Planted Tree Re-Inventory Protocol

April 2014

Version 1.1

Developed by:

Bloomington
Urban
Forestry
Research
Group at
CIPEC

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Table of Contents

Foreword

The purpose of this booklet is to provide a set of procedures that tree-planting organizations and their volunteers can use to keep track of planted urban trees over time. After reading this booklet, you should be able to measure all of the Planted Tree Re-Inventory Protocols variables described within, record the data you gather, and have some ideas about data analysis. Descriptions of many unfamiliar terms can be found in the Glossary at the end of this booklet.

A Note on Figures

The diagrams and figures that appear in this book were all drawn by Jess Vogt (except where indicated otherwise). Please feel free to use these figures for your own, non-commercial purposes. We only ask that you include the following citation for any figure you use: "Jessica M. Vogt, *Planted Tree Re-Inventory Protocol*, Bloomington Urban Forestry Research Group at CIPEC, Indiana University."

I.

Why do we need a Protocol for Planted Tree Re-Inventory?

Tree-planting initiatives often aim to increase the number of trees in cities and urban tree canopy cover. Urban forestry and tree-planting nonprofits and cities often keep records of the trees they plant. However, few of these organizations systematically re-inventory these trees to track tree mortality or measure growth rates over time. Urban trees benefit city residents by decreasing air pollution and urban heat island effects, mitigating stormwater and carbon dioxide, and increasing aesthetic and property values. Determining accurate survival rates of tree-planting initiatives can help make sure that we maximize these benefits and optimize the allocation of limited tree-planting resources.

Ultimately, the ecosystem services provided by urban trees are maximized when trees survive and grow quickly to maturity (***Figure 1***). The greatest benefits are provided by mature trees in the urban forest. Thus, maximizing the amount of time a tree spends in this mature phase by increasing growth rates of young trees and delaying the onset of senescence (aging and subsequent death) by monitoring condition and providing proper tree care also maximizes the benefits provided by the urban forest. The Planted Tree Re-Inventory Protocol presented here enables tree-planting organizations to monitor the survival, growth and condition of their trees to this end.

The Planted Tree Re-Inventory Protocol provides tree-planting organizations of all types with standardized methods to re-inventory their planted trees. This means organizations can not only track tree success (survival and growth), but also gather informa-

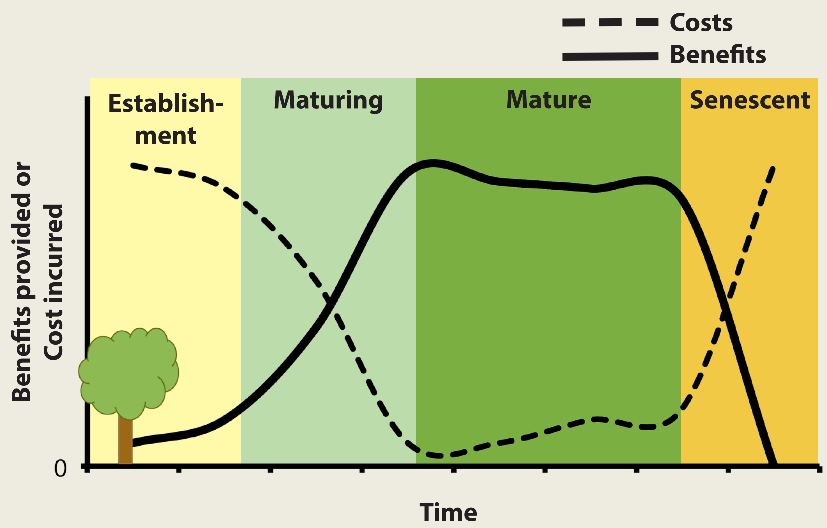


Figure 1. Phases of a tree's lifespan. Benefits provided and costs incurred change over the course of a tree's lifetime. Benefits are maximized during the mature phase of a tree.

tion on the local environment that influences tree success. The Protocol is informed by research on factors related to urban tree growth and mortality, as well as existing urban forest inventory protocols and standards, including the Urban Forestry Data Standards,[1] the site assessment tools of the Young Street Tree Mortality Study of the New York City Parks & Recreation Department,[2] and the International Society of Arboriculture's Best Management

1 The Urban Forestry Data Standards are a joint effort of the International Union of Forest Research Organizations-Urban Forestry Working Group, the International Society of Arboriculture, the United States Forest Service, and the Urban Natural Resources Institute (UNRI). The most recent draft version of the Standards along with more information about the effort is available at the UNRI Standards website: http://www.unri.org/standards.

2 The Site Assessment Tools document of inventory methods used in the New York City Young Street Tree Mortality Study is available at the following website: http://www.nycgovparks.org/trees/ystm.

Practices for Tree Inventories.[3] A complete list of variables and the original sources for each can be found in Appendix A: Sources of Variable Collection Methods.

