Town of Cary, NC
i-Tree Canopy Assessment Project| 2016

Submitted by

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Town of Cary i-Tree Canopy Assessment Project

MAKING THE MOST OF YOUR ASSESSMENT REPORT

Who's Who

Those who conducted the assessment and prepared this document are members of the Bartlett Inventory Solutions (BIS) team. They are also employees of Bartlett Tree Experts and operate from the Bartlett Tree Research Laboratories in Charlotte, North Carolina. Readers may interpret the terms "Bartlett Tree Experts," "Bartlett," "the BIS team," "the team," "we," and "our" as the Bartlett company and those who conducted the assessment and prepared this report.

Definitions & Bolded Terms

Some definitions or specifications are detailed within a given section to explain how readers should interpret certain terms or classifications. We have also appended a Glossary for other terms that appear throughout the document. The first reference to each of these terms appears in bold for the reader's convenience.

Executive Summary

The BIS team determined the total **canopy** cover for the Town of Cary to be **46.0%**. This canopy is also associated with over **$3,969,652.64** in benefits through carbon storage and annual environmental services. These benefits will accrue over time with continued urban forest monitoring and management.

BACKGROUND INFORMATION

Land Cover Classes

Land cover classification can be defined as the act of classifying land sections or areas based on what type of material is covering them. Examples include **pervious** and **impervious** material, tree or non–tree cover, water, roads, grass, etc. Land covers are generally classified to determine the percentages that each cover class makes up of a given area. That information can be used to set benchmarks or used as a basis to monitor change through out time.

Environmental services

Environmental services (tree benefits) can be described as the economic, environmental, and social benefits people receive from trees and the environment. Examples include: **carbon storage**, **carbon sequestration**, **air pollution removal**, reduction in **stormwater runoff**, **noise attenuation**, energy conservation, recreational and cultural value, and increases in public health and quality-of-life.

The urban environment can create a host of environmental problems that mostly impact the local area, but can collectively impact larger regions. Therefore, being able to quantify the benefits that are being provided locally and working to improve or increase them can have an impact on an entire region.

i-Tree

The USDA Forest Service developed a science-based, peer-reviewed computer model designed to calculate urban forest ecosystem services and their associated values based upon measurements taken in the field during inventories or through **remote analyses**. This analysis and benefits assessment software suite is called i-Tree, and there are currently eight applications that can be utilized in and around urban environments. i-Tree is designed to highlight the significance of community trees and advocate for them as sustainable infrastructure, which assist in pollution mitigation, energy conservation, carbon sequestration, carbon storage, etc. The intention is for i-Tree users to improve tree and urban forest management through strategic planning, community awareness and advocacy, and engage decision makers and stakeholders.

i-Tree Canopy is utilized to estimate land cover classes within a given project area. The tool uses aerial imagery to classify pre-determined land cover classes. The tool also estimates carbon storage and sequestration, and air pollution removal amounts and values for tree cover classes. The results can be used to monitor canopy change over time and can be utilized as input for other i-Tree tools. i-Tree Canopy results provide a snapshot of the benefits provided by the tree canopy and can be used as a tool to jumpstart a more in-depth analysis of the project site to achieve a more accurate picture of the benefits being provided.

The environmental services that i-Tree Canopy reports on are described below:

- Carbon Monoxide (CO) – gas that is produced by products and equipment such as cars and lawn mowers.
- Nitrogen Dioxide (NO2) – gas that is emitted in the exhaust of cars and trucks.
- Ozone (O3) – compound that is formed after the reaction of nitrogen oxides and hydrocarbons.
- Particulate Matter greater than 2.5 microns and less than 10 microns (PM10*) – solids created by combustion of fossil fuels, industrial processes, and several other activities (PM10* is an adjusted PM10 concentration where PM2.5 concentrations where subtracted from PM10 concentrations).
- Particulate Matter less than 2.5 microns (PM2.5) – solids created by combustion of fossil fuels, industrial processes, and several other activities.
- Sulfur Dioxide (SO2) – gas produced as a result of coal and oil burning.
- Carbon Dioxide (CO2) – gas that is naturally present in the atmosphere and produced by the combustion of fossil fuels.

Air pollution (CO, NO2, O3, PM10*, PM2.5, and SO2) rates and values were derived from a large scale i-Tree Eco project throughout the conterminous US. CO2 sequestration and storage rates and values were derived using national average estimates.

INTRODUCTION

In April 2016, the Town of Cary, NC retained Bartlett Inventory Solutions (BIS) to perform an i-Tree Canopy Assessment of the city. BIS member Jordan Endahl performed the assessment on July 28th.

The assessment included:

- utilizing a pre-existing **shapefile** boundary obtained from the Town of Cary GIS website;
- classifying randomly generated points as specific land cover classes based on point location within the site boundaries and client criteria.

The methods and procedures we used to make the above determinations are detailed in the following sections.

GOALS & OBJECTIVES

An effective report communicates clear goals and the specific objectives designed to carry out those goals. We intend "goal" to mean the overall aim or result we expect to achieve for the client in producing the assessment and project report. The objectives are the specific actions taken or recommended to support goal completion. Table 1 below describes each goal and its corresponding objective(s).

Table 1: GOALS & OBJECTIVES

GOAL	OBJECTIVES TO ACCOMPLISH GOAL
Establish land cover classes and percentages.	Using the i-Tree Canopy software, create random points to determine the land cover classification.
Estimate environmental services provided by tree cover.	Using the i-Tree Canopy software, estimate amounts and values for carbon storage and sequestration, and air pollution removal.

PROJECT SITE

The BIS team performed an i-Tree Canopy Assessment of the Town of Cary, NC. The project boundaries are displayed in Figure 1.

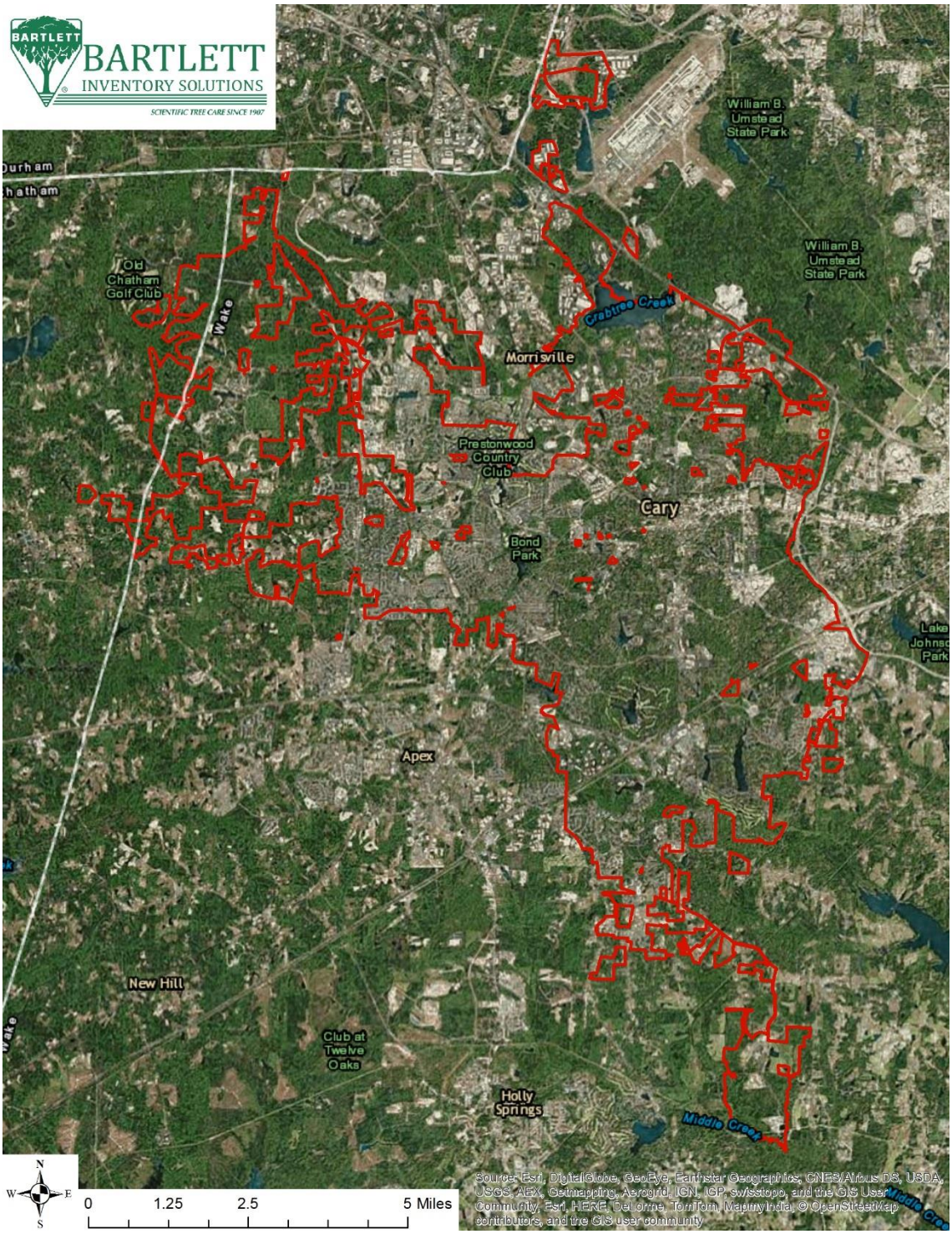

Figure 1: Project site boundaries for the Town of Cary.

ASSESSMENT METHODOLOGY

Project Site Boundary

BIS acquired a shapefile of the town limits from the Town of Cary GIS department website and used ArcGIS to reproject the file into the proper coordinant system to import into the i-Tree Canopy software.

Land Cover Classifications

The land cover classes used for the classification are described in Table 2.

Table 2: LAND COVER CLASSES AND DESCRIPTIONS

Land Cover Class	Description
Grass/Herbaceous	Areas covered with grass or herbaceous groundcovers
Tree/Shrub	Trees or shrubs
Impervious Buildings	Buildings with impervious material
Impervious Road	Roads with impervious material
Impervious Other	Objects with impervious material other than buildings and roads
Water	Lakes, ponds, streams, or other water features
Soil/Bare Ground	Areas determined to be soil or bare ground

Land Cover Class Sampling

The i-Tree Canopy software was used to classify randomly generated points within the project site boundaries. Each point was visually classified into one of the pre-determined land cover classes. However, it is important to note that while using the latest aerial imagery available in Google ™ Earth, classification of random points may not be 100% accurate. The accuracy depends on the aerial imagery, the precision of land cover classes, and the visual interpretation of the assessor.

BIS standard practice is to classify enough random points to where each land cover class has a **standard error** of ≤ 2. The total number of random points to achieve this depends on the total number of cover classes and size of the project site. A typical range of 500-1,000 random points is necessary; 1000 points were classified for this assessment project.

Environmental Services Calculations

i-Tree Canopy provides estimates of environmental services for the land cover class that best represents tree canopy. The appropriate state, county, and project site classification (rural, urban, or a combination of both) are selected to provide the most accurate estimates possible. The removal rates and monetary values are assigned based on the site classifications (Table 3).

