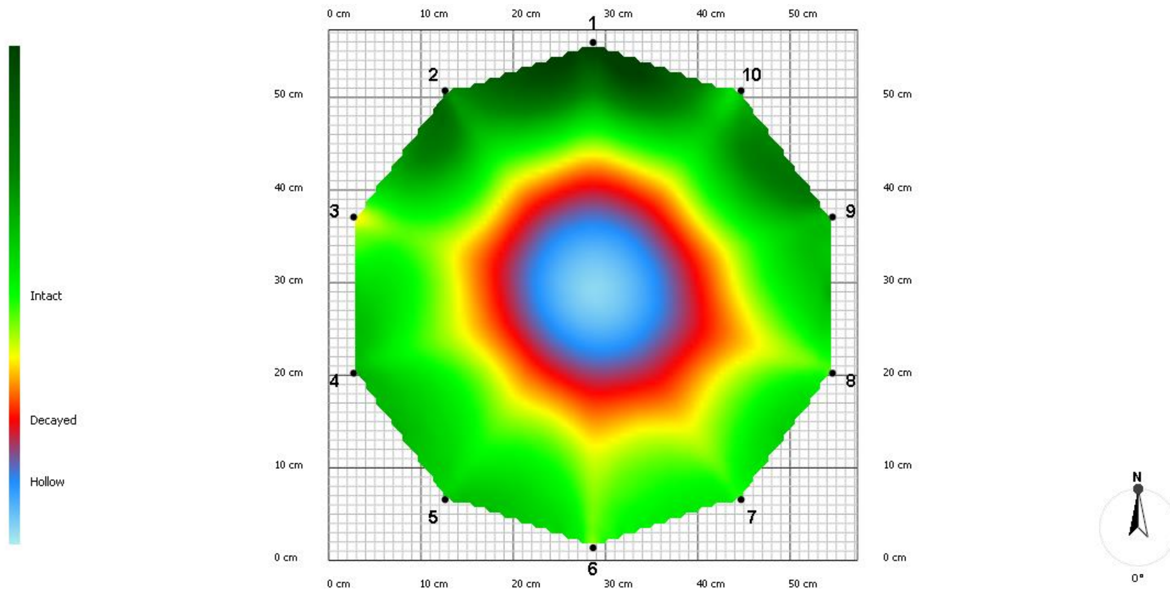


Figure 17 Beech Layer 1 - 2d Map

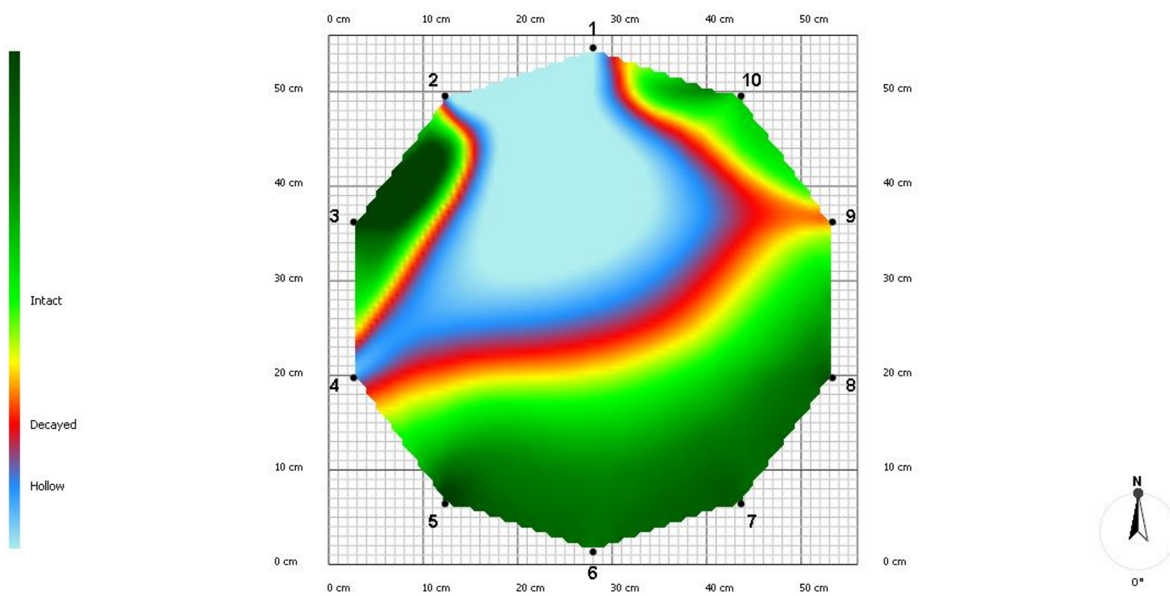


Figure 18 Beech Layer - 2d Map

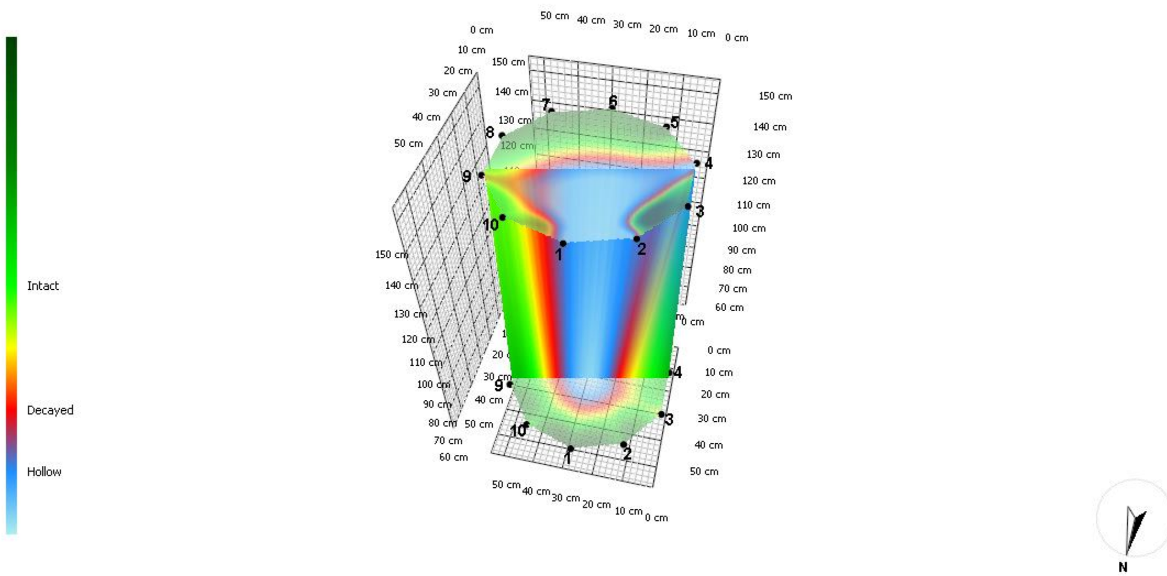


Figure 19 Beech Multilayer - Velocity

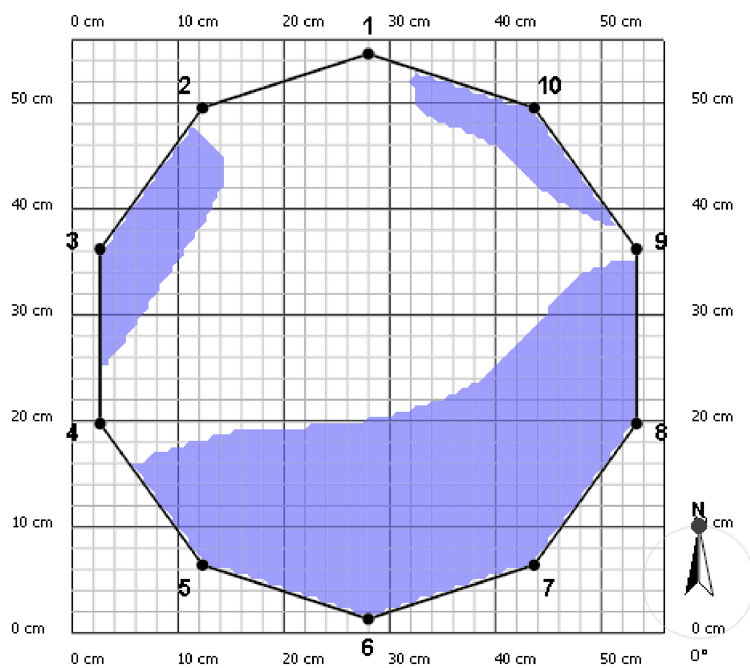


Figure 20 Beech Area Map- no color is hollow/decay zone

Interpretation

The ArborSonic tomograph shows central hollowing and developing decay within the beech. The results show the most significant decay and hollowing at layer 2. The trunk is compromised at this point given the poor trunk taper, decay fungus and considerable interior weakness due to the hollow and associated dead wood. The tree is particularly vulnerable to wind load on the weak trunk portion.

Recommendations

The consultant recommends immediate removal of the beech. The extent of the decay and hollow coupled with its location on the trunk exposes the tree to a higher degree than the initial tree risk assessment found.