The Protocol is organized according to four main categories of measurable variables that influence tree success:

1. ***Tree characteristics*** (features of the tree itself),
2. ***Local environment*** (information about the biophysical environment where the tree is growing),
3. ***Management*** (evidence of management and maintenance practices), and
4. ***Community*** (characteristics of the neighborhood and local social norms related to trees).

These four categories align with the Urban Forests as Social-Ecological Systems organizing framework (*see next section*) developed by the Bloomington Urban Forestry Research Group (BUFRG) at the Center for the Study of Institutions, Populations and Environmental Change (CIPEC), a research center at Indiana University, Bloomington.

3 The ISA's "Best Management Practices - Tree Inventories" guide can be purchased at the ISA web store: http://www.isa-arbor.com/store/product.aspx?ProductID=137.

II.

Urban Forests as Social-Ecological Systems: An Organizing Framework

The **Urban Forests as Social-Ecological Systems (UFs as SESs) Framework** posits that the urban forest system is best understood in the context of four subsystems that interact to produce the outcomes of the urban forest (trees that survive and grow, ecosystem services, etc.). This perspective combines the social-ecological system (SES) framework developed in rural common pool resource management settings (forests, fisheries, and irrigation systems) by Elinor Ostrom and colleagues (Ostrom 2009, Ostrom & Cox 2010), the Model of Urban Forest Sustainability developed in the field of urban forest management by Jim Clark and colleagues (Clark et al. 1997), and an organizing framework used in tree growth and physiology research (Kozlowski & Pallardy 1997) (***Table 1***).

Table 1. Thinking about urban forests as social-ecological systems can help organize all the factors that influence urban forest outcomes (tree survival, ecosystem services, etc.)

	Social-Ecological Systems (SES) Framework (Ostrom 2009)	Model of Urban Forest Sustainability (Clark et al. 1997)	Growth Control of Woody Plants (Kozlowski & Pallardy 1997)	Our Framework: Urban Forests as Social-Ecological Systems
Subsystems	Resource Units	Vegetative Resource	Physiology	Trees
	Resource System		Environment	Biophysical Environment
	Governance Systems	Resource Management	Cultural Practices	Institutions & Management
	Resource Users or Actors	Community Framework	--	Community

The production of ecosystem services in urban forests (i.e., benefits of trees) is affected by the features of the trees themselves, the surrounding biophysical growing environment, the characteristics of the community of people around the trees, and the institutions and management (formal and informal rules and shared strategies that structure how people and groups of people interact with one another and with the physical world) that affect how a community manages trees (***Figure 2***). The interactions between the trees, environment, community, and management strategies influence the outcomes of the urban forest, including tree structure (survival, growth), functions, and benefits (ecosystem services).

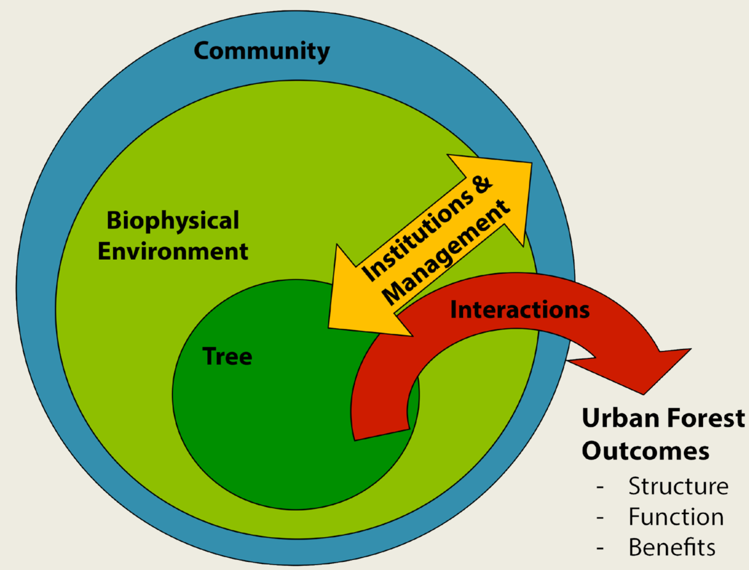


Figure 2. Urban Forests as Social-Ecological Systems (UFs as SESs) Framework. Interlinked human and natural subsystems (the Tree, Biophysical Environment, Institutions and Management, and Community) interact (curved arrow) to produce urban forest outcomes, including surviving and growing trees, and the benefits, or ecosystem services, trees produce.

III.

How to Use This Protocol

This protocol was designed to allow tree-planting organizations to return to planted trees to measure their progress since planting. Ideally, a re-inventory should occur between 3 and 5 years after planting. This timing means that the trees should be outside the establishment phase (typically, 2 years for trees 3-5 cm [1-2”] in caliper at planting), but still small enough that the re-inventory could be combined with any remaining young tree maintenance (mulching, stake removal, training pruning, etc.). The Protocol is designed to be used by minimally-trained, non-professional data collectors (i.e., citizen scientists). This means that a tree-planting organization can use volunteers or interns and collect much more data than if they were using only arborists or trained staff.