Table 3: ENVIRONMENTAL SERVICES, DESCRIPTIONS, RATES, AND VALUES

Abbreviation	Environmental Service Description	Removal Rate (lbs/acre/yr)	Monetary Value ($/T/yr)
CO	Carbon Monoxide removed annually	1.846	$380.30
NO2	Nitrogen Dioxide removed annually	5.845	$89.19
O3	Ozone removed annually	43.121	$391.47
PM10*	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	11.406	$1,843.32
PM2.5	Particulate Matter less than 2.5 microns removed annually	1.720	$27,374.95
SO2	Sulfur Dioxide removed annually	1.660	$25.76
CO2seq	Carbon Dioxide sequestered annually in trees	10,199.655	$36.29
CO2stor	Carbon Dioxide stored in trees (Note: this is not an annual rate)	251,395.359	$36.29

RESULTS

Land Cover Classes

Land cover classes utilized for this assessment and their resulting standard errors and percent coverage of the project site are presented in Figure 2 and Table 4.

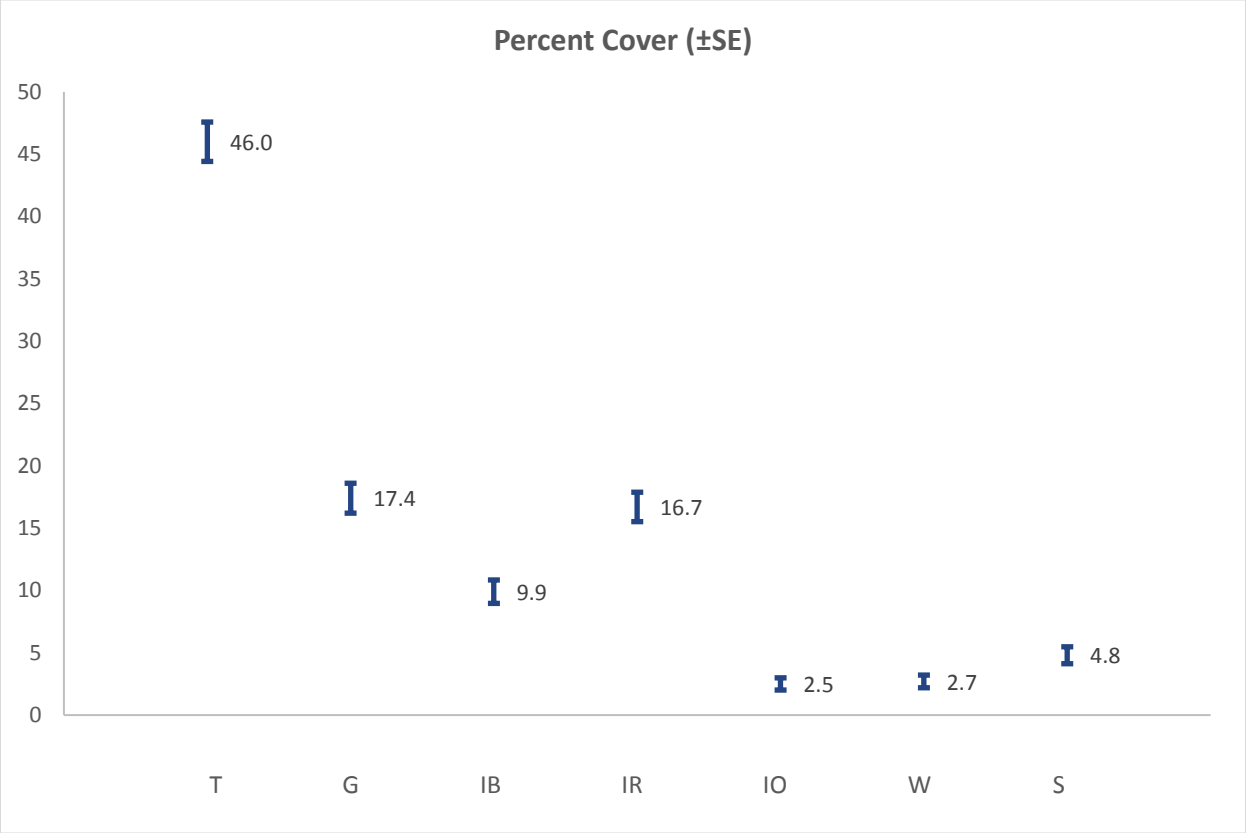

Figure 2: Land cover class percentages and standard errors.

Table 4: LAND COVER CLASSES AND PERCENTAGES

Land Cover Class	Description	Abbreviation	Points	% Cover
Tree/Shrub	Trees or shrubs	T	460	46.0 ±1.58
Grass/Herbaceous	Areas covered with grass or herbaceous groundcovers	G	174	17.4 ±1.20
Impervious Buildings	Buildings with impervious material	IB	99	9.90 ±0.94
Impervious Road	Roads with impervious material	IR	167	16.7 ±1.18
Impervious Other	Objects with impervious material other than buildings and roads	IO	25	2.50 ±0.49
Water	Lakes, ponds, streams, or other water features	W	27	2.70 ±0.51
Soil/Bare Ground	Areas determined to be soil or bare ground	S	48	4.80 ±0.68

Environmental Services

Environmental services results for the land cover class that best represented tree canopy are presented in Table 5. The estimated annual value of benefits provided by the tree canopy was **$3,969,652.64**, with an estimated CO2 storage value of **$79,351,082.48**.

Table 5: ENVIRONMENTAL SERVICES ESTIMATES

Environmental Service	Value ($)	±SE	Amount (T)	±SE
CO removed annually	$6,107.32	±209.25	16.12 T	±0.55
NO2 removed annually	$4,534.86	±155.38	51.02 T	±1.75
O3 removed annually	$146,833.84	±5,030.88	376.41 T	±12.90
PM2.5 removed annually	$409,473.53	±14,029.55	15.01 T	±0.51
SO2 removed annually	$371.94	±12.74	14.49 T	±0.50
PM10* removed annually	$182,885.46	±6,266.10	99.57 T	±3.41
CO2 sequestered annually	$3,219,445.69	±110,305.98	89,034.92 T	±3,050.55
CO2 stored	$79,351,082.48	±2,718,759.67	2,194,482.49 T	±75,188.27

Conclusions

The economic, environmental, and social benefits provided by trees are numerous. These benefits can be sustained into the future with both proactive and reactive approaches to assessing, planning, and managing the urban forest. The i-Tree Canopy assessment provided by BIS is a top down approach to assessing the Town of Cary's urban forest. The improved understanding of land cover class composition and percentages can be utilized to track, strategize, and implement plans for urban forest improvement.

Effectively planning the urban forest requires a detailed understanding of what the resource currently looks like, what stakeholders involved with the resource want it to look like, and a plan to meet the needs of stakeholders' urban forest goals. Setting a reasonable goal for tree canopy cover can be accomplished through analysis of i-Tree Canopy results. As a complement to tree canopy cover, annual ecosystem services can also be tracked and goals set for initiatives like carbon neutrality or human health improvement.

Recommendations

There are several activities the Town of Cary can undertake to further improve management of its urban forest. These can include, but are not limited to, both top-down and bottom-up approaches to assessing the urban forest. The following activities are ordered in terms of priority:

- Complete a tree inventory to assess the current structure of the urban forest
- Collect environmental services data related to i-Tree Eco in complement to a tree inventory
- Set a goal for total tree canopy to be met within the next 5-10 years
- Continue to reassess the current tree canopy composition annually

The Town of Cary understands the value of its trees and can continue to sustain its valuable resource with education, outreach, planning, and tracking of its urban forest.

GLOSSARY

air pollution removal: removal of pollutants from the air by plants through natural processes

canopy: the portion of a tree including the branches and foliage; or a collective group of tree canopies

carbon sequestration: removal of carbon from the air by plants through natural processes

carbon storage: storage of carbon removed from the air in plant tissues

impervious: property of land covers where water doesn't infiltrate or move through, generally running off the surface

noise attenuation: reducing sound levels via materials, structures, plants, etc.

pervious: property of land covers where water infiltrates or moves through the material

remote analysis: analysis of the urban environment or tree canopy cover utilizing aerial or satellite imagery

shapefile: electronic file format for storing geospatial location and tabular data, generally used with ArcGIS software

standard error: measure of precision; the amount that a sample average can differ from the true average, being either smaller (-) or larger (+) than the true average

stormwater runoff: water (generally from rain or snow melt) that flows over the ground after storm events

LIST OF APPENDED ITEMS

Technical Reports

Bartlett Inventory Solutions (BIS) and i-Tree
BIS Inventory Data Collection
i-Tree Canopy Air Pollutant Removal and Monetary Value Model Descriptions
i-Tree Canopy Technical Notes
Mulch Application Guidelines
New Concepts in Tree Planting
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Small Trees Suitable for Planting Under Utility Lines
Structural Pruning of Young Trees
Tree Planting Space Opportunities

Bartlett Inventory Solutions and i-Tree

The USDA Forest Service developed a science-based, peer-reviewed computer model designed to calculate urban forest ecosystem services, which are the economic, environmental, and social benefits people receive from trees and the environment, and their associated values based upon measurements taken in the field during inventories or through remote analyses. This analysis and benefits assessment software suite is called i-Tree, and there are currently eight applications that can be utilized in and around urban environments. i-Tree is designed to highlight the significance of community trees and advocate for them as sustainable infrastructure, which assist in pollution mitigation, energy conservation, carbon sequestration and storage, etc. The intention is for i-Tree users to improve tree and urban forest management through strategic planning, community awareness and advocacy, and engage decision makers and stakeholders.

i-Tree projects are unique given their data collection requirements, analysis procedures, and reporting. i-Tree projects can be broken into two categories; field based and remote. i-Tree projects that are field based must have the data collected in a very detailed and exact manner. This detailed data collection is required to obtain the reports from i-Tree on the ecosystem services benefits. Depending on what field based application is being used, and whether or not a sample or complete inventory is being conducted, i-Tree projects can require a significantly larger amount of field time compared to a standard inventory project. i-Tree projects also require specific training to collect field data or perform remote assessments in an accurate manner.

Field Based i-Tree Applications:

i-Tree Eco assesses **entire urban tree populations**, which may include street trees. i-Tree Eco uses field data from complete inventories or randomly located plots throughout a community along with local hourly air pollution and meteorological data to quantify urban forest structure, function, and benefits. Reports include: carbon storage and sequestration, air pollution removal, effects on building energy usage and reduction in carbon dioxide emissions, rainfall interception and reduction in stormwater flow, reduction in public health incidence and the economic benefits, estimated compensatory value, and leaf area and biomass. These results are reported on an individual tree basis.