Tree number 3

The tree, a 45” dbh American elm (*Ulmus americana*) with a tag # 4723 is located off York Street and is the dominant tree in the Branford College open courtyard.

Figure 22 American Elm in Branford Courtyard

The tree was rated as a “moderate risk” after completing a Level II Risk Assessment prior to the tomography.

Figure 21 Arborist Setting Sensors on Elm

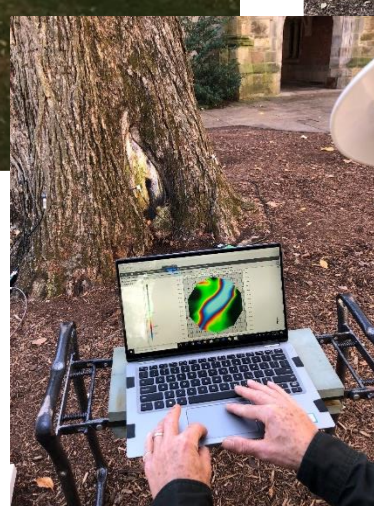


Figure 23 Arborist Checking Sensor Readings on Elm

Tree 3 Scan Results

The elm showed a hollowed zone (area in shades of blue) and adjacent decayed (area in red/brown) portions at the layer 1 tested height (50 centimeters above grade) and minimal shading decay/hollowing layer 2 (120 cm above grade). The exterior visible decayed area warranted the initial two-layer scan.

There was considerably more hollow area at the base (see layer 1) indicating increasing decay as one moved closer to the ground during trunk examination.