Necessary Pre-Existing Information

In order to re-inventory, you must have a record of when the tree was planted, the size of the tree at planting, and its location. *Planting date* is important to determine the amount of time the tree has been in the ground. Planting date can be combined with the tree’s size-at-planting and current size to calculate growth rate. We recommend that the record of tree planting dates be as precise as possible. At minimum, planting date records should include the season and year (e.g., Fall 2008 or Spring 2009). From this, you can count the number of growing seasons a tree has been in the ground.

Size-at-planting should ideally be measured as caliper or diameter at breast height (DBH). However, other common measures of tree size used by nurseries, such as container size or tree height

at time of sale, can often be combined with species information to estimate an average DBH or caliper at planting (e.g., average caliper measurement for a 4-ft tall London plane tree from the nursery used by the tree-planting organization). If you do not have size at planting now, you can still collect data using the Protocol, but you will not be able to calculate tree growth rate for this first re-inventory.

Planting location is crucial so that the trees planted by your organization can be accurately found and the same tree can be tracked over time. Planting location assignment usually involves assigning either every tree or every planting space a unique identification number. Trees can then be located and tracked a number of ways. The most accurate method is matching tree ID numbers on tree tags attached to the tree itself with global positioning system (GPS) coordinates, accurate to within a couple meters. However, tracking location by address or landmarks may also work, as long as trees can be found year after year and the same tree can be attributed to the same unique tree identification number during re-inventory.

Knowing the species of tree planted in a particular location can help you verify that the tree on record is still the same tree growing in this location. Species information is desirable but not necessarily required for a re-inventory.

Paper versus Electronic Data Collection

To begin a re-inventory of planted trees, generate a list of trees to be inventoried, with their identification numbers, planting location information, date of planting, size at planting, and species (if available). This list can be in the form of a spreadsheet where each tree is represented by a row of data, or any electronic database to which you can add columns of new, tree-specific information collected in the re-inventory.

To collect inventory data on paper, the list should be transferred to a form with space for additional information collected on the categories of variables included in the Planted Tree Re-Inventory Protocol. (A set of sample paper data collection sheets is included at the end of this booklet, and both PDF and Microsoft Excel versions of the data collection sheets are available for download at the BUFRG website: http://www.indiana.edu/~cipec/research/bufrg_protocol.) Data collected on paper should be transferred to a permanent electronic format (e.g., an Excel spreadsheet) as soon as possible following data collection to help minimize the risk of losing the data. We also recommend that electronic data entry be performed by the same individual(s) who collected data in the field, as this reduces the risk of misinterpreting handwriting and increases data accuracy and reliability.

Data is usually easier to collect and tabulate electronically. Electronic data collection results in greater consistency in the data and dramatically reduces processing time after data collection. Electronic data collection devices can be hand-held personal digital assistants (PDAs), smartphones, GPS-based devices, specialized tree inventory devices, and more. Devices can either be live-updating (accessing remotely served data from the cloud) or require data to be manually downloaded to a computer. Live-updating devices enable collection and analysis simultaneously and thus allow organizations to see the results of a re-inventory instantly.

Inventory Equipment

Required Equipment

The Planted Tree Re-Inventory requires the following tools: *(Note that you will need one set of tools for each data collection team.)*

- **Data recording equipment:** For paper data collection, you will need several pencils with erasers, a clipboard, and enough paper data collection forms. For electronic data collection, you will need the electronic device (see previous section), a protective case, and any extra batteries or charging equipment (such as a car charger).
- **DBH tape:** A DBH tape (sometimes called a D-tape) is a specialized measuring tape that is used to measure the diameter of a round object by wrapping the tape around the circumference of the object. The diameter of a tree is typically measured at breast height (1.37 m or 4.5 ft), thus, this measuring tape is called a DBH (diameter at breast height) tape. The numbers on one side of a DBH tape are already converted to diameter measurements and the other side of the tape usually has standard metric or English units that can be used for measuring short linear distances.
- **Hypsometer or clinometer:** A **clinometer** is a mechanical instrument that can be used to measure the height of an object. To measure the


DBH tape


Clinometer

Hypsometer

height of an object, such as a tree, the user stands on level ground, looks at the top of the tree through the eye hole on the clinometer, and multiplies the percent visible in the instrument by the known distance between the user and the object, and adds the users height.

A range finder, or **hypsometer**, is a digital version of a clinometer which measures angles, linear distances, and heights with the click of a button and can be used to measure dimensions in the local environment (e.g., distance to nearest road or building, etc.). Although a hypsometer is more expensive and a combination of a clinometer and a meter tape can be used to collect all the dimensions data in the Protocol, we recommend investing in a hypsometer to improve accuracy and make data collection easier.