While BIS tree inventories capture some of the required information for i-Tree Eco, there are several fields that are not covered. The information and measurements include the tree species, tree location, DBH (diameter at breast height), DBH height (where the DBH measurement is taken), total tree height, height to the live top of the tree, height to the base of the crown, two crown width measurements (North/South and East/West), an estimate of percent crown missing, an estimate of percent crown dieback, and the amount of crown light exposure. Additional information is required for plot samples (e.g. percent shrub, grass, or bare soil cover). Unlike i-Tree Streets, this information is sent to the Forest Service via an online submission process and is reported back typically within one week. Due to the intensity of data collection, i-Tree Eco inventories require significantly more field time.

i-Tree Streets focuses on the benefits provided by communities' **street trees** using sample or complete inventory data to quantify urban forest structure and put a dollar value on the street trees' annual environmental and aesthetic benefits and help describe future management needs. Reports include: energy conservation, air quality improvement, carbon dioxide reduction, storm-water reduction, and property value increase. These results are presented on a species basis, not an individual tree basis. Tree data required for i-Tree Streets is collected during BIS tree inventories and is entered into the application with reports being generated automatically. It is important to understand that i-Tree Streets was developed to assess street tree populations, not the entire urban forest.

i-Tree Storm is a pre-storm/post-storm application used to help create storm plans and plan for vegetative debris cleanup after storms, specifically ice and wind events. Random road segments are selected and only the tree size class is needed for data collection. Results include: potential and actual amounts of debris, and potential time and cost estimates for debris removal, tree removal, and hazard pruning. The application can help municipalities plan for and recover from storm events.

Remote i-Tree Applications:

i-Tree Canopy can be used to estimate land cover types and set urban tree canopy goals. The application uses aerial imagery to classify pre-determined land cover types. Results include: statistically valid land cover estimates, air pollution removal amounts and values, and atmospheric carbon removal amounts and values. The results can be used to create benchmarks and monitor canopy change over time, set canopy cover goals, inform individuals on the certain ecosystem services provided by the trees, and can be utilized in i-Tree Vue to look at canopy change and as data input for i-Tree Hydro.

i-Tree Design can help estimate how tree species, size, and placement around a home can affect tree benefits and energy usage. Utilizing the site location, a tree species can be selected to estimate the ecosystem services that will be provided. Results include: annual benefits, projected tree growth and future benefits, storm water interception, air quality improvement, carbon sequestration and avoidance, and energy usage analyses. This application can be used to help determine the best location to plant trees around a home while considering the ecosystem benefits that would be provided.

i-Tree Species can aid in tree species selection based on desired ecosystem services. This application uses the plant hardiness zone of the subject area to determine tree species options, and then ranks the species by the ecosystem services desired. Results include: tree species ratings based on air pollution removal, air temperature reduction, carbon storage, building energy conservation, wind reduction, steam flow reduction, ultraviolent radiation reduction, and pollen allergenicity. i-Tree Species results can produce lists of species that fit a community's ecosystem services needs.

i-Tree Vue can be used to assess land cover types to estimate ecosystem services. This application utilizes satellite-based imagery to determine land cover type and then estimates some ecosystem services for the cover types. Canopy change scenarios can also be modeled utilizing data from i-Tree Canopy. Results include: land cover types and percentages, available planting space and existing stocking levels, carbon storage and sequestration, air pollution removal, and canopy change scenarios. Results from an i-Tree Vue project can help urban forest managers understand their land cover types and the ecosystem services provided by each while providing a method to assess future possibilities.

i-Tree Hydro models how changes in forest canopy and impervious surfaces changes urban stormwater runoff. Results include hourly and total changes in water quality and stream flow. This application can help communities looking for stormwater mitigation strategies and information for better management. i-Tree Hydro can utilize estimates from i-Tree Canopy as input; however, data from an i-Tree Eco project would produce more accurate results.

BARTLETT TREE RESEARCH LABORATORIES

Technical Report

Data Collection Attributes, Descriptions, and Options for a ***Bartlett Inventory Solutions (BIS) Tree Inventory & Management Plan***

When starting a tree inventory using the Bartlett Inventory Solutions (BIS) team it is important that the BIS team know what field categories and attributes will be collected from the site before arrival. There are many categories of information that can be recorded for a tree. The following is a list of common data fields that can be collected for clients' trees. Keep in mind data to be collected is not limited to the items on this list, but it must be reiterated that the data that is to be collected must be known before field work begins on site. Attribute collection for tree inventories will be conducted using a sub-meter accuracy GPSr device having an error in location not greater than 3 meters.

Standard Field Data Attributes & Descriptions

Data Field	Description/Options
Botanical Name	According to local ISA chapter Tree Species list
Common Name	According to local ISA chapter Tree Species list
Tree Id Number	Sequential Numbering
Dedicated	It will be noted if the tree has a dedication and the dedication description will be recorded.
Diameter at Breast Height (DBH)/ Caliper (12" above grade)	Inches
	Record up to 6 largest stems
Number of Stems	Record total number of stems
Canopy/Root zone Radius (For construction planning/ estimate canopy cover)	Feet/Meters - Estimate from stem to drip line of canopy
Height Class	**Small** - <15'
	Medium - 15' - 40'
	Large - >40'

Age Class	**New Planting** - A tree that is not yet established.
	Young - Established tree that has not been in the landscape for many years.
	Semi-mature - Established tree that has not yet reached full growth potential.
	Mature - A tree within its full growth potential.
	Over-mature - A tree that is declining or beginning to decline due to its age.
Condition Class	**Dead**
	Poor - Most of the canopy is affected with dieback undesirable leaf color, leaf size and new growth. Tree or parts of the tree are likely to fail.
	Fair - Parts of the canopy undesirable leaf color, leaf size and new growth. Parts of the tree are in the process of failure.
	Good - Tree health and condition is acceptable.
Root Zone Infringement (Based on dripline, estimated grayscape impact on root zone)	<25%
	25%-50%
	51%-75%
	>75%
Location Value (An average rating for the site and the tree's contribution and placement)	Excellent
	Good
	Fair
	Poor
	Unacceptable
Location Type	Foundation, Median, Open, Street Tree, Well
Tree Care Priority	1 Priority
	2 Priority
	3 Priority
	4 Priority (optional)
	5 Priority (optional)
Clean	Selective pruning to remove one or more of the following parts: dead, diseased, and/or broken branches.
Clean Size (minimum size branch to prune to) **(**optional)	1/2"
	1"
	2"
	4"
Raise	Selective pruning to provide vertical clearance.
Raise Height (optional)	Feet
Raise From	Bench, Building, Driveway, Street, Wall, etc.
Reduce	Selective pruning to reduce height and/or spread.
Reduce From	Branch weight, Building, Light, Street, Wall, etc.
Removal	Remove
	Wildlife snag
Structural	Selective pruning to improve tree structure.

Thin	Selective pruning to reduce density of live branches.
Thin Percent (maximum percent to prune to) (optional)	5%
	10%
	15%
	20%
Cable	New
	Inspect/ New
	Repair
	New w/Brace Rod
Number of Cables (optional)	1
	2
	3
	4
	5
Size of Cable (optional)	Small
	Large
Brace Rod	New
Ground Support	New
Lightning Protection (LP)	New
	Inspect
	Repair
Soil Care	Root Invigoration
	Soil Rx
	Micronutrient
Root Collar Excavation (RCX)	Excavation of dirt/mulch from around the stem/root flare.
Overhead Lines	Within the tree canopy
	Within 10' of the tree canopy
Pictures	Pictures can be taken of defects, pests, conditions, or memorial trees/plaques
Estimated Value (Based on a modified version of the Trunk Formula Method used does not consider cost of purchase and installation of the largest available "like tree.")	Size (DBH) x Species Factor(Determined by local ISA chapter) x Condition Factor x Location Factor
Defect/Condition	Cavity, Codominant stems, Crack, Fungi/Conks, Girdling Roots, Sidewalk Lifting, etc.
Pest/Disease	Borers, Leaf Spot, Mites, Phytophthora, Scale, Vines, etc.
Plant Health Care (PHC)	Adelgid Treatment, Bark Beetle Treatment, Borer Treatment, Dutch Elm DiseaseTreatment (DED), Mite Treatment, Scale Treatment, etc.

Basic Tree Risk Assessment	Conditions are present that prompt a risk rating to be estimated.
Plant Part of Concern	Branches
	Crown
	Roots
	Stem
Primary Target	Building, Lighting, Parking, Sidewalk, Walking Path, etc.
Secondary Target	Building, Lighting, Parking, Sidewalk, Walking Path, etc.
Likelihood of Failure*	Imminent
	Probable
	Possible
	Improbable
Likelihood of Impacting a Target*	High
	Medium
	Low
	Very Low
Consequences of Failure*	Severe
	Significant
	Minor
	Negligible
Overall Risk Rating* (Ranks the relative degree of risk for prioritizing remedial treatments when managing large tree populations)	**Extreme** - Failure imminent and there is a high likelihood of impacting a target.
	High – Mitigation measures should be taken.
	Moderate – Mitigation and/or retaining and monitoring may be recommended
	Low – Some trees with this level of risk may benefit from mitigation or maintenance measures, but immediate action is not usually required.
Advanced Assessments Needed	Crown
	Roots
	Stem

*****These fields are based on the ISA Best Management Practices on Tree Risk Assessment and this manual along with the ANSI standard (A300 (Part 9)-2011 Tree Risk Assessment a. Tree Structure Assessment) should be consulted for more detailed explanations.

Optional Field Data Attributes & Descriptions

In addition, it is possible to break down the field areas described into more specific categories. Other types of site specific data can be identified, such as; memorial trees, historic trees, or trees in relation to buildings/ monuments. Photographs can also be included within the inventory to document potential tree hazards, and/or other characteristics of the tree.

DBH; Canopy Radius; Height Class; Clean Size; Raise Height	These measurements and sizes can be recorded in metric units if needed.
Address	House/Building address which may include the Street Name, City, State, or Postal Code
Mulch Needed	Mulch is recommended to help improve soil conditions.
Invasive Species	The tree is a noted invasive species in the area.
Historic Tree	It can be noted if the tree is of historical significance.
Native	It can be noted if the tree is native to the area/state.
Bird Nest	It can be noted if a bird nest is present.
Parasitic Plant	It can be noted if there is a parasitic plant present on the tree.

Optional i-Tree Eco/Streets Field Data Attributes & Descriptions

Ecosystem services information and results can also be determined with a BIS tree inventory. i-Tree Eco is used for the entire urban forest (parks, residences, large areas) to help estimate the ecosystem services being provided and requires several additional attributes to be collected (this increases the total time required to complete the inventory). i-Tree Streets is used for street tree populations and only requires the tree species and DBH to estimate the ecosystem services being provided.

i-Tree Eco	Requires DBH, total tree height, live top, crown base, crown width N/S and E/W, percent crown missing, crown dieback.
i-Tree Streets	Requires tree species and DBH.

Results from an i-Tree Eco inventory include carbon storage/sequestration, air pollution removal, leaf area/biomass, energy effects, etc. Results from an i-Tree Streets inventory include carbon storage/sequestration, air pollution removal, energy effects, stormwater runoff, and aesthetic value.

BIS Management Plan and ArborScope™ Web Based Management Program

BIS evaluates and confirms all data that is collected in the field and then provides the collected information along with examples, explanations, and technical reports in a BIS management plan. The data will also be overlain onto digital aerial photographs of the property. It may be possible to use existing client maintained GIS or CAD data for the site if applicable. BIS provides 2 printed copies of all management plans along with an electronic version in .pdf format.

It may be possible to export collected tree data in to additional formats for inclusion into existing mapping or management software (e.g. geodatabase file, shapefile, ‘.dwg’,‘.dxf’(AutoCAD), ‘.csv’ file, ‘.mdb’ file, ‘.dbf’, file, '.txt' file, `or a’.xls' file). However, this request must be made before data collection is started to ensure data formatting meets expectations.