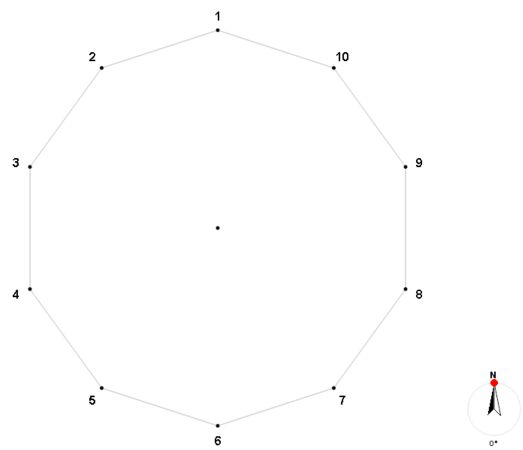


Figure 83 Elm Sensor Orientation

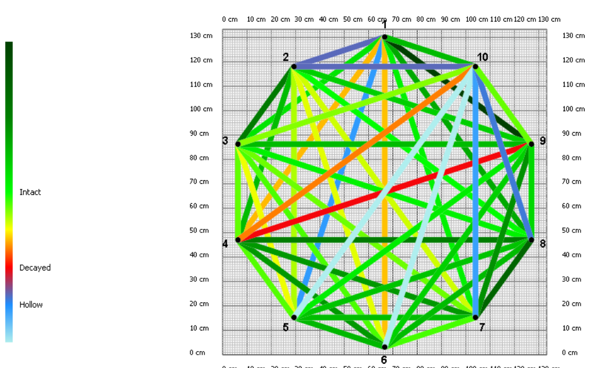


Figure 25 Branford Elm Layer 1 - Graph

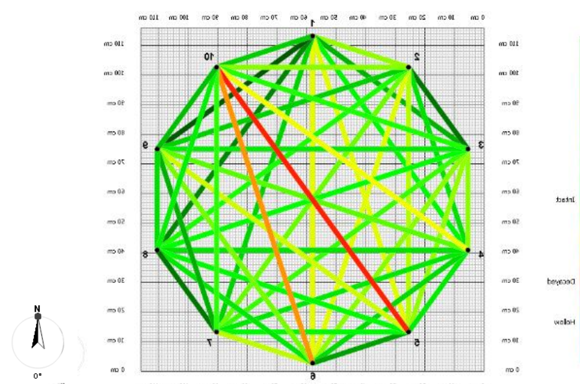


Figure 26 Branford Elm Layer 2 - Graph

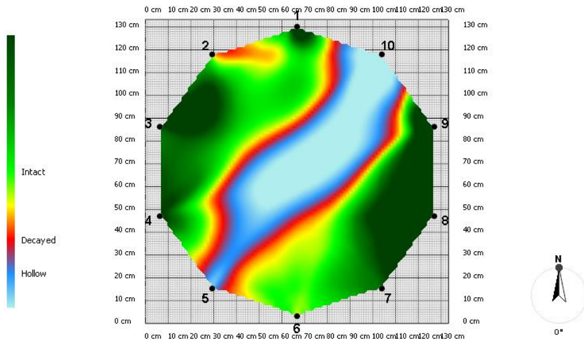


Figure 27 Branford Elm Layer 1 - 2d Map

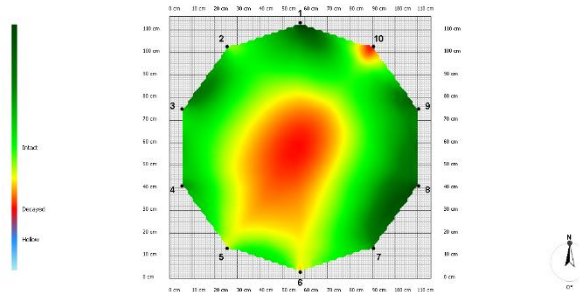


Figure 28 Branford Elm Layer 2 - 2d Map

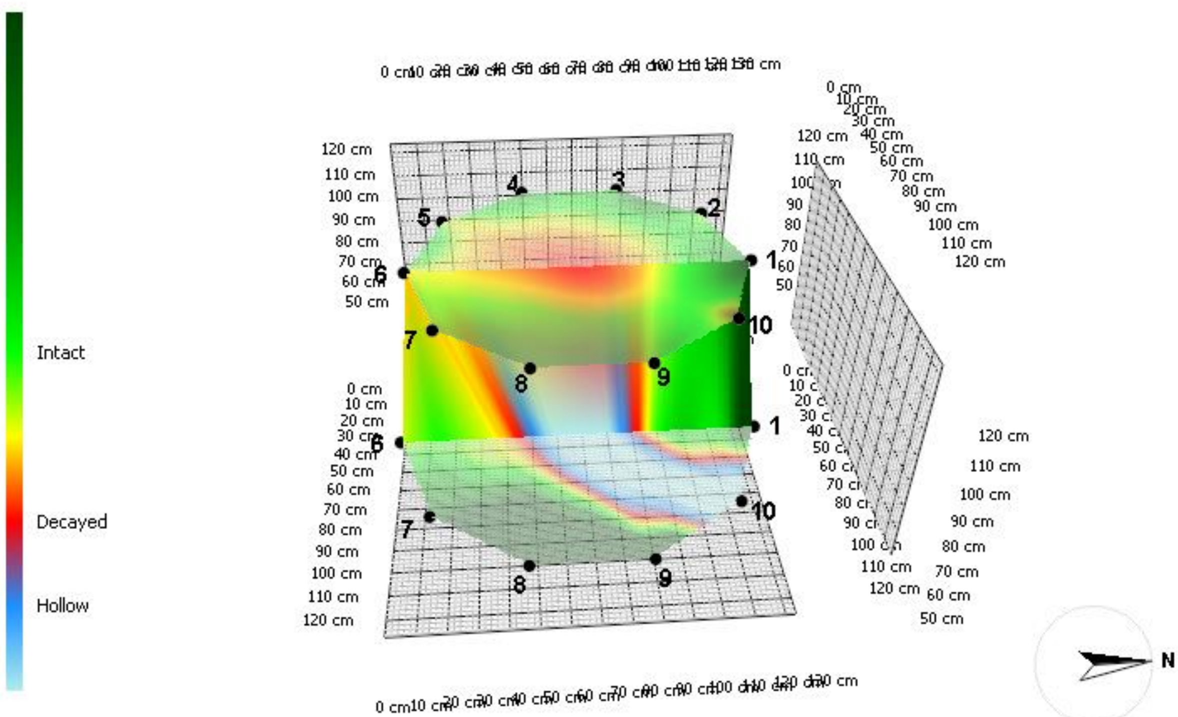


Figure 29 Branford Elm Multilayer - Velocity

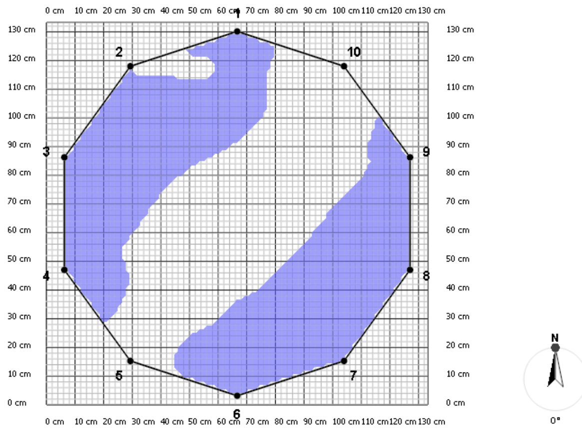


Figure 30 Branford Elm Layer 1 - Area Map

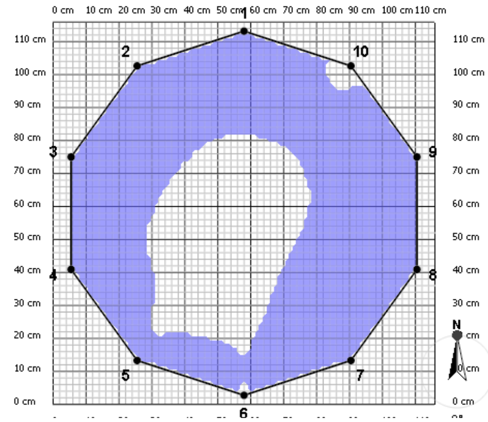


Figure 31 Branford Elm Layer 2 - Area Map

Interpretation

The ArborSonic tomograph shows increasing hollowing and decay within the elm as the scan tests approach ground level. The results show the most significant decay and hollowing at layer 2.

Tree stability is potentially compromised at this point given the trunk lean and increased hollowing at the base indicating the possibility of compromised roots due to decay. The lean of the tree places stress on the root area of concern further compromising roots.

Recommendations

The consultant recommends immediate further testing for the tree. A lower layer of additional tomographic testing would provide additional insight. A pull test would be ideal though space is limited for an ideal analysis and might not be possible. Otherwise, root excavation on the North side and root resistance drilling and tomography is recommended.

Tree number 4

The tree, a 36" dbh American elm (*Ulmus americana*) with a tag # 4825 is located off York Street and is located adjacent to the Yale university Theater entrance.

Figure 32 University Theater Elm

The tree was rated as a "moderate risk" after completing a Level II Risk Assessment prior to the tomography.

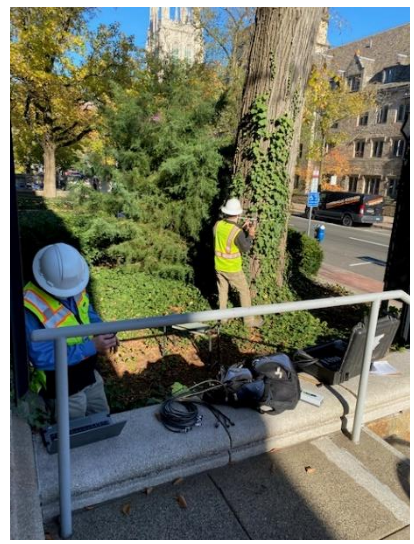


Figure 33 Arborist Techs Setting up at Elm

Tree 4 Scan Results

The tree was tested at 120 cm above grade at test point one. The tree has a lean to the south side as well as a small planting bed due to the raised planter the tree is located in. This would limit the ability of the roots to spread out providing needed stability.