- **Meter tape:** A 50- or 100-m long measuring tape in meters (or feet, if using; see box on page 27 for notes on units) allows you to measure distances longer than the standard units-side of a DBH tape (which typically is only 10-m long). A meter tape is essential if your data collection teams will be using clinometers instead of hypsometers.
- **Neon safety vest:** A bright orange, yellow or green safety vest with reflectors is important when completing an inventory of street trees or doing any work in the right-of-way to make sure data collectors are visible to passing vehicles.

Recommended Equipment

- **Backpack:** A backpack is useful to keep all equipment in one place and prevent it from being lost. Backpacks can also allow you to carry a water bottle or other personal items with you during a day of data collection.
- **GPS Units:** A global positioning system (GPS) unit that provides accurate information about location in the form of longitude and latitude (X and Y coordinates) can be extremely valuable for a tree-planting organization. Having unambiguous information about a tree's location enables accurate tracking of tree success over time, not to mention allow an organization to map planted trees in relation to other neighborhood or community characteristics.

  GPS capabilities are often incorporated in other devices, such as smartphones, range finders, hand-held PDAs, or specialized tree inventory devices. Using a data collecting device that also has GPS built-in can be an efficient way to collect location and other information about trees. Furthermore, as society becomes more wired, digital data collection using methods that are live-updating or cloud-based can keep data automatically backed-up. Cloud-based smartphone apps can also expand the potential for citizen participation in data collection.

  Note that GPS-enabled devices vary in their accuracy. For instance, some can identify location only to an accuracy of within 10 m (30 ft). The more closely together your organization's trees are planted, the more accurate a GPS unit you will need in order to unambiguously identify trees. If your organization plants trees closer together than 10 m (30 ft), then a GPS device with this level of accuracy will not unambiguously identify tree location. You should choose a GPS unit that has a minimum accuracy of one-half the average distance between the trees you plan to re-inventory.

Choosing Data Collectors and Trees

Once you have a list of trees with location information, have decided on paper or electronic data collection, and obtained the requisite equipment described above, you'll need to decide two final things: who will collect the data and which trees you inventory.

This Protocol was initially designed for use by high school students from Keep Indianapolis Beautiful, Inc.'s Youth Tree Team. We hope that the Protocol can be used by most citizens with fairly minimal training in urban forestry. Thus, data collectors could be individuals from your organization's volunteer list or tree maintenance team, interns, or any existing or recruited personnel suitable for the purpose. We recommend data collectors work in teams of two. Two-person teams allow data collectors to work more efficiently and to consult with one another on qualitative variables. This increases overall accuracy and reliability. Data collection teams should be trained using this booklet as a guide. Part of training should be going through several example trees together to reach a consensus on the proper value for each variable.

Deciding which trees to inventory should occur before data collection starts. There are several options for choosing trees, but ultimately, your organization will be limited by the number of teams collecting data and the time period over which the inventory will be conducted. In our experience, data collection takes an average of 7-10 minutes of team-time per tree, including travel time between trees. For instance, if you have two teams collecting data for 15 hours per week for 8 weeks during a summer, this amounts to a total of 240 team-hours (14,400 minutes). If it takes a team 10 minutes per tree, approximately 1,440 trees can be surveyed in the team-hours allotted. Thus, if your organization planted more trees between 3 and 5 years ago[4] than can be inventoried in the available team-hours, you must choose which trees to inventory. There are several strategies to choosing trees, each

4 Recall that the Planted Tree Re-Inventory Protocol is designed for young trees (<5 years in the ground) that are outside of the establishment period (>2 years in the ground).

of which allows you to say something slightly different about tree success.

- **Inventory all trees in a single project or projects.** One of the simplest ways to choose which trees to inventory is to select a number of tree-planting projects that meet certain criteria of interest (i.e., occurred in a given year, planted greater or fewer than a certain number of trees, were watered by the neighborhood, etc.) and inventory all the trees in these projects.

  This type of sampling will allow your organization to say something about the success of the tree-planting projects that met these criteria.

- **Inventory a proportion of all trees planted in all projects.** Another simple way to choose which trees to inventory is to simply sample a proportion (e.g., 50%) of all trees planted in all projects. Once you've figured out what proportion of trees planted can be inventoried, you can decide how to choose specific trees: randomly or systematically.

  For example, suppose your organization has planted approximately 14,000 trees between 3 and 5 years ago and you have chosen to allocate enough data collection team-hours to inventory approximately 1,440 of these trees (see previous page). Since 1,440 is roughly 10% of 14,000, you could decide to inventory every 10th planted tree along all streets in the city on which your organization has planted trees. This is called *systematic sampling*. Alternatively, you could take the list of trees you've generated, use a random number generator to assign a number 1 through 10 to each tree, randomly select a single number between 1 and 10, and inventory all the trees with this number. This is called *random sampling*.