It may be possible to import existing customer data into the Bartlett Inventory. A copy of any useful existing data must be made available prior to data collection to ensure the data are compatible with Bartlett software.

ArborScope™

ArborScope™ is a Bartlett product and the new web based tree inventory and management program. This is a program that allows for customization of each inventory and gives the client complete control over their data and access to their data. Inventories and data will be laid on top of Google Maps and provide a simple efficient means to view, update, and query any collected information. Information can be displayed in map, table, and standard or custom report views.

i-Tree Canopy Air Pollutant Removal and Monetary Value Model Descriptions

Version 1.2

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Abstract

The default values (the multipliers) of air pollutant removal rates (g m^{-2} yr^{-1}) and monetary values ($ m^{-2} yr^{-1}) for a unit tree cover were derived from i-Tree Eco analyses in the conterminous United States in 2010 (Nowak et al. in review). Three analyses were conducted for rural and urban areas in all counties and then aggregated into the county-level; 1) derivation of the total tree cover, evergreen percentage and leaf area index, 2) estimation of air pollutant removals and concentration changes, and 3) valuation of air pollutant removals.

1. Introduction

i-Tree Canopy is designed to allow users to easily and accurately estimate tree and other cover classes (e.g.,grass, building, roads, etc.) within their city or any area they like. This tool randomly lays points (number determined by the user) onto Google Earth imagery and the user then classifies what cover class each point falls upon. The user can define any cover classes that they like and the tool will show estimated percentage for each cover class throughout the interpretation process. Based on the area classified as the tree cover class, the tool provides annual amount of air pollutants removed through dry deposition process by trees and associated monetary values. The air pollutants estimated are six criteria pollutants defined by the U.S. Environmental Protection Agency (EPA); carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter (PM), which includes particulate matter less than 2.5 microns ($PM_{2.5}$) and particulate matter greater than 2.5 and less than 10 microns (PM_{10*}).

The default values (the multipliers) of air pollutant removal rates (g m^{-2} yr^{-1}) and monetary values ($ m^{-2} yr^{-1}) for a unit tree cover were derived from i-Tree Eco analyses in the conterminous United States in 2010 (Nowak et al. in review). Three analyses were conducted; 1) derivation of the total tree cover, evergreen percentage and leaf area index, 2) estimation of air pollutant removals and concentration changes, and 3) valuation of air pollutant removals. These analyses were performed for rural and urban areas in all counties and then aggregated into the county-level values. i-Tree

Canopy currently uses the county-level multipliers to estimate annual air pollutant removals and associated monetary values.

This document describes the materials, methods and limitations in the model and processes used to derive the default multipliers.

2. Materials and Methods

2.1. Rural/urban area classification

Urban areas were delimited using 2010 Census data and definitions (U.S. Census Bureau 2013), while rural areas were defined as all land not classified as urban.

2.2. Tree parameters

The tree cover was derived from 2001 National Land Cover Database (NLCD) tree cover maps (USGS 2008) with an adjustment (Nowak and Greenfield 2010). Percent tree cover classified as evergreen was determined for each county based on evergreen, deciduous and mixed forest land covers as classified by the NLCD. Maximum leaf area index (LAI) was derived from the level-4 MODIS/Terra global Leaf Area Index product for the 2007 growing season (USGS 2013). The default values of 4.9 (Nowak et al. 2008) and 3.2 (Schlerf et al. 2005) for urban and rural areas, respectively, were employed for areas with missing or abnormally low LAI.

2.3. Air pollutant removals and concentration changes

Air pollutant removal and concentration change due to dry deposition to trees were estimated on an hourly-basis and then summarized for a year with i-Tree Eco (Nowak et al. 2006; 2013, Hirabayashi et al. 2011; 2012). For each area, the total tree cover, evergreen percentage, LAI, as well as the surface weather, upper air, and air pollutant concentration data at the monitoring station closest to the area's geographic center were used in the analyses. Totally 979 weather stations from the National Climatic Data Center (NCDC 2013), 74 radiosonde stations from the National Oceanic and Atmospheric Administration (NOAA 2013), and 4,116 air pollutant monitoring stations from the U.S. EPA's Air Quality System (US EPA 2013) were employed. The $PM_{2.5}$ concentration was subtracted from the PM_{10} concentration to produce an adjusted PM_{10} concentration denoted as PM_{10*} (2.5- to 10-micron particles) to avoid PM_{10} double counting $PM_{2.5}$ values. The minimum and maximum estimates of removal were based on minimum and maximum deposition velocities from the literature.

2.4. Air pollutant removal valuation

The U.S. EPA's BenMAP was used to estimate the incidence of adverse health effects and associated monetary values resulting from changes in NO_2, O_3, $PM_{2.5}$ and SO_2 concentrations (US EPA 2012). The pollutant removal value for CO and PM_{10*} were CO = \$1,470 t^{-1} and PM_{10*} = \$6,910 t^{-1} for urban and CO = \$27 t^{-1} and PM_{10*} = \$126 t^{-1} for rural areas. Urban values were estimated using national median externality values (Murray et al. 1994) adjusted to 2010 values using the producer price index (U.S. Department of Labor 2012), while rural values were derived

from urban values adjusted based on the rural to urban value ratio for all four BenMAP pollutants (NO_2, O_3, $PM_{2.5}$, and SO_2).

For each rural and urban area in counties, calculated total removal amount and monetary value were divided by the area's total tree cover to derive the removal amount and monetary value multipliers, respectively. For the entire county, the multipliers were derived by aggregating rural and urban areas in the county. In i-Tree Canopy, the air pollutant amount annually removed by trees and the associated monetary value can be calculated with the tree cover in the area of interest multiplied by these multipliers based on the county-level values in the United States. For countries outside the United States, county multipliers derived from the Unites States' total removal amount, monetary value and tree cover can be used. Table 1 presents national values for the entire rural and urban areas as well as counties in the conterminous United States.

Table 1 Multipliers derived from the United States' total values

Pollutant	Removal Multiplier ($g\ m^{-2}\ yr^{-1}$)			Value Multiplier ($\$\ m^{-2}\ yr^{-1}$)		
	Rural	Urban	County	Rural	Urban	County
CO	0.100	0.127	0.101	0.00000268	0.000186	0.00000948
NO_2	0.545	0.700	0.551	0.00000398	0.000337	0.0000163
O3	5.493	5.404	5.490	0.000287	0.0155	0.000850
PM_{10*}	1.851	1.534	1.839	0.000233	0.0106	0.000617
$PM_{2.5}$	0.266	0.276	0.267	0.000578	0.0324	0.00176
SO_2	0.347	0.344	0.347	0.00000101	0.0000507	0.00000285

3. Limitations of modeling approach

3.1. Adverse effects of trees for $PM_{2.5}$

Tree is a temporary retention site for atmospheric particles; $PM_{2.5}$ intercepted by trees due to dry deposition may be resuspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall. In i-Tree Eco, $PM_{2.5}$ is intercepted and accumulated on trees on an hourly-basis with no rain or low wind conditions, typically resulting in decrease in the $PM_{2.5}$ concentration. The $PM_{2.5}$ accumulated on leaves is washed off from leaves to the ground with a rain event. When an hourly high wind event occurs, larger amount of accumulated $PM_{2.5}$ than deposited in that hour may be resuspended to the atmosphere, typically causing increase in the $PM_{2.5}$ concentration. The $PM_{2.5}$ concentration can also be affected by the atmospheric mixing height: when the $PM_{2.5}$ quantity remains the same in atmosphere, higher mixing height leads to lower concentration and vice versa. Because of these atmospheric factors the mean $PM_{2.5}$ concentration may be increased annually or quarterly in areas with low rain and high winds throughout a year. As a result, monetary values for $PM_{2.5}$ removal are computed negative in BenMAP, indicating trees decrease the air quality and thus the incidence of adverse health effects is increased. Tables 2-4 present counties with the negative monetary value multipliers for $PM_{2.5}$

Table 2 County rural areas with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($ m^{-2} yr^{-1})
Arizona	04	La Paz	012	-0.000000523
Iowa	19	Buena Vista	021	-0.0000109
Iowa	19	Cherokee	035	-0.0000434
Iowa	19	Crawford	047	-0.0000359
Iowa	19	Ida	093	-0.0000258
Iowa	19	O'Brien	141	-0.0000223
Iowa	19	Sac	161	-0.0000183
Minnesota	27	Stevens	149	-0.00000301
Nevada	32	Clark	003	-0.000000477
Texas	48	Culberson	109	-0.000000128
Texas	48	Pecos	371	-0.000000286
Texas	48	Reeves	389	-0.000000192
Virginia	51	Alleghany	005	-0.0000225
Virginia	51	Bath	017	-0.00000446
Virginia	51	Giles	071	-0.00000210
West Virginia	54	Nicholas	067	-0.00000319

Table 3 County urban areas with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($ m^{-2} yr^{-1})
Arizona	04	Apache	001	-0.00208
Arizona	04	La Paz	012	-0.000993
Arizona	04	Mohave	015	-0.000283
Arizona	04	Navajo	017	-0.00196
Arizona	04	Yuma	027	-0.00254
California	06	Imperial	025	-0.00248
Colorado	08	Adams	001	-0.0143
Colorado	08	Bent	011	-0.0217
Colorado	08	Broomfield	014	-0.0108
Colorado	08	El Paso	041	-0.000901
Colorado	08	Huerfano	055	-0.00310
Colorado	08	Las Animas	071	-0.00245
Colorado	08	Logan	075	-0.00255
Colorado	08	Morgan	087	-0.000695
Colorado	08	Otero	089	-0.0161
Colorado	08	Pueblo	101	-0.00280
Colorado	08	Yuma	125	-0.00268
Iowa	19	Buena Vista	021	-0.00564

Iowa	19	Cherokee	035	-0.0111
Iowa	19	Crawford	047	-0.00764
Iowa	19	O'Brien	141	-0.0102
Kansas	20	Finney	055	-0.00457
Kansas	20	Grant	067	-0.0154
Kansas	20	Pawnee	145	-0.000642
Kansas	20	Scott	171	-0.00314
Kansas	20	Seward	175	-0.0126
Kansas	20	Stevens	189	-0.0201
Minnesota	27	Blue Earth	013	-0.00348
Minnesota	27	Le Sueur	079	-0.00233
Minnesota	27	Nicollet	103	-0.00324
Minnesota	27	Waseca	161	-0.00541
Montana	30	Custer	017	-0.000678
New Mexico	35	Bernalillo	001	-0.00327
New Mexico	35	Curry	009	-0.00391
New Mexico	35	Dona Ana	013	-0.00436
New Mexico	35	Eddy	015	-0.00724
New Mexico	35	Grant	017	-0.00664
New Mexico	35	Luna	029	-0.0103
New Mexico	35	Otero	035	-0.00140
New Mexico	35	Quay	037	-0.00773
New Mexico	35	Roosevelt	041	-0.00650
New Mexico	35	Sierra	051	-0.0128
New Mexico	35	Socorro	053	-0.00220
New Mexico	35	Torrance	057	-0.000744
New Mexico	35	Valencia	061	-0.00129
Oklahoma	40	Texas	139	-0.0122
Oklahoma	40	Woodward	153	-0.00725
South Dakota	46	Meade	093	-0.000280
South Dakota	46	Pennington	103	-0.0107
Texas	48	Bailey	017	-0.00363
Texas	48	Carson	065	-0.00303
Texas	48	Castro	069	-0.00349
Texas	48	Childress	075	-0.00175
Texas	48	Coryell	099	-0.00769
Texas	48	Crane	103	-0.00369
Texas	48	Dallam	111	-0.0204
Texas	48	Deaf Smith	117	-0.0126
Texas	48	Ector	135	-0.00202