The elm sounded hollow on a portion of the lower trunk's South side. Tomographic testing showed no hollowing leading the consultant's inconclusive diagnosis of the interior tree condition. Additional tomographic testing would provide a better sense of the existence of a cavity that may have produced a hollow sound.

The South lean is also an indicator of root instability on the North side.

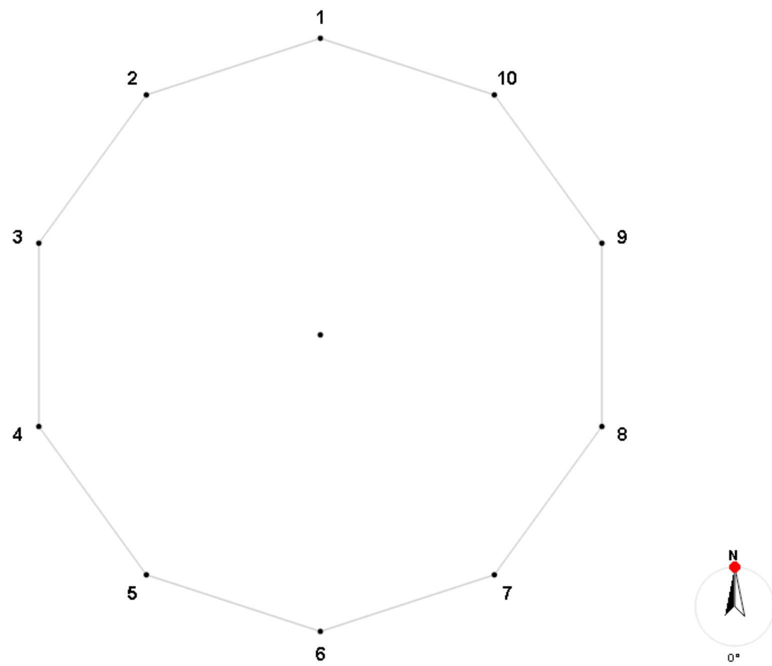


Figure 34 University Elm Sensor Orientation

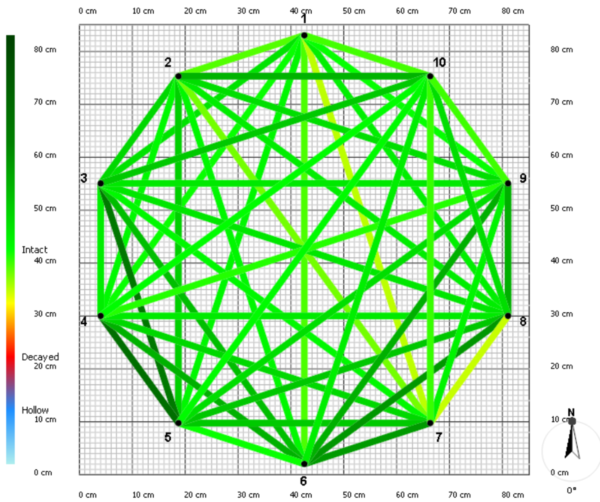


Figure 35 Elm Layer - Graph

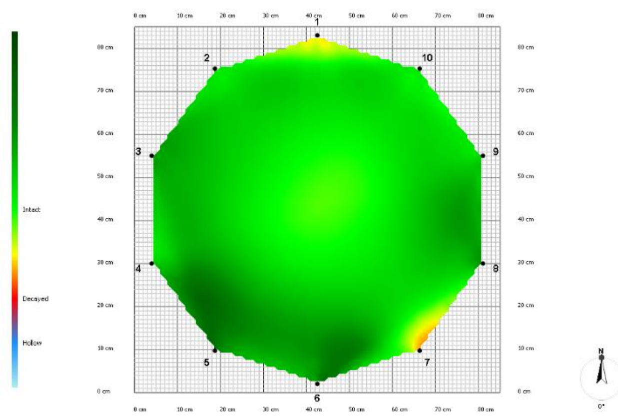


Figure 36 Elm Tomograph Layer - 2d Map

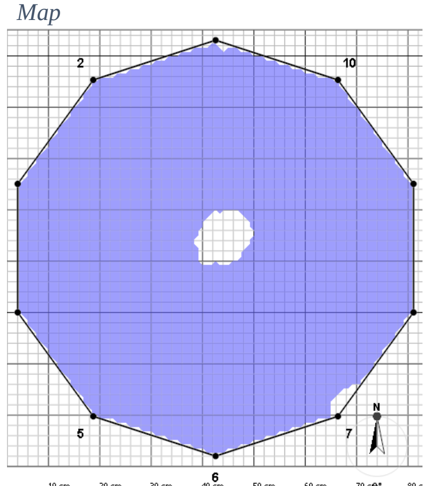


Figure 37 Elm Layer - Area Map - no color denotes hollow/decay

Interpretation

The ArborSonic tomograph shows no hollowing despite a hollow sound produced during the Level II Tree Risk Assessment. The tomography test was therefore inconclusive and additional testing of the upper and lower trunk region is recommended.

Tree stability is potentially compromised at this point given the trunk lean and increased hollowing at the base indicating the possibility of compromised roots.

Recommendations

The consultant recommends further tomographic and pull testing for the tree. The pull test would provide insight as to the extent of root instability, though space is limited for ideal analysis. Otherwise, root excavation and resistance drilling or tomography is recommended if substantial root mass is available.

Tree number 5

The tree, a 44" dbh American elm (*Ulmus americana*) with a tag # 4885 is located off Park Street and is located dominantly within the Pierson College courtyard.

Figure 38 Pierson College Elm

The tree was rated as a "high risk" after completing a Level II Risk Assessment prior to the tomography.

Figure 39 Arborists Installing Sensors on Elm

Tree 5 Scan Results

The tree was tested at 140 cm above grade at test point one. The tree has a slight lean to the south side.

Tomographic testing showed no hollowing or decay leading the consultant's inconclusive diagnosis of the interior tree condition. The upper trunk showed signs of cavities and fungal growth. Additional tomographic testing higher on the trunk adjacent to the cavities and decay would provide additional insight.