Systematically or randomly sampling a proportion of all trees planted will allow your organization to say something about the success of all trees planted, and possibly about the success of individual planting projects where a sufficient[5] number of trees were surveyed.

- **The same number of trees in each project:** If your organization is like most, you do not plant the same number of trees in each tree-planting project. However, you may find it desirable to inventory the same number of trees in each project (for instance, to standardize the amount of time the data collection teams spend at each project location). For example, if your organization has planted 25 trees in one project, 30 in a second project, and 150 in a third project, you may decide to sample 25 trees per project (all of the first, 5 in 6 trees in the second, and 1 in 6 in the last project). This is called *stratified sampling*.

  This type of sampling will allow your organization to say something about neighborhood-level project success, but *not* about the overall success of all organization plantings (without using advanced statistical techniques).

Once your organization has chosen which trees to inventory, selected who will collect the data, decided on paper or electronic data collection, and gathered inventory equipment, you're ready to use the Planted Tree Re-Inventory Protocol to assess the success of your trees!

5 "Sufficient" usually means surveying at least 20 trees or, for much larger projects, 10% of all trees planted in that project.

IV.

Planted Tree Re-Inventory Protocol

The 41 variables collected in the Planted Tree Re-Inventory Protocol are explained below. In the left-hand margins next to each variable there is a boxed number, which can be used to refer to the variable. Variable explanations are organized as follows: The first paragraph gives a definition and explanation of the variable and why it is useful. The second paragraph describes the units and equipment used to measure quantitative variables and describes possible values of qualitative or categorical. Diagrams or images are provided as necessary. Finally, any special considerations relevant to a variable are given.

Some Important Notes:

The following descriptions of the 41 variables in the Protocol may seem overwhelming at first glance. However, in order to collect quality data, **it is important to read all variable descriptions completely and to carefully follow the instructions provided during data collection.** This will allow you to compare the tree data collected by your organization to other organizations who also use this Protocol.

Additionally, although 41 variables seems like a large number, in our experience **it takes about 7 to 10 minutes per tree** to collect all information for all the variables, including travel time in between individual trees. Thus, the Protocol allows you to collect a lot of data on planted trees fairly quickly.

List of Variables

Tree Characteristics

The set of *Tree Characteristics* in the Protocol includes information related to the tree itself, including identifying information, size, and canopy, trunk and overall condition.

Identifying Information

V1

Tree ID #

The *Tree ID#* is a unique identification number assigned by your organization to each planted tree. These identification numbers may include digits that correspond to the planting project, to an employee managing the tree planting, or other identifying characteristic as suitable to your organization. Whatever format is most convenient for your organization will work, as long as each tree has a unique number, and no single number is repeated. *Tree ID#* is useful for linking information about the same tree through multiple re-inventories and tracking trees over time.

Tree ID# should be recorded on the data collection sheets or in the electronic device *before* inventory activity begins, so that data collectors can be sure to inventory every tree required.

V2

Location

Tree *Location* is identifying information about the physical location of the tree. Tree location information can be in the form of an address (street number and name) in front of which the tree is planted, geographic coordinates (GPS latitude and longitude), distance and direction of the tree from an intersection, or in many other forms. As discussed above, we recommend using GPS coordinates and a GPS-enabled data collection device, but any location information that is unchanging and enables data collectors to unambiguously locate trees for inventorying is fine.

If a street address is used as the identifying tree location information, data collectors should be careful: there may be other trees at an address (e.g., in front of a house) that were not planted by the tree-planting organization. Thus, location information should be cross-checked with information about *Species* (see V3 below) and date-of planting to verify that the tree being re-inventoried is of the correct species and appropriate size.

Location should be recorded on the data collection sheets or in the electronic device *before* inventorying activity begins, so that data collectors can locate trees and can be sure they are inventorying the correct tree.

V3

Species

Species is the biological name for the type of tree that was planted. Both the scientific name (the Latin genus and species, e.g., *Acer rubrum*) and the local common name (e.g., red maple) should be recorded if known, but record at least one or the other. Scientific name is preferred because the same species may have different common names in different places (e.g., blue beech, ironwood, and hornbeam are all *Carpinus caroliniana*). Different species of tree grow differently in the urban environment, so it is important to consider tree success in the context of tree species.

Ideally, species information should be included along with *Tree ID#* and *Location* on the paper data collection sheet or in the electronic device being used before data collection. Species information can help data collectors determine that the tree being inventoried is the correct tree. In some cases, species information may not have been recorded at the time of planting, or only the genus may have been recorded (e.g., if only *Acer* is noted, it tells us that the tree is a species of maple but not what type of maple). In this case, during re-inventory, the tree should be identified at least to the level of species, and, if possible, to variety or cultivar. Species may be later grouped to the level of genus or family for data analysis, but in the field, collect the greatest level of detail possible.