Texas	48	El Paso	141	-0.00998
Texas	48	Floyd	153	-0.0144
Texas	48	Gray	179	-0.0137
Texas	48	Hale	189	-0.00428
Texas	48	Hansford	195	-0.0117
Texas	48	Hartley	205	-0.0204
Texas	48	Hemphill	211	-0.00775
Texas	48	Hutchinson	233	-0.00911
Texas	48	McCulloch	307	-0.000872
Texas	48	Moore	341	-0.0129
Texas	48	Ochiltree	357	-0.0126
Texas	48	Parmer	369	-0.00820
Texas	48	Pecos	371	-0.0160
Texas	48	Potter	375	-0.0122
Texas	48	Randall	381	-0.0125
Texas	48	Reagan	383	-0.000276
Texas	48	Reeves	389	-0.0213
Texas	48	Swisher	437	-0.00403
Texas	48	Tom Green	451	-0.00162
Texas	48	Ward	475	-0.00431
Texas	48	Willacy	489	-0.00519
Texas	48	Winkler	495	-0.00663
Virginia	51	Covington	580	-0.000904
West Virginia	54	Greenbrier	025	-0.00021
Wisconsin	55	Clark	019	-0.00082
Wisconsin	55	Taylor	119	-0.00049

Table 4 Counties with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($ m^{-2} yr^{-1})
Arizona	04	La Paz	012	-0.00000177
Arizona	04	Navajo	017	-0.00000740
Arizona	04	Yuma	027	-0.0000293
California	06	Imperial	025	-0.0000240
Colorado	08	Adams	001	-0.00194
Colorado	08	Bent	011	-0.0000154
Colorado	08	Broomfield	014	-0.0078
Colorado	08	Logan	075	-0.00000670
Colorado	08	Otero	089	-0.000133
Iowa	19	Buena Vista	021	-0.0000565
Iowa	19	Cherokee	035	-0.000120

Iowa	19	Crawford	047	-0.000147
Iowa	19	Ida	093	-0.0000258
Iowa	19	O'Brien	141	-0.000127
Iowa	19	Sac	161	-0.0000183
Kansas	20	Finney	055	-0.0000110
Kansas	20	Grant	067	-0.00000322
Kansas	20	Seward	175	-0.000108
Minnesota	27	Blue Earth	013	-0.000193
Minnesota	27	Le Sueur	079	-0.0000230
Minnesota	27	Nicollet	103	-0.00000501
Minnesota	27	Waseca	161	-0.0000702
New Mexico	35	Bernalillo	001	-0.000433
New Mexico	35	Curry	009	-0.0000195
New Mexico	35	Dona Ana	013	-0.000137
New Mexico	35	Eddy	015	-0.0000358
New Mexico	35	Luna	029	-0.0000367
New Mexico	35	Sierra	051	-0.0000164
New Mexico	35	Socorro	053	-0.000000132
New Mexico	35	Valencia	061	-0.0000753
Oklahoma	40	Woodward	153	-0.0000308
South Carolina	45	Calhoun	017	-0.00000375
Texas	48	Coryell	099	-0.000125
Texas	48	Crane	103	-0.00000262
Texas	48	Culberson	109	-0.000000128
Texas	48	Deaf Smith	117	-0.0000148
Texas	48	Ector	135	-0.0000781
Texas	48	El Paso	141	-0.00281
Texas	48	Gray	179	-0.0000414
Texas	48	Hale	189	-0.00000629
Texas	48	Hansford	195	-0.00000279
Texas	48	Hemphill	211	-0.0000127
Texas	48	Hutchinson	233	-0.000144
Texas	48	Moore	341	-0.0000123
Texas	48	Ochiltree	357	-0.0000379
Texas	48	Pecos	371	-0.0000177
Texas	48	Potter	375	-0.000120
Texas	48	Randall	381	-0.0000604
Texas	48	Reeves	389	-0.0000410
Texas	48	Tom Green	451	-0.0000122
Texas	48	Ward	475	-0.0000248

Texas	48	Winkler	495	-0.0000192
Virginia	51	Bath	017	-0.00000446
Virginia	51	Covington	580	-0.000898

3.2. BenMAP internal errors

It is known that counties and pollutants listed in Table 5 have internal errors in BenMAP, and thus the BenMAP valuation scheme is not applied. For these areas and pollutants, the monetary values were estimated based on a linear robust regression between the dollar values per tonne of pollutant removed and population density for all of the other counties. The regression equations employed for the rural areas are:

NO_2: $y = 0.6264x + 0.108$ ($R^2 = 0.96$)

O_3: $y = 4.0598x + 3.9829$ ($R^2 = 0.91$)

$PM_{2.5}$: $y = 149.405x + 186.4572$ ($R^2 = 0.87$)

SO_2: $y = 0.2203x + 0.0132$ ($R^2 = 0.91$)

,where y is dollars per tonne and x is population density (people per km^2). The regression equations employed for the urban areas are:

NO_2: $y = 0.5544x + 30.3794$ ($R^2 = 0.65$)

O_3: $y = 3.8897x + 103.4157$ ($R^2 = 0.50$)

$PM_{2.5}$: $y = 148.4872x + 8269.303$ ($R^2 = 0.39$)

SO_2: $y = 0.1493x + 22.21$ ($R^2 = 0.45$)

For the counties and pollutants in Table 5, rural and urban monetary values estimated above were aggregated to derive total values for the county.

Table 5 Counties and air pollutants excluded from the analyses due to BenMAP internal errors

State	State FIPS	County	County FIPS	Pollutant
Arkansas	05	Columbia	027	NO2
Georgia	13	Jackson	157	NO2
Georgia	13	Walton	297	NO2
South Carolina	45	Calhoun	017	NO2
Washington	53	Mason	045	O3
California	06	Fresno	019	PM2.5
California	06	Lake	033	PM2.5
Iowa	19	Calhoun	025	PM2.5
Iowa	19	Palo Alto	147	PM2.5
Iowa	19	Pocahontas	151	PM2.5
Iowa	19	Shelby	165	PM2.5

Louisiana	22	Orleans	071	PM2.5
Maine	23	Sagadahoc	023	PM2.5
Michigan	26	Iron	071	PM2.5
Michigan	26	Mason	105	PM2.5
Minnesota	27	Clay	027	PM2.5
Mississippi	28	Hancock	045	PM2.5
Montana	30	Dawson	021	PM2.5
Nebraska	31	Cedar	027	PM2.5
Nebraska	31	Rock	149	PM2.5
North Dakota	38	Emmons	029	PM2.5
North Dakota	38	McKenzie	053	PM2.5
South Dakota	46	Campbell	021	PM2.5
South Dakota	46	Clay	027	PM2.5
Texas	48	Brooks	047	PM2.5
Texas	48	Walker	471	PM2.5
Washington	53	Kittitas	037	PM2.5
Washington	53	Wahkiakum	069	PM2.5
Wisconsin	55	Sheboygan	117	PM2.5
Wisconsin	55	Waupaca	135	PM2.5
Arkansas	05	Boone	009	SO2
Arkansas	05	Hot Spring	059	SO2
Arkansas	05	St. Francis	123	SO2
Arkansas	05	White	145	SO2
Arkansas	05	Woodruff	147	SO2
Iowa	19	Dubuque	061	SO2
Kentucky	21	Carlisle	039	SO2
Louisiana	22	Jefferson	051	SO2
Nevada	32	Mineral	021	SO2
North Carolina	37	Iredell	097	SO2
Oklahoma	40	Ottawa	115	SO2
Texas	48	Loving	301	SO2

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i-Tree Canopy Technical Notes

This tool is designed to allow users to easily and accurately estimate tree and other cover classes (e.g., grass, building, roads, etc.) within their city or any area they like. This tool randomly lays points (number determined by the user) onto Google Earth imagery and the user then classifies what cover class each point falls upon. The user can define any cover classes that they like and the program will show estimation results throughout the interpretation process. Point data and results can be exported for use in other programs if desired.

There are three steps to this analysis:

1) Import a file that delimits the boundary of your area of analysis (e.g., city boundary). Many standard boundary files can be located on websites such as ESRI's Census 2000 TIGER data site (http://arcdata.esri.com/data/tiger2000/tiger_download.cfm) and the US Census Cartographic Boundary Files site (http://www.census.gov/geo/www/cob/bdy_files.html). Data from these sites will require some minor processing in GIS software to select and export a specific boundary area polygon.
2) Name the cover classes you want to classify (e.g., tree, grass, building). Tree and Non-Tree are the default classes given, but can be easily changed.
3) Start classifying each point: points will be located randomly within your boundary file. For each point, the user selects from a dropdown list the class from step 2 that the point falls upon.

The more points that are interpreted, the more accurate the estimate.

Credits

The concept and prototype of this program were developed by David J. Nowak, Jeffrey T. Walton and Eric J. Greenfield (USDA Forest Service). The current version of this program was developed and adapted to i-Tree by David Ellingsworth, Mike Binkley, and Scott Maco (The Davey Tree Expert Company).

Limitations

The accuracy of the analysis depends upon the ability of the user to correctly classify each point into its correct class. Thus the classes that are chosen for analysis must be able to be interpreted from an aerial image. As the number of points increase, the precision of the estimate will increase as the standard error of the estimate will decrease. If too few points are classified, the standard error will be too high to have any real certainty of the estimate. Information on calculating standard errors can be found below. Another limitation of this process is that the Google imagery may be difficult to interpret in all areas due to relatively poor image resolution (e.g., image pixel size), environmental factors, or poor image quality.

Calculating Standard Error and Confidence Intervals from Photo-Interpreted Estimates of Tree Cover

In photo-interpretation, randomly selected points are laid over aerial imagery and an interpreter classifies each point into a cover class (e.g., tree, building, water).

From this classification of points, a statistical estimate of the amount or percent cover in each cover class can be calculated along with an estimate of uncertainty of the estimate (standard error (SE)). To illustrate how this is done, let us assume 1,000 points have been interpreted and classified within a city as either "tree" or "non-tree" as a means to ascertain the tree cover within that city, and 330 points were classified as "tree".

To calculate the percent tree cover and SE, let:

N = total number of sampled points (i.e, 1,000)
n = total number of points classified as tree (i.e., 330), and
p = n/N (i.e., 330/1,000 = 0.33)
q = 1 – p (i.e., 1 - 0.33 = 0.67)
SE = √ (pq/N) (i.e., √ (0.33 x 0.67 / 1,000) = 0.0149)

Thus in this example, tree cover in the city is estimated at 33% with a SE of 1.5%. Based on the SE formula, SE is greatest when p=0.5 and least when p is very small or very large (Table 1).