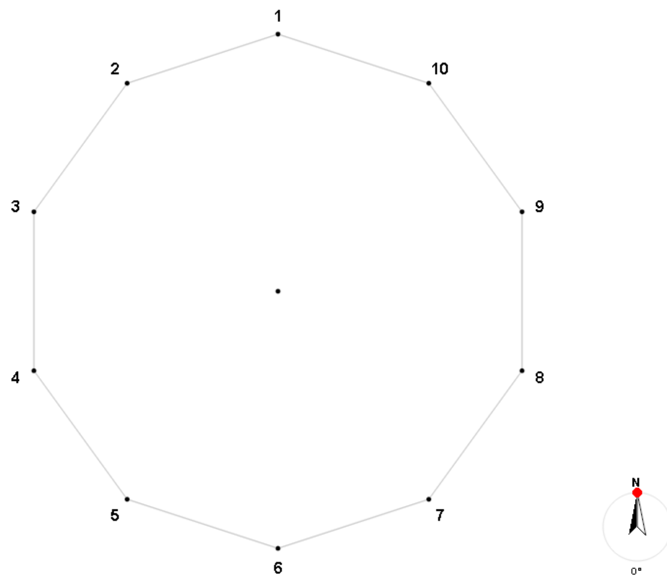


Figure 40 Pierson Elm Sensor Orientation

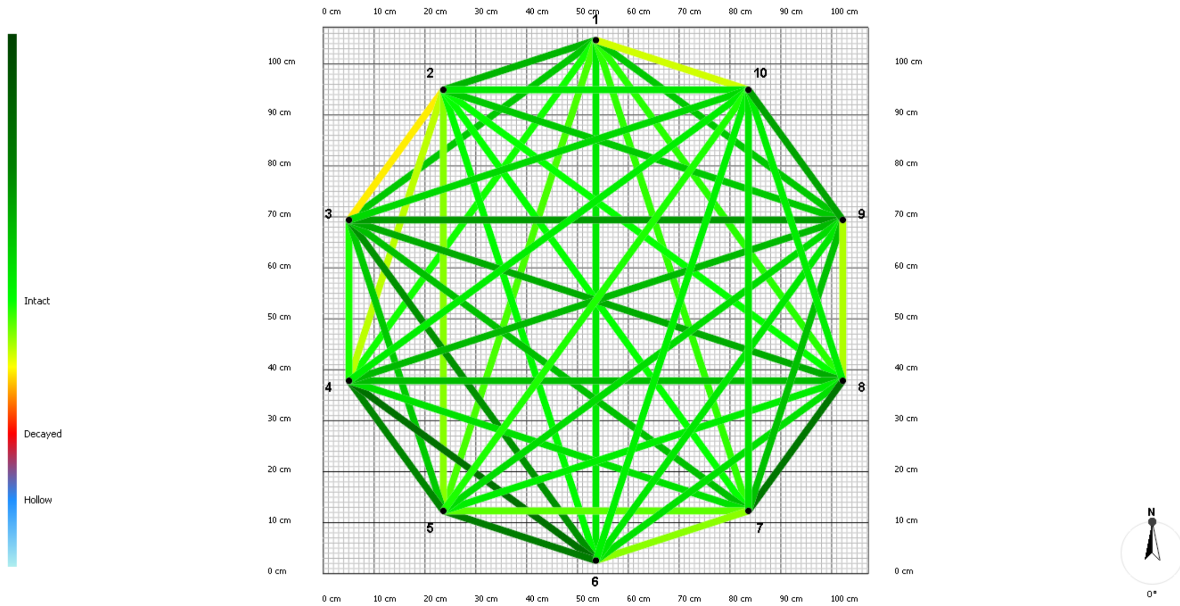


Figure 41 Pierson Elm Layer - Graph

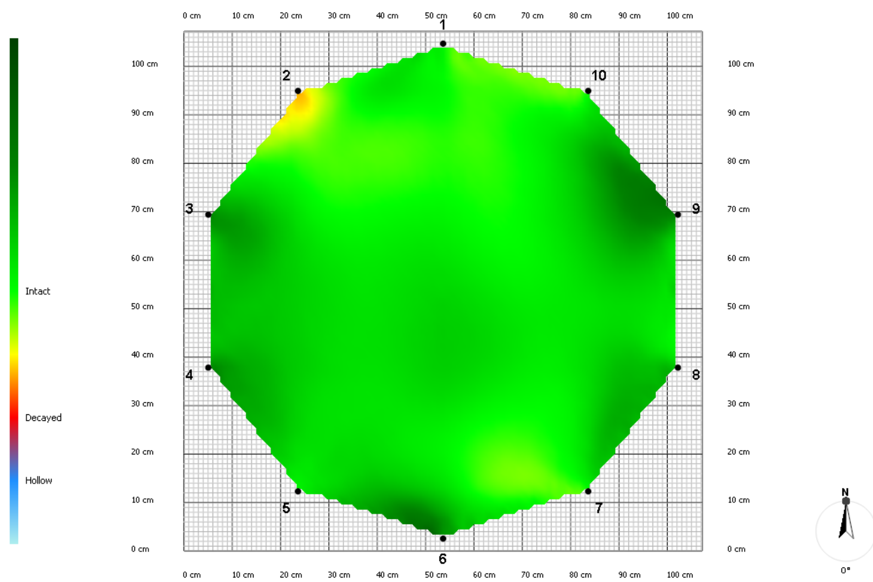


Figure 42 Pierson Elm -2d Map

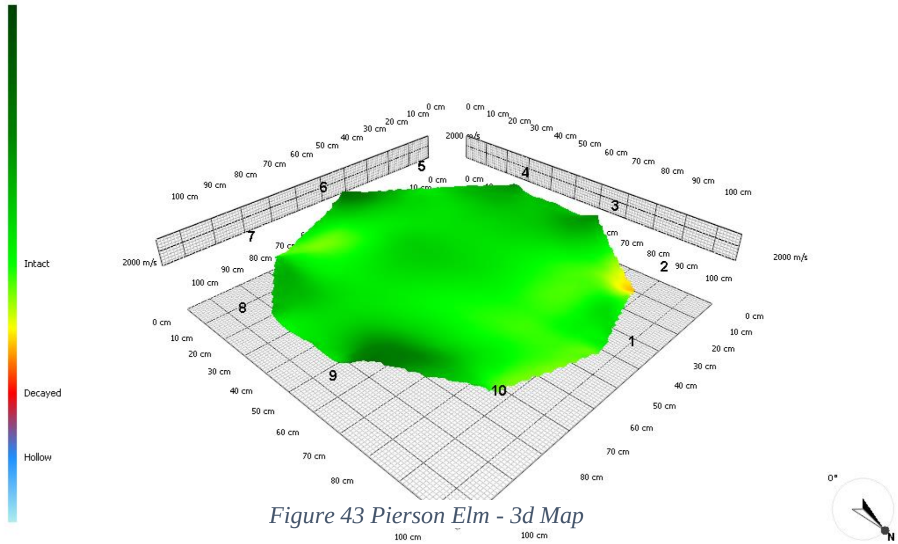


Figure 43 Pierson Elm - 3d Map

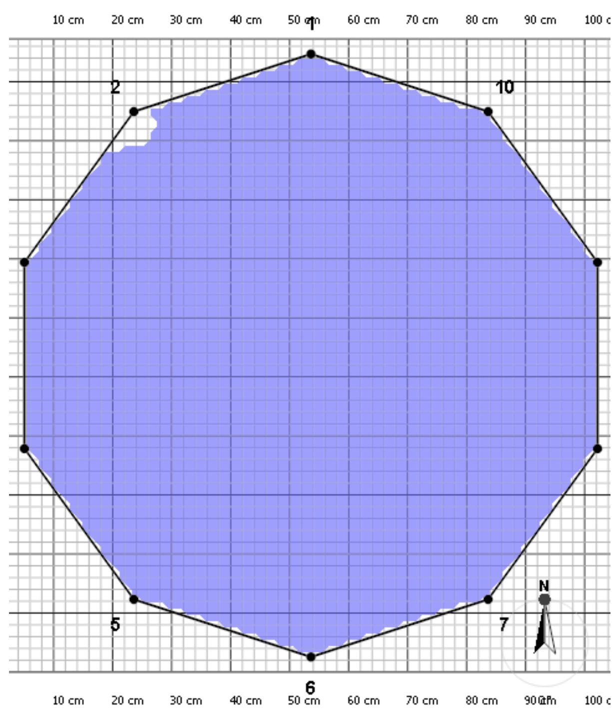


Figure 44 Pierson Elm - Area Map- no color denotes hollow/decay

Interpretation

The ArborSonic tomograph shows no decay or hollowing on the current layer.

Recommendations

The consultant recommends further tomographic testing adjacent (above and below) to the cavity and decay area, bracing and crown reduction for the tree. The Level II Risk Assessment provided additional insight to the upper trunk and canopy of the tree. There is a weak attachment of a significant branch to the tree trunk. This may or may not be due to a suspected internal cavity.

Figure 45 Pierson Elm Looking Up on North Side - notice cavities/weak attachment

There is considerable weight on the branch extending out from the suspected decay area. There is also a crack extending down the middle of the tree. Bracing and significant crown reduction might be an option after further testing aloft. The additional information will provide the critical insight needed for final recommendations.

Appendix 10 A.

ArborSonic 3D Measurements Report

Timothy Dwight Ginkgo

11/29/2020 2:25 PM

Tree species: Ginkgophyta (Ginkgos)

Tree location	Timothy Dwight College
Measurement date	Thursday, November 5, 2020 9:59 AM
Tree identifier	4286
Project identifier	Yale University
Trunk diameter at 4 feet	55 inches
Status report	
Root status	Intact
Root collar status	Intact
Trunk status	Hollow, Slanting
Crown collar status	Intact
Crown status	Pruned
Other state	codominant tree with included bark
Proposed treatment	
Root treatment	Not necessary
Root collar treatment	Not necessary
Trunk treatment	Hollow treatment
Crown collar treatment	Not necessary
Crown treatment	Pruning
Other treatment	recommend further inspection, resistance drilling, multiple bracing rods, check current cabling and enhance

Biomechanics

Wind	
Wind model:	EN1991
Terrain:	City
Base wind velocity:	26.0 m/s
Dry air temp.:	9 °C
Crown	
Crown model:	Calculator
Area:	0 m2
Top height:	0 m
Center height:	0 m
Bottom height:	NaN m
Trunk	

Degree of lean:	90 °
Direction of lean:	0 °
Tree	
Wind load:	0 N