Species codes can be used if desired. Species codes are a standardized shorthand for plant identification developed by the United States Department of Agriculture (USDA). Typically, the code is four letters composed of the first two letters of both the species and genus name (although this is not the case for all species so caution is advised when assigning species codes for unknown or unusual species). A few codes for species commonly planted in the eastern United States are found in the list below, and a full list of all species codes as used by the USDA can be found at the PLANTS Database website: http://plants.usda.gov.

USDA PLANTS Codes for Common Urban Tree Species

PLANTS Code	Scientific Name	Common Name
AMCA	*Amelanchier canadensis*	Serviceberry
ACRU	*Acer rubrum*	Red maple
ACSA2	*Acer saccharum*	Sugar maple
CACA	*Carpinus carolineana*	American hornbeam
CASP	*Catalpa speciosa*	Northern catalpa
CECA	*Cercis canadensis*	Eastern redbud
COFL	*Cornus florida*	Flowering dogwood
CRVI	*Crataegus viridis*	Green hawthorn
FAGR	*Fagus grandifolia*	American beech
GLTR	*Gleditsia triacanthos*	Honey locust
GYDI	*Gymnocladus dioicus*	Kentucky coffeetree
LIST	*Liquidambar styraciflua*	Sweetgum
OSVI	*Ostrya virginiana*	American hophornbeam
QUMA1	*Quercus macrocarpa*	Bur oak
QURU	*Quercus rubra*	(Northern) Red oak
TIAM	*Tilia americana*	American basswood
ULAM	*Ulmus americana*	American elm

Size

V4 DBH

Diameter at breast height (*DBH*) is the diameter, or width, of the main trunk of the tree at breast height. DBH is one of the most common, consistent, and accurate measures of the size of a tree. DBH can be used to calculate a variety of benefits provided by urban trees, including stored carbon. Change in DBH over time is also a common way to measure the growth of a tree.

DBH is measured at "breast height," which is officially 1.37 m or 4.5 ft from ground level (the base of the tree). It can be helpful to measure exactly where this height is on your own body, or even pin a safety pin at this spot, to ensure that *DBH* is measured at the same point on every tree. Measure *DBH* using a DBH tape, which is a special measuring tape in a scale that converts circumference to diameter automatically (see Inventory Equipment in section III). Wrap the DBH tape around the trunk of the tree perpendicular to the trunk (panel a in ***Figure V4***), taking care that the tape is not twisted or crooked. *DBH* should be recorded to the nearest 0.1 cm or 0.1" (depending on the unit system used, see box at

A Note on Units: Metric versus English

Most of the world uses the metric system (kilometers, meters, centimeters). However, the U.S. and a few other countries use English units (miles, feet, inches). Since science is typically conducted using the International System of Units (metric), this Protocol recommends using metric units, although the sample data sheet does allow the data collector to specify the units used for each variable, and wherever units are used in variable descriptions, we provide an English conversion of metric measurements.

right), which is usually the finest resolution[6] provided on DBH tapes.

DBH can be tricky to measure if the tree has a bulge or branch at breast height (panels b and c in ***Figure V4***), leans one way (panel d in ***Figure V4***), has multiple trunks greater than 2 cm (3/4”) in diameter (panels e and f in ***Figure V4***). For trees on uneven or sloped ground, measure breast height from the base of the tree on the upper side of the slope.

V5 Caliper

Caliper refers to the diameter of the trunk of the tree at 15 cm (6”) above the first lateral root. The first lateral root is the root nearest to the soil surface that reaches out horizontally or roughly parallel to the soil surface. Caliper is a commonly used measure of size for small trees, right out of the nursery, that are not yet tall enough to measure DBH. Because trees are often sold from the nursery by caliper size, caliper-at-planting is often part of nursery and planting records kept by a tree planting organization. We can measure the caliper of recently planted trees and calculate the annual growth rate as the change in caliper divided by the number of growing seasons that have elapsed since planting.

Caliper should be measured using the DBH tape, and recorded to the nearest 0.1 cm (or 0.1”). The plain units side of the DBH tape can be used to measure up 15 cm (or 6”) along the trunk of

6 “Resolution” as used in the Protocol refers to the scale in which numerical measurements are recorded. For instance, “to the nearest 0.1 cm” means that if a measurement of 10.55 cm is indicated on a DBH tape, 10.6 should be recorded in the DBH field of a data sheet or electronic data collection device. If recording “to the nearest 0.5 m” is called for, a measurement of 4.6 m obtained from a hypsometer should be written as 4.5 m, while a measurement of 4.8 should be recorded as 5.0 m.