Table 1. Estimate of SE (N = 1000) with varying p.

p	SE
0.01	0.0031
0.1	0.0095
0.3	0.0145
0.5	0.0158
0.7	0.0145
0.9	0.0095
0.99	0.0031

Confidence Interval

In the case above, a 95% confidence interval can be calculated. "Under simple random sampling, a 95% confidence interval procedure has the interpretation that for 95% of the possible samples of size *n*, the interval covers the true value of the population mean" (Thompson 2002). To calculate a 95% confidence interval (if N>=30) the SE x 1.96 (i.e., 0.0149 x 1.96 = 0.029) is added to and subtracted from the estimate (i.e., 0.33). The result is a 95% confidence interval between 30.1% and 35.9%.

SE if n < 10

If the number of points classified in a category (n) is less than 10, a different SE formula (Poisson) should be used as the normal approximation cannot be relied upon with a small sample size (<10) (Hodges and Lehmann, 1964). In this case:

SE = (√n) / N

For example, if n = 5 and N = 1000, p = n/N (i.e., 5/1,000 = 0.005) and SE = √5 / 1000 = 0.0022. Thus the tree cover estimate would be 0.5% with a SE of 0.22%.

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BARTLETT TREE RESEARCH LABORATORIES
CHARLOTTE, NC

Technical Report

Mulch Application Guidelines

E. Thomas Smiley, Ph. D., Plant Pathologist

Mulches provide many benefits for trees and shrubs. They moderate soil temperatures, reduce soil moisture loss, reduce soil compaction, provide nutrients, improve soil structure, keep mowers and string trimmers away from the trunk. These benefits result in more root growth and healthier plants. When applying mulch the following guidelines should be observed:

1. The best mulch materials are wood chips, bark nuggets, composted leaves or pine needles. Plastic, stone, sawdust, finely shredded bark, and grass clippings should be avoided. Do not use redwood or walnut mulch due to allelopathic effects.

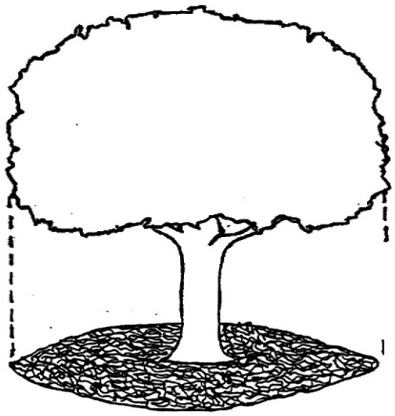


Figure 1. Mulch should be applied from the trunk to the dripline.

2. Mulch should be applied from the dripline to the trunk (Figure 1). If this is not practical, minimum mulch circle radii should be 3 feet for small trees, 8 feet for medium trees and 12 feet for large trees.

3. When applying mulch it is not necessary to kill or remove existing ground cover. However, turf should be mowed very short and clippings removed prior to application. Mulch should be applied directly to the soil surface, do not use landscape fabric to separate the mulch from the soil.

Figure 2. Mulch layer should be 2-4 inches thick and not be against the trunk.

4. Mulch layer should be 2-4 inches thick depending on tree species and mulch (Figure 2).

5. Additional mulch should be added to maintain a 2-4 inch depth.

6. Mulch should not be placed against the trunk (Figure 2). Mulch will retain too much moisture against the trunk, potentially resulting in disease problems.

BARTLETT TREE RESEARCH LABORATORIES
CHARLOTTE, NC
Technical Report

New Concepts in Tree Planting

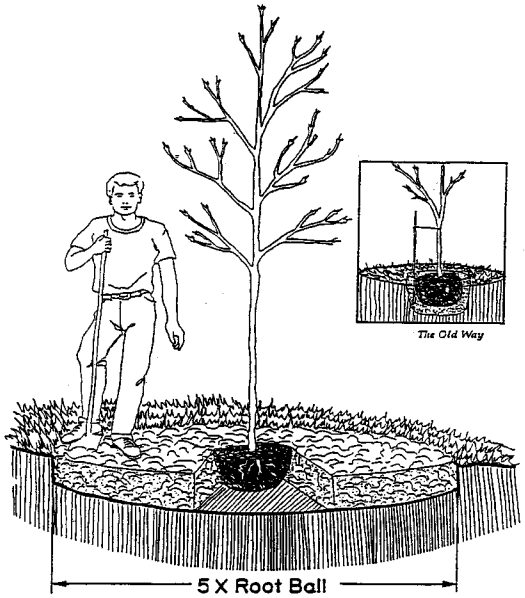
Bruce R. Fraedrich, Ph. D., Plant Pathologist

Successful establishment of new plantings is dependent on correctly matching species to site and creating a soil environment that will allow new transplants to rapidly regenerate a root system. During transplanting, more than 95% of a root system is lost when the tree is dug by hand or with a tree spade. Soil surrounding the new plantings must have sufficient water, air space and nutrients to support rapid root regeneration to ensure plant survival. The following 10 steps will help ensure planting success.

1. **Assess planting site characteristics prior to species selection**. Soil analysis for pH, nutrient levels, organic matter content texture and drainage is essential to match species with the site. Attempting to alter soil conditions to support a species cultural preferences can be expensive and is seldom successful. The presence of utility lines, buildings, streets and other structures must be considered when selecting species that are suited to the site. A computer based tree selection program has been developed that assists in selecting species, which are compatible with site characteristics (*Southern Trees* 800-627-3819).

2. **Determine the available soil volume for the site** and select species and planting distances that allow the plant to reach maturity. Most premature decline of urban plantings is the result of water deficiency related to insufficient soil volume (root space). Recent research at Cornell University has provided methods to determine soil volumes to meet the water demands of mature urban trees. In general, at least two cubic feet of soil is required for each square foot of crown projection (crown projection is the soil area beneath the crown). Calculating available soil volumes and selecting species whose mature size is compatible with the site is an integral component of the planning stage.

3. **Specify small caliper trees when possible.** Small caliper nursery stock regenerates a root system to pre-transplant levels more quickly than larger transplants. This translates into higher survival rates and lower maintenance costs during the establishment period. Crown growth rates of small transplants are much faster than larger stock following transplanting. After a ten-year period, two-inch transplants will be a similar



size to ten-inch stock. In general, 2 - 2 1/2" caliper or smaller stock is recommended. Larger sizes may be necessary in high use areas where vandalism is a factor.

4. **Prepare a large planting area.** The planting hole should be three-to-five times wider than the root ball especially in heavy clay or compacted soils. This will allow rapid regeneration of the root system following planting. The depth of the planting hole must be no greater than the root ball to prevent settling and root mortality. When preparing the planting site, amend the existing soil rather than use different backfill. In clay soils, using a well-drained loam backfill will result in water collecting in the planting hole following high rainfall, which can result in root mortality. Amend the soil with fertilizer, organic matter, lime or sulfur per soil analysis results. After planting cover the root ball and backfill with 2 - 4" of organic **mulch** such as wood chips to conserve soil moisture and moderate soil temperature. When planting in compacted or heavy clay soils, a large planting hole should be dug or the soil outside the hole should be tilled. After planting, mulch the entire area.

5. **Ensure the Root Collar of the transplant is flush with or slightly above the natural grade.** "Planting too deep" is a leading cause of death of new transplants. Specifications traditionally have required that the top of the root ball be flush with grade. In recent years, trees from some nurseries have soil on top of the root collar and against stem tissues. In these instances, the soil must be removed from the top of the ball until the root collar is exposed. Soil on top of the root collar will increase the incidence of stem disease and root disorders including root disease and girdling roots. When mulching after transplanting, make sure the mulch does not contact the trunk.

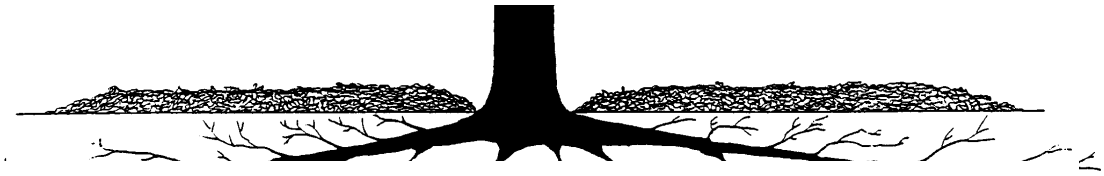
6. **Remove "foreign" materials from root balls**. Wire baskets must be removed from the upper 6-8 inches of the ball to prevent girdling of major support roots. Synthetic burlap, nylon twine and straps must be removed entirely from the root ball. Natural burlap can become water repellant and must be removed from the upper part of the ball to facilitate water infiltration.

7. **Do not wrap the trunk.** Recent research reveals that tree wraps provide little benefit in terms of stem protection from temperature extremes. Wraps may actually increase the incidence of certain pest infestations. Leave lower limbs to shade the trunk rather than wrapping.

8. **Stake or guy the plant only if necessary** to provide support or protect against strong winds and vandalism. Inspect guys periodically to ensure against girdling and bark injuries. Guys usually can be removed after one year.

9. **Prune only broken, dead and diseased limbs at planting time**. Research has shown that pruning the crown to "compensate for root loss" actually impedes root regeneration and slows establishment. Structural pruning should be delayed until the tree is established.

10. **Implement an intensive plant health care program following installation.** Young transplants stressed by root loss are sensitive to environmental stress and pest infestations. Periodically monitoring the trees for soil moisture conditions, decline symptoms, pest infestations, nutrient deficiencies and other plant health related conditions will facilitate early detection and correction of problems before mortality occurs.



Mulching after transplanting will reduce water loss, moderate soil temperature and eliminate turf competition. These benefits should result in higher survival rate, faster growth, and a healthier tree.

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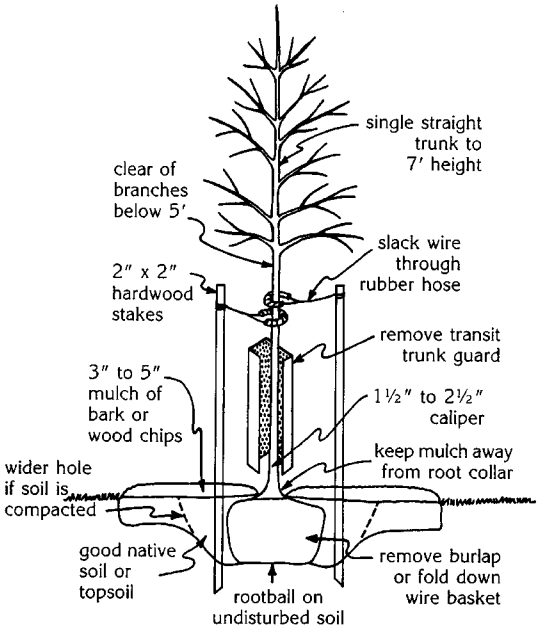
BARTLETT TREE RESEARCH LABORATORIES
CHARLOTTE, NC

Plant Health Care Program

Newly Planted Trees

When trees are first planted, there is an establishment period lasting at least two years when intensive maintenance is required. Studies show that transplanted trees lose as much as 95% of their root system during digging. Subsequently, most of the plants energy is initially channeled into root regeneration. During the establishment period, shoot growth and leaf size is reduced and wilting and leaf browning may occur. These symptoms are often referred to as "transplant shock". If a newly planted tree cannot rapidly regenerate roots, the tree generally fails to establish and dies. This usually can be attributed to one or more of the following causes:



Soil Moisture Extremes: Due to root loss during digging, new plantings are very sensitive to moisture extremes. Root balls tend to dry out rapidly during periods of low rainfall leading to desiccation and death of the plant. This is particularly a problem with plants that were transplanted from containers. Excessive—irrigation can kill new plantings by reducing soil oxygen levels which causes root mortality.