Center height:	0 m
Drag factor:	0.22
Yield strength:	18.3 MPa

Layer #1

Sensor Geometry

Height	85 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	428
PD	4
BT	3

Time Data (µs)

	341±6	657±2	814±2	782±2	823±2	725±1	805±1	676±2	381±12
318±1		412±1	675±2	747±1	829±1	784±2	941±1	893±1	655±1
657±1	416±1		363±1	563±1	788±1	753±1	972±3	946±3	834±4
751±14	548±15	355±4		285±6	543±4	760±5	1004±6	988±7	1238±32
782±0	750±0	560±0	348±1		431±6	603±0	915±1	936±2	1202±0
834±2	838±2	794±1	701±1	328±2		330±2	696±2	813±1	817±3
728±3	788±3	757±2	779±3	608±2	330±0		419±2	594±2	646±2
803±0	938±0	968±1	2285±1	909±1	685±0	411±1		379±0	585±0
677±2	895±2	950±5	1458±23	932±3	804±2	585±2	378±1		333±2
296±8	619±3	817±2	1222±1	850±1	785±3	643±1	592±1	290±16	

Tomograms (m/s)

	2023	1600	1591	1692	1615	1828	1547	1551	1963
2023		1573	1726	1667	1583	1707	1398	1385	1653
1600	1573		1840	1889	1574	1757	1372	1385	1505
1591	1726	1840		2118	1694	1620	786	1080	1058
1692	1667	1889	2118		1729	1744	1357	1407	1294
1615	1583	1574	1694	1729		2019	1517	1537	1651
1828	1707	1757	1620	1744	2019		1569	1795	1952
1547	1398	1372	786	1357	1517	1569		1733	1798
1551	1385	1385	1080	1407	1537	1795	1733		2155
1963	1653	1505	1058	1294	1651	1952	1798	2155	

Appendix 10 B:

ArborSonic 3D Measurements Report

Branford Beech

11/29/2020 5:04 PM

Tree species: Fagaceae (Beech family)

Tree location	Branford College
Measurement date	Thursday, November 5, 2020 10:06 AM
Tree identifier	4726
Project identifier	Yale University
Trunk diameter at 4 feet	23 inches
Status report	
Root status	
Root collar status	Intact
Trunk status	Damaged, Decayed, Hollow
Crown collar status	Intact
Crown status	Intact
Other state	poor trunk taper, decay, climacodon fungus
Proposed treatment	
Root treatment	Not necessary
Root collar treatment	Not necessary
Trunk treatment	Not necessary
Crown collar treatment	Not necessary
Crown treatment	Not necessary
Other treatment	Recommend removal

Biomechanics

Wind	
Wind model:	EN1991
Terrain:	City
Base wind velocity:	26.0 m/s
Dry air temp.:	9 °C
Crown	
Crown model:	Calculator
Area:	0 m2
Top height:	0 m
Center height:	0 m
Bottom height:	NaN m
Trunk	

Degree of lean:	90 °
Direction of lean:	0 °
Tree	
Wind load:	0 N
Center height:	0 m
Drag factor:	0.25
Yield strength:	23.9 MPa

Layer #2

Sensor Geometry

Height	150 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	180
PD	2
BT	1

Time Data (µs)