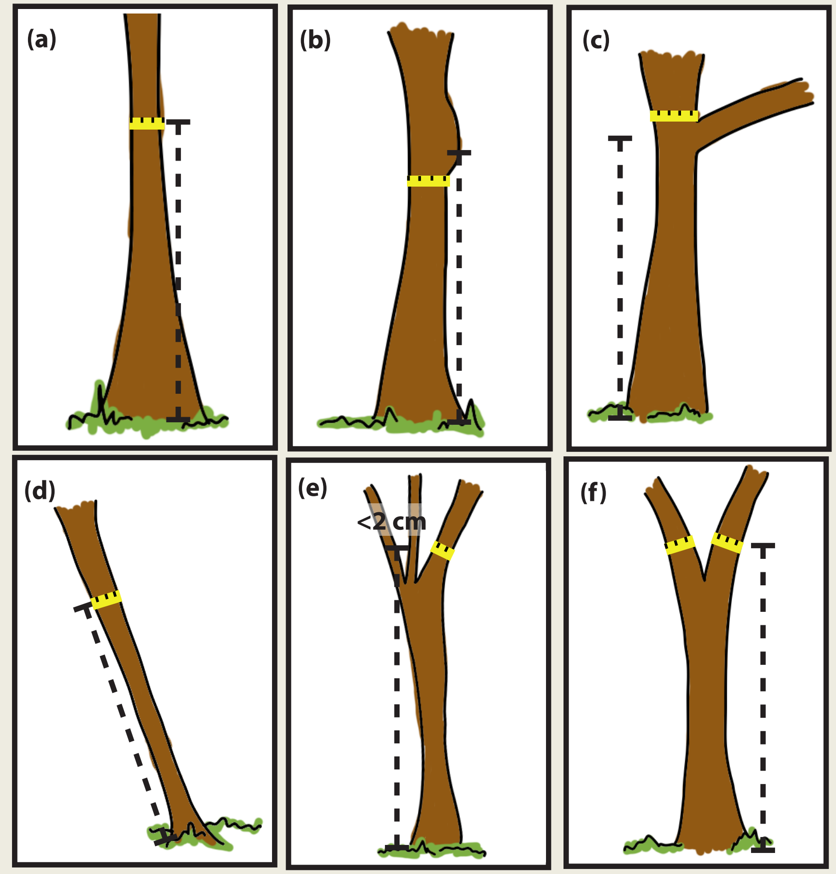


Figure V4. Where to measure *DBH* (yellow ruler). On all diagrams, “breast height” (1.37 m, 4.5 ft) is indicated by the dashed line. **(a)** *DBH* on most trees should be measured at 1.37 m (4.5 ft) above ground level (dashed line in all panels). **(b)** Where the tree has a bulge, measure *DBH* as close as possible to 1.37 m above or below the bulge. **(c)** Where the tree has a branch at 1.37 m, measure just above the branch point. **(d)** For trees that lean, measure *DBH* at a distance of 1.37 m along the trunk, or where 1.37 m would be were the tree standing straight up. **(e)-(f)** For trees with multiple trunks, measure the DBH of all trunks greater than 2 cm (3/4”), recording the DBH of the largest trunk in the *DBH* field and the DBH of all secondary trunks in the *Additional Notes* field.

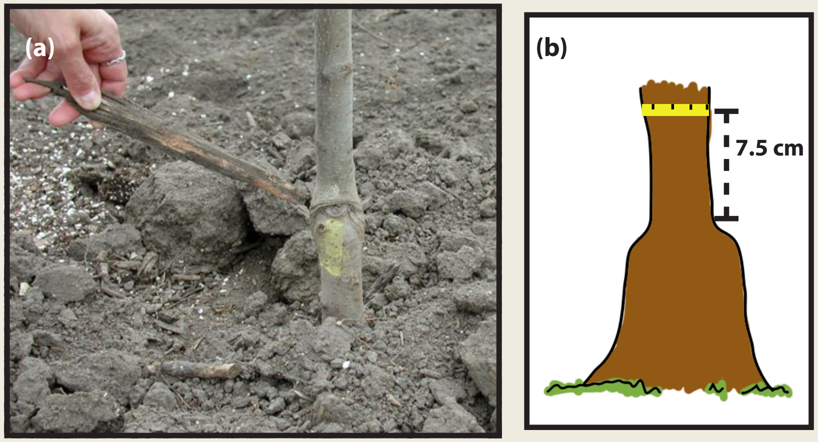


Figure V5. Where to measure *Caliper* on irregular trees. (a) Some trees display a prominent grafting union, recognizable by a bulge on one or more sides of the tree and possibly different textured bark. **(b)** Where the tree has a grafting union visible, measure *Caliper* at 7.5 cm (3") above the graft (yellow ruler).

Image (a) obtained from University of Minnesota Extension. Citation: Doug Foulk, "Apples and Pears in Minnesota Home Gardens," http://www.extension.umn.edu/distribution/horticulture/M1157.html.

the tree. For a tree that is not planted too deeply, 15 cm above the first lateral root is the same as 15 cm above ground level. For trees with mulch at the base of the tree, you may need to dig down into the mulch to find the soil line at the base of the tree. If digging into mulch does not reveal a first lateral root, measure caliper 15 cm above the soil line. For trees that display a visible grafting union above soil level (see panel a in ***Figure V5***), measure *Caliper* 7.5 cm (3") above the graft bulge (panel b in ***Figure V5***).