Planting Related Causes: Many plants fail to establish because the root ball was installed below grade or it settled in the planting hole following installation. When the root ball is "too deep", roots can "suffocate". Soil or mulch against the stem can directly damage these tissues and lead to insect and disease infestations.

Compacted soil, which commonly occurs on new developments, has low oxygen levels, poor moisture retention characteristics and imposes a physical resistance to root growth. These characteristics severely impede root growth which prevents establishment.

Plants also frequently die because synthetic burlap, wire baskets, and nylon twine and strapping are left on the root ball. These materials will restrict root development and can eventually girdle the stem or major roots years after planting.

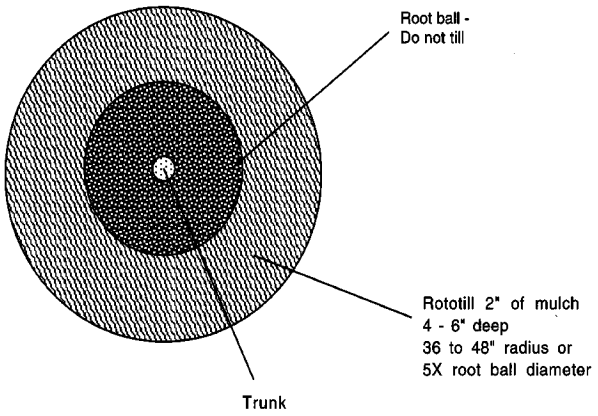
Pest Problems: Many plant species are highly prone to pest problems when stressed by transplanting. Borers, bark beetles, scale, mites and canker and root diseases are common on stressed plants. New transplants also are less capable of tolerating defoliating insect and disease pests.

A key objective of PHC programs for newly planted trees is to encourage root regeneration. New plantings also require frequent inspections and intensive care to maintain them through the critical establishment period. In order to achieve these goals, a program of monitoring, soil treatments and pest management is required.
New plantings are very fragile and can decline and die rapidly due to environmental stress or pest infestations. Frequent inspections are essential to detect subtle changes in plant health and pest infestations. Homeowners should inspect new plantings several times each week during the growing season. A professional arborist should monitor plants on a bi-monthly basis.

Irrigation is the most critical factor for survival of recently transplanted trees. When rainfall is insufficient during the establishment period, water must be applied to the root ball and the surrounding soil. Do not apply excessive amounts of water which causes saturated soil conditions which can lead to root disease and mortality. Soil moisture must be monitored every few days during the growing season by sampling the soil or by installing a tensiometer to measure soil moisture.

Since a plant's energy for growth and other physiological processes comes from the leaves, avoid removing any live branches during the establishment period. Dead, dying, diseased and broken branches should be removed. Removing any competing leaders to maintain a strong central terminal should be considered soon after planting.

Maintaining adequate soil fertility and the recommended pH for the plant species will promote root growth. Fertilization and soil amendments should be based on soil test reports. Use slow release fertilizers such as Bartlett BOOST. Quick release agricultural fertilizers can injure woody plants.



If plants were installed in compacted or severely disturbed soil, the area surrounding the root ball should be cultivated to improve physical characteristics. This involves roto-tilling organic matter such as compost into the upper 4-6 inches of soil. The area treated should be three-to-five times larger than the diameter of the root ball.

The root flare should be visible on all new plantings. If the flare is covered by soil and/or mulch, excavation is required. Inspect the top of the root ball for plastic twine, and straps,

synthetic burlap and wire baskets that may have been left at planting time. Remove these materials or pull them back from the top of the ball when it is not practical to remove them.

Organic mulches are highly effective for improving the soil environment for root growth. Mulches moderate soil temperatures, conserve moisture, provide organic matter and buffer the soil against compaction. Two-to-four inches of wood chips, bark nuggets or similar organic matter should be placed on the root ball and surrounding area. Do not allow mulch to accumulate against bark tissues.

Guys or stakes should be examined frequently to ensure that wires or ties are not girdling stem tissues. Generally supports can be removed after 1 to 2 years.If a trunk wrap was used, remove it before the growing season. Increased risk of borer and canker infestations can occur if wraps remain during spring and summer months. Wraps can be re-applied during the dormant months, however research shows that wraps do not protect stem tissues from temperature extremes.

An aggressive pest management program using integrated pest management technology is essential to plant survival. The MoniTor® Integrated Pest Management program provides regular inspections and treatments to prevent significant injury from pests. Cultural, biological and/or chemical treatments are used to maintain pest populations below damaging levels.

BARTLETT TREE RESEARCH LABORATORIES
CHARLOTTE, NC

Technical Report

Small Trees Suitable For Planting Under Utility Lines

(STREET OR RESIDENTIAL TREES)

Common Name	**Botannical Name**
Trident Maple	*Acer buergerianum*
Hedge Maple	*Acer campestre*
Amur Maple	*Acer ginnala*
Tatarian Maple	*Acer tatarian*
Texas Redbud	*Cercis reniformis 'Oklahoma',*
Chinese Fringetree	*Chionathus retusus*
Kousa Dogwood	*Cornus kousa*
Thornless Cockspur Hawthorne	*Crateagus crusgalli*
Crapemyrtle	*Lagerstromeia indica*
Amur Maackia	*Maackia amurense*
Crabapple	*Malus sp.* (Disease resistant cultivars)
Chinese Pistache	*Pistachia chinensis*
Japanese Apricot	*Prunus mume*
Yoshino Cherry	*Prunus x yeodensis*

BARTLETT TREE RESEARCH LABORATORIES
CHARLOTTE, NC

Technical Report

Structural Pruning of Young Trees

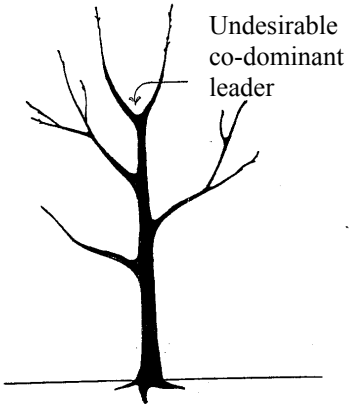
Bruce R. Fraedrich, Ph.D.

Most structural defects that occur in older trees can be prevented by pruning when the tree is young. This practice can avoid the need for more expensive tree care practices later in the life of the plant and can extend the lifespan of the tree by decreasing the likelihood of branch failures. Structural pruning of young, developing trees provides a desirable and stable form at maturity and is one of the best investments that consumers can make in their landscape.

In nature, trees tend to develop a sound structure in response to competition. They grow in close proximity to other trees and the shade created by the developing forest canopy suppresses growth of lower limbs. At the same time, the dominant trees in the forest tend to maintain a single stem and narrow crown as they grow toward light. This results in a reasonably strong structure in mature forest trees.

Conditions are radically different when trees are planted in the landscape. The crown is exposed to full sun, which encourages a broader, more complex crown than one growing in the forest. Lower branches may grow very large, limbs develop in close proximity to one anther and multiple stems can develop. Certain species, particularly those with a decurrent growth form and with an opposite branching habit, are particularly prone to developing structural defects.

Structural Pruning Techniques

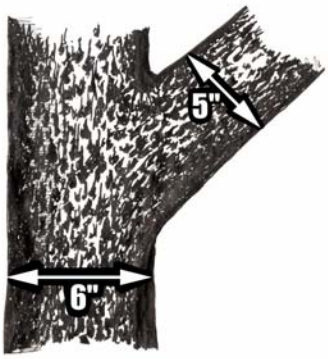


Maintain a single central stem/leader. Unless the tree is intentionally grown as a multi-stemmed specimen as is often done with certain species such as birch and serviceberry, a single stem should be maintained for approximately half of the eventual mature height of the tree. On large maturing species, such as ash or maple, that can eventually reach 70 feet in height, a single stem should be maintained for at least 35 feet before it is allowed to develop multiple leaders of approximately equal size. On smaller maturing trees such dogwood, a single stem should be maintained for approximately 10 feet. Trees with decurrent branching habits, such as elm, honeylocust and redbud, will need a greater emphasis on structural pruning to develop a single central leader

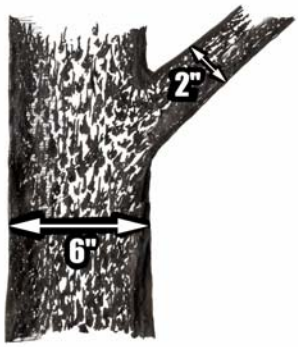
than trees with excurrent habits such as most oak species, tuliptree and conifers. Opposite branched species such as maple, ash and dogwood also have a greater tendency to develop co-dominant stems at a young age. In some cases, competing leaders can be removed entirely to maintain one central stem. This is most appropriate for very young trees that have a single co-dominant stem. On trees with excurrent branching habits that tend to develop multiple leaders, subordinating the leaders by reducing and thinning is usually the best option rather than removal (see section below on subordination).

Maintain Branch/Leader Size: The diameter of all branches and leaders, especially those developing in the lower portion of the crown, should never be larger than 50% of the diameter of stem at the point of attachment. Branches that exceed this guideline, or are growing at a more rapid rate than the primary stem, should be thinned and/or reduced to slow their growth rate relative to the growth rate of the primary stem . This is referred to as **subordination**.

To subordinate a vigorous limb, it should be pruned by at least 50% to achieve a reduction in growth. When pruning to subordinate, removal of branches should be concentrated in the outer half of the limb. Subordination of large or rapidly growing branches should continue as necessary for the life of the plant. Permanent branches that are less than half the diameter of the stem are more strongly attached than larger ones. Subordination also encourages development of branch collars that contain protection zones that discourage development of decay in stems if branches are ultimately removed. Subordinating rapidly growing temporary branches and leaders prior to removal will reduce the development of decay in parent limbs and stems following pruning.