	430±40	311±12	789±4	510±4	428±1	338±0	254±0	182±0	114±0
356±34		119±1	176±2	223±2	299±2	383±2	476±2	546±4	462±6
423±3	121±1		142±2	213±2	286±1	367±3	456±3	499±6	469±5
479±6	174±1	137±2		138±1	236±1	314±2	394±3	478±4	635±28
524±2	229±3	212±3	144±3		145±3	244±3	322±3	402±3	486±3
439±2	313±1	293±1	250±1	150±0		154±1	251±1	330±1	394±3
347±2	392±2	372±2	329±2	248±1	153±1		152±1	244±1	303±1
256±1	478±2	456±3	416±5	321±2	246±1	148±1		142±1	214±1
186±2	548±4	576±4	587±21	402±3	324±2	239±2	144±2		128±1
121±2	400±3	410±3	625±6	468±1	389±1	303±2	222±1	134±1	

Tomograms (m/s)

	569	1096	777	1073	1338	1684	2114	2438	2472
569		2403	2594	2434	1911	1513	1171	909	919
1096	2403		1951	2050	1828	1548	1267	1030	1151
777	2594	1951		1923	1750	1626	1399	1072	870
1073	2434	2050	1923		1808	1723	1626	1410	1206
1338	1911	1828	1750	1808		1715	1702	1592	1451
1684	1513	1548	1626	1723	1715		1776	1762	1736
2114	1171	1267	1399	1626	1702	1776		1888	1984
2438	909	1030	1072	1410	1592	1762	1888		2127
2472	919	1151	870	1206	1451	1736	1984	2127	

Layer #1

Sensor Geometry

Height	60 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	184
PD	2
BT	1

Time Data (μs)

	138±2	218±2	284±2	345±2	407±2	351±2	282±2	197±2	128±2
135±1		135±1	215±1	283±1	343±2	413±3	378±4	284±3	214±3
216±2	137±2		150±2	244±2	311±2	380±1	450±1	371±1	307±3
277±3	216±3	148±2		146±3	235±2	307±2	368±4	409±5	375±7
345±1	287±1	244±1	149±1		143±1	242±0	310±1	368±1	415±2
417±1	357±1	319±1	245±1	150±1		156±1	250±1	320±1	371±1
359±3	425±2	385±3	315±3	246±3	154±3		147±3	243±4	301±3
283±6	382±6	449±5	371±5	309±4	244±4	143±4		149±4	225±4
198±1	291±1	373±1	412±2	365±1	313±0	236±1	150±1		131±1
135±2	225±2	307±2	373±3	418±3	373±2	303±2	235±1	138±2	

Tomograms (m/s)

	2057	2048	1942	1710	1447	1658	1925	2291	2164
2057		2062	2064	1908	1681	1421	1537	1888	2015
2048	2062		1831	1784	1702	1524	1317	1573	1751
1942	2064	1831		1857	1816	1728	1584	1453	1562
1710	1908	1784	1857		1876	1781	1733	1598	1431
1447	1681	1702	1816	1876		1736	1757	1691	1572
1658	1421	1524	1728	1781	1736		1897	1822	1783
1925	1537	1317	1584	1733	1757	1897		1819	1912
2291	1888	1573	1453	1598	1691	1822	1819		2095
2164	2015	1751	1562	1431	1572	1783	1912	2095	

Appendix 10 C:

ArborSonic 3D Measurements Report

Branford Elm

11/29/2020 7:14 PM

Tree species: Ulmaceae (Elm family)

Tree location	Branford College
Measurement date	Thursday, November 5, 2020 11:23 AM
Tree identifier	4723
Project identifier	Yale University
Trunk diameter at 4 feet	45 inches
Status report	
Root status	Damaged
Root collar status	Decayed
Trunk status	Decayed, Slanting
Crown collar status	Damaged
Crown status	Pruned, One-sided
Other state	significantly leaning ttree, trunk damage low on base
Proposed treatment	
Root treatment	Wound treatment
Root collar treatment	Decay treatment
Trunk treatment	Decay treatment
Crown collar treatment	Decay treatment
Crown treatment	Pruning
Other treatment	root collar and root excavation, possible root decay, possible guying

Biomechanics

Wind	
Wind model:	EN1991
Terrain:	City
Base wind velocity:	26.0 m/s
Dry air temp.:	9 °C
Crown	
Crown model:	Calculator
Area:	0 m2
Top height:	0 m
Center height:	0 m
Bottom height:	NaN m

Trunk	
Degree of lean:	90 °
Direction of lean:	0 °
Tree	
Wind load:	0 N
Center height:	0 m
Drag factor:	0.25
Yield strength:	20 MPa

Layer #2

Sensor Geometry

Height	120 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	372
PD	4
BT	3

Time Data (µs)

	266±1	380±1	544±2	686±1	708±2	572±1	458±1	319±2	228±2
263±2		204±3	405±3	594±3	680±2	669±3	628±3	507±2	449±2
377±0	203±0		263±1	454±1	579±1	633±0	643±1	596±1	553±1
543±5	408±6	263±4		240±4	397±5	527±5	592±6	666±10	698±13
687±2	599±2	457±2	243±2		215±2	423±2	551±2	681±3	819±4
717±1	695±3	590±1	408±2	220±1		270±1	417±1	583±1	737±3
578±2	676±3	638±3	532±2	424±2	268±1		209±1	380±2	561±3
454±2	625±1	640±2	590±2	544±2	406±1	199±3		235±2	414±2
322±2	513±3	602±3	668±4	680±2	576±2	375±2	239±2		224±2
235±1	456±2	561±3	687±3	804±3	734±2	559±2	420±3	230±1	

Tomograms (m/s)

	1699	2076	1845	1632	1630	1970	2229	2499	1983
1699		2312	1920	1670	1631	1732	1800	1975	1707
2076	2312		1706	1697	1706	1772	1822	1885	1796
1845	1920	1706		1887	1941	1897	1914	1747	1618
1632	1670	1697	1887		2136	1837	1831	1649	1422
1630	1631	1706	1941	2136		1663	1895	1723	1518
1970	1732	1772	1897	1837	1663		2302	2080	1787
2229	1800	1822	1914	1831	1895	2302		1931	1866
2499	1975	1885	1747	1649	1723	2080	1931		2030
1983	1707	1796	1618	1422	1518	1787	1866	2030	

Layer #1

Sensor Geometry

Height	50 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	424
PD	4
BT	3

Time Data (µs)

	415±0	482±0	917±0	1137±0	882±0	717±0	571±0	337±0	259±0
409±4		238±2	458±4	698±4	808±3	835±5	735±4	601±4	866±12
482±4	241±2		310±4	557±4	669±4	770±5	747±5	657±2	731±28
602±2	446±1	296±1		291±1	419±1	544±1	590±1	671±2	934±7
1141±0	711±0	566±0	311±0		260±0	452±0	595±0	718±0	2706±0
887±3	822±2	677±1	440±2	263±1		299±1	457±1	607±1	2163±4
719±3	838±3	771±2	560±2	453±2	300±2		221±17	429±2	1360±3
564±3	730±2	739±3	600±3	586±3	447±3	233±4		273±4	945±17
338±0	601±2	656±1	1309±37	708±2	598±1	419±1	275±1		305±1
266±0	584±1	652±0	835±1	962±2	852±1	681±1	534±0	302±0	