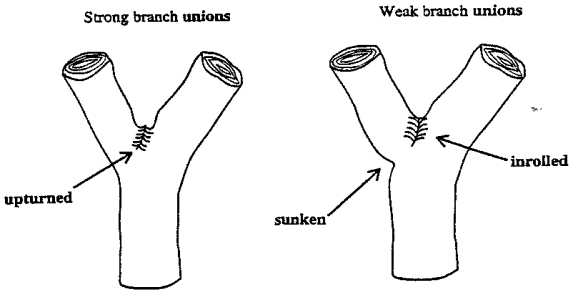


Branches that exceed 50% of the stem diameter at point of attachment are more prone to failure and should be

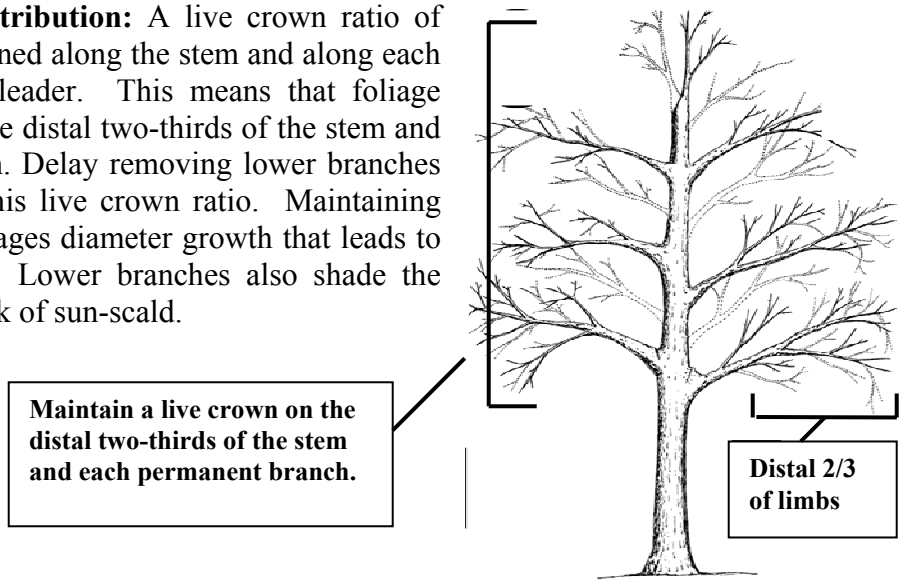


Subordinate permanent limbs so they never exceed 50% of the diameter of the stem at the point of attachment. Subordinate temporary branches prior to pruning.

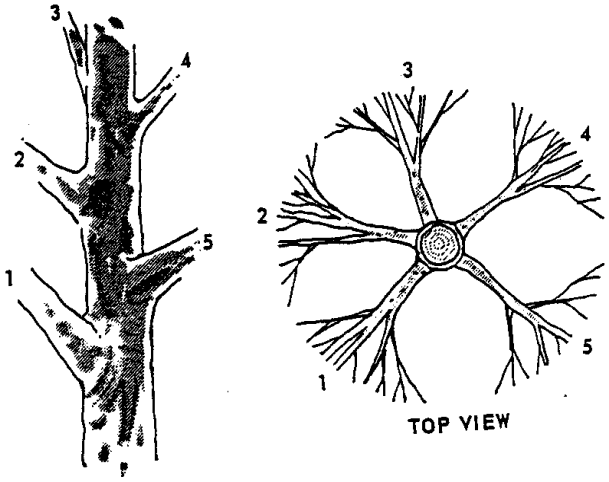
Branch Attachments: Favor branches that have protruding branch bark ridges as a permanent part of the crown. Branches with in-rolled bark attachments will be more prone to failure and must be subordinated if they are to remain as permanent branches.



Maintain Foliage Distribution: A live crown ratio of 66% should be maintained along the stem and along each permanent branch or leader. This means that foliage should cover at least the distal two-thirds of the stem and each permanent branch. Delay removing lower branches in order to maintain this live crown ratio. Maintaining lower branches encourages diameter growth that leads to desirable trunk taper. Lower branches also shade the stem and reduce the risk of sun-scald.



Branch distances/distribution: Thin out closely spaced branches as the crown develops. Prune so that at maturity branches are approximately 12-18 inches apart on large tree species and 6-8 inches apart on small trees. Maintain a balanced radial distribution of branches on the stem to distribute weight and stress.



When to Prune

Structural pruning is best undertaken in winter when leaves do not obscure the branches. Pruning should begin as soon as trees establish and resume normal growth rates following planting. This generally occurs two years after planting but may be longer on large transplants. Inspect trees on an annual basis for the first ten years after they becomes established and prune as needed to provide desirable structure. On small maturing species, the first ten years after establishment is the critical period for structural pruning but on large maturing species, pruning for structure should continue for up to 25 years following planting. Pruning cycles generally can be extended to every 2-4 years during the 11-25 year period following establishment.

Species Requirement for Structural Pruning

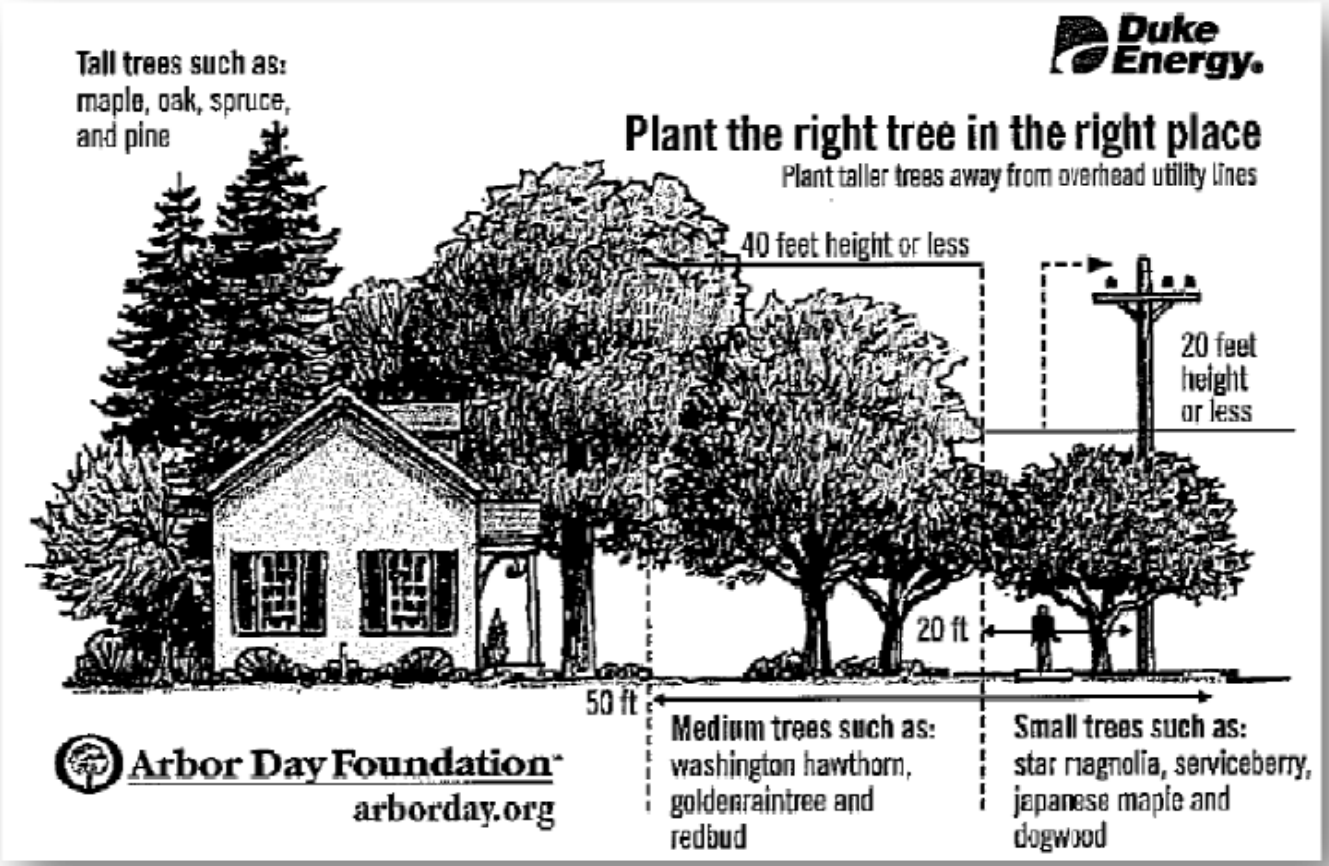
High Maintenance Species **Species requiring frequent inspection and greater attention to structural pruning** **Most high maintenance species have excurrent branching habits**		
Latin Name	**Common Name**	**Inherent structural defects**
Acer	Maple	Tends to develops co-dominant stems. Opposite branching habit results in closely spaced limbs. Poor angle of branch attachment. Weak wood. Decay prone. Dense branch ends.
Betula	Birch	Tends to develop multiple leaders from root collar. Can be grown as a multi-stemmed tree or must receive training to develop a single stem On river birch, the terminal tends to dieback during droughts resulting in co-dominant leads.
Cercidphyllum	Katsuratree	Tends to develop multiple leaders low on the stem. Can be grown as a multi-stemmed tree or must receive training to develop a single stem
Cercis	Redbud	Tends to develop multiple leaders branching at a low height. Leaders have narrow angle of attachment.
Cladrastris	Yellowwood	Tends to develop multiple leaders branching at a low height. Leaders have narrow angle of attachment
Cornus	Dogwood	Tends to develop multiple leaders branching at a low height. Opposite branching habit results in closely spaced limbs.
Fraxinus	Ash	Narrow angle of branch attachment. Upright growth habit. Tends to develop multiple leaders branching at a low height. Opposite branching habit results in closely spaced limbs.
Gleditsia	Honeylocust	May develop multiple leaders but failures seldom occur at maturity.
Lagerstroemia	Crapemyrtle	Tends to develop multiple leaders from root collar. Can be grown as a multi-stemmed tree or must receive training to develop a single stem

High Maintenance Species (cont.)		
Latin Name	**Common Name**	**Inherent structural defects**
Malus	Crabapple	Closely spaced limbs, dense crown.
Pyrus	Pear	Narrow angle of branch attachment. Upright growth habit. Tends to develop multiple leaders branching at a low height and a common location on the stem. Multiple leaders on nursery trees are difficult to correct. Pruning for sound structure must begin in the nursery
Salix	Willow	Branches tend to develop low on the stem and grow rapidly.
Sophora	Pagoda Tree	Branches tend to develop low on the stem and grow rapidly. Dense branch ends. Brittle wood.
Tilia	Linden	Co-dominant leaders. Closely spaced branches, Weak wood. Dense branch ends.
Ulmus	Elm	Develops multiple leaders low on the stem. Narrow angle of branch attachment. Develops dense branch ends.
Zelkova	Zelkova	Narrow angle of branch attachment. Upright growth habit. Tends to develop multiple leaders branching at a low height and a common location on the stem. Multiple leaders on nursery trees are difficult to correct. Pruning for sound structure must begin in the nursery.

Lower Maintenance **Species that tend to develop good structure in full sun**		
Latin Name	**Common Name**	**Comments**
Pinus, Picea, Abies, Tsuga, etc.	Conifers	Monitor for co-dominant stems.
Fagus	Beech	Maintain size of lower branches.
Ginkgo	Ginkgo	
Liquidambar	Sweetgum	
Liriodendron	Tuliptree	
Magnolia	Magnolia	
Platanus	Sycamore	
Poplar	Poplar	Brittle wood and prone to decay. Monitor for co-dominant stems.
Quercus	Oak	Certain oaks such as live oak tend to develop multiple leaders at a low height and require more attention to structural pruning.

Tree planting space opportunities

- Small maturing tree- < 21’ at maturity
- Medium maturing tree- < 41’ at maturity
- Large maturing tree- >41’ at maturity



Guidline for Planting Street Trees