Tomograms (m/s)

	1188	1835	1489	1108	1494	1792	2025	2711	1970
1188		2193	1967	1610	1568	1584	1754	1905	1188
1835	2193		1672	1558	1690	1664	1794	1970	1643
1489	1967	1672		1683	2081	2086	2185	1330	1440
1108	1610	1558	1683		1979	1964	1942	1804	706
1494	1568	1690	2081	1979		1694	1967	1899	831
1792	1584	1664	2086	1964	1694		2334	2106	1094
2025	1754	1794	2185	1942	1967	2334		1876	1164
2711	1905	1970	1330	1804	1899	2106	1876		1669
1970	1188	1643	1440	706	831	1094	1164	1669	

Appendix 10 D:

ArborSonic 3D Measurements Report

University Theatre Elm

11/29/2020 8:18 PM

Tree species: Fagaceae (Beech family)

Tree location	University Theatre
Measurement date	Thursday, November 5, 2020 1:41 PM
Tree identifier	4825
Project identifier	Yale University
Trunk diameter at 4 feet	36 inches
Status report	
Root status	Damaged
Root collar status	Decayed
Trunk status	Hollow
Crown collar status	Intact
Crown status	Intact, Pruned
Other state	overetended branching, hollow sound w/hammer on South, lean to south, raised planter
Proposed treatment	
Root treatment	Wound treatment
Root collar treatment	Decay treatment
Trunk treatment	Hollow treatment
Crown collar treatment	Not necessary
Crown treatment	Pruning
Other treatment	testing inconclusive, further trunk testing due to thick bark

Biomechanics

Wind	
Wind model:	EN1991
Terrain:	City
Base wind velocity:	26.0 m/s
Dry air temp.:	9 °C
Crown	
Crown model:	Calculator
Area:	0 m2
Top height:	0 m

Center height:	0 m
Bottom height:	NaN m
Trunk	
Degree of lean:	90 °
Direction of lean:	0 °
Tree	
Wind load:	0 N
Center height:	0 m
Drag factor:	0.25
Yield strength:	23.9 MPa

Layer #1

Sensor Geometry

Height	120 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	286
PD	5
BT	3

Time Data (µs)

	207±1	315±1	417±2	444±1	476±2	487±1	400±1	326±1	201±1
202±0		181±22	324±2	375±1	438±1	481±2	437±1	384±2	286±1
309±3	194±3		196±3	265±2	364±2	442±3	444±3	430±3	369±2
401±4	322±3	191±3		157±2	284±2	378±2	432±2	463±3	441±2
443±2	379±3	266±4	164±3		198±4	299±3	375±3	426±3	456±2
478±1	448±1	371±1	295±1	200±2		172±2	283±2	362±2	434±1
489±1	490±1	446±1	387±1	300±1	172±1		218±4	323±1	415±1
393±2	435±2	442±2	436±2	370±2	276±2	211±1		174±2	303±2
327±1	388±1	434±1	474±2	424±1	358±0	318±0	179±1		200±1
205±7	295±5	378±5	455±9	461±7	438±5	419±6	316±5	206±6	

Tomograms (m/s)

	1827	1999	1893	1927	1834	1735	1955	1895	1842
1827		2037	1919	2068	1928	1799	1963	2015	2167
1999	2037		1959	2400	2128	1924	1986	1980	2090
1893	1919	1959		2470	2175	2036	1972	1868	1907
1927	2068	2400	2470		1894	2090	2096	2016	1915
1834	1928	2128	2175	1894		2256	2264	2177	1961
1735	1799	1924	2036	2090	2256		1726	1937	1851

1955	1963	1986	1972	2096	2264	1726		2183	2015
1895	2015	1980	1868	2016	2177	1937	2183		1845
1842	2167	2090	1907	1915	1961	1851	2015	1845	

Appendix 10 E:

ArborSonic 3D Measurements Report

Pierson Elm

11/29/2020 8:41 PM

Tree species: Ulmaceae (Elm family)

Tree location	Pierson Elm
Measurement date	Thursday, November 5, 2020 2:11 PM
Tree identifier	4885
Project identifier	Yale University
Trunk diameter at 4 feet	44 inches
Status report	
Root status	Intact
Root collar status	Intact
Trunk status	Damaged
Crown collar status	Damaged
Crown status	Pruned, Damaged limbs
Other state	overextended tree, crown needs reduction, codominant and poorly attached significant branch on upper trunk
Proposed treatment	
Root treatment	Not necessary
Root collar treatment	Not necessary
Trunk treatment	Wound treatment
Crown collar treatment	Not necessary
Crown treatment	Pruning
Other treatment	bracing and crown reduction recommended

Biomechanics

Wind	
Wind model:	EN1991
Terrain:	City
Base wind velocity:	26.0 m/s
Dry air temp.:	9 °C
Crown	
Crown model:	Calculator
Area:	0 m2

Top height:	0 m
Center height:	0 m
Bottom height:	NaN m
Trunk	
Degree of lean:	90 °
Direction of lean:	0 °
Tree	
Wind load:	0 N
Center height:	0 m
Drag factor:	0.25
Yield strength:	20 MPa

Layer #1

Sensor Geometry

Height	140 cm
Scheme	Circle
Sensor count	10

Sensor position data

C	346
PD	4
BT	3

Time Data (μs)

	213±1	368±2	528±1	601±1	577±1	592±2	527±1	366±1	255±1
210±2		261±3	440±2	547±2	573±2	601±3	583±2	470±2	383±2
369±1	268±1		242±1	371±0	434±1	525±1	528±1	494±0	485±1
515±3	434±3	233±2		197±3	313±2	488±3	516±2	531±2	559±3
602±1	553±2	368±1	201±1		193±1	418±1	505±1	549±1	613±3
584±1	585±1	438±1	325±1	198±0		269±6	386±1	499±1	570±1
598±1	609±2	527±1	498±1	420±2	230±2		195±1	366±1	495±2
527±2	585±2	527±2	528±3	503±2	381±2	191±3		251±2	391±2
372±3	479±5	498±4	546±9	551±4	498±3	364±3	255±3		206±3
260±1	392±1	488±1	573±1	609±1	569±1	494±1	392±1	207±1	

Tomograms (m/s)

	2042	1978	1783	1737	1873	1758	1764	1977	1624
2042		1570	1641	1684	1811	1793	1792	1975	1873
1978	1570		1778	1973	2163	2005	2074	2136	1922
1783	1641	1778		2201	2324	1895	2021	2030	1853
1737	1684	1973	2201		2244	1719	1851	1912	1774
1873	1811	2163	2324	2244		1681	1894	1873	1842
1758	1793	2005	1895	1719	1681		2286	2001	1888

1764	1792	2074	2021	1851	1894	2286		1651	1852
1977	1975	2136	2030	1912	1873	2001	1651		2103
1624	1873	1922	1853	1774	1842	1888	1852	2103	