Note that if a tree was planted too deeply, it may be difficult or impossible to find a first lateral root in order to accurately measure *Caliper*. If this is the case, make a note, so that you know that calculating change in caliper since planting may not be a completely accurate measure of tree growth.

V6 Total Height

Total Height is the height of a tree from the base of the tree (ground) to the tops of its branches. *Total Height* is another important measure of size. Height can tell us about the ability of a tree to provide benefits (e.g., shade or stored carbon) and potential future interference with overhead infrastructure or with other trees. It can also be used in combination with *Height to Crown* (see V7 below) to give us an approximate measure of canopy volume and potential for photosynthesis and growth.

Total Height can be measured with a clinometer or digital hypsometer/range finder (see Inventory Equipment in section III). Since these devices are used very differently, please refer to the instructions provided with purchase of your clinometer or hypsometer. *Total Height* is measured as the distance from the ground to the top of the tree, including any dead branches at the top of the tree. Record *Total Height* to the nearest 0.5 m (or nearest foot if using English units). For severely leaning trees, height is considered the distance along the main trunk from the ground to the top of the tree.

V7 Height to Crown

Height to Crown is the distance along a tree's main trunk between the ground and the beginning of the canopy or crown. The crown, or canopy, of a tree is the leaves and branches of a tree that make up the green leafy tops of deciduous trees (trees that lose their leaves in fall) or coniferous trees (trees with needles). *Height to Crown* can be subtracted from the *Total Height* (see V6 above) of the tree to get a rough measure of the size of the tree's canopy. For trees close to pedestrian or vehicular right-of-ways, *Height to Crown* can help urban forest managers anticipate when a recently planted tree may need to be pruned up.

Height to Crown is measured using a clinometer or hypsometer, and record to the nearest 0.5 m (or to the nearest foot if using English units). Measure *Height to Crown* as the distance between the ground and the lowest hanging part of the live crown. Live branches that are less than 3 cm (1 3/16") in diameter *and* more than 1.5 m (4.9 ft) below the main crown can be excluded.

Canopy

V8 Crown Dieback

Crown Dieback is the amount of dead branches on the top and outsides of the tree canopy (***Figure V8***). Dieback occurs from the top down and from the outside inward. Dead branches within the live canopy of the tree or underneath other live branches on the underside of the canopy are not part of crown dieback because these branches might naturally die off due to self-shading and self-pruning. *Crown Dieback* serves as a measure of tree health. Dieback is often one of the early symptoms of root zone stress and in severe cases can be a precursor to the death of the entire tree. Trees exhibiting dieback symptoms are also likely to have depressed growth rates.

Figure V8. Example of *Crown Dieback*. A red maple (Acer rubrum) exhibiting crown dieback. This tree would receive a Crown Dieback rating of 3, corresponding to 40-60% dieback.

Images obtained from ForestryImages.org. Citation: Jason Sharman, Vitalitree, Bugwood.org.

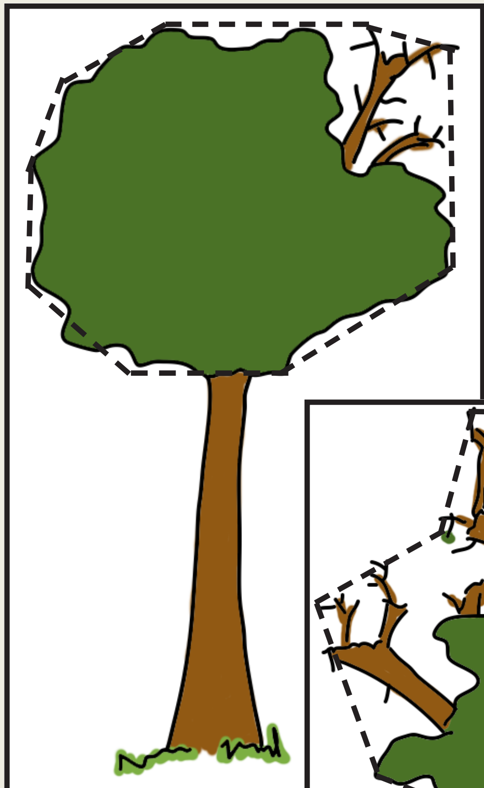
Table V8. Explanation of *Crown Dieback* values. Observers should look at tree from more than one angle and imagine drawing a line around the outermost visible branches and determining the percent of missing canopy within.

Crown Dieback Rating	Visually estimated percent dieback
0	0% (no dieback)
1	1-20% dieback
2	21-40% dieback
3	41-60% dieback
4	61-80% dieback
5	81-99% dieback (very few living branches)
6	100% dieback (complete dieback, no living canopy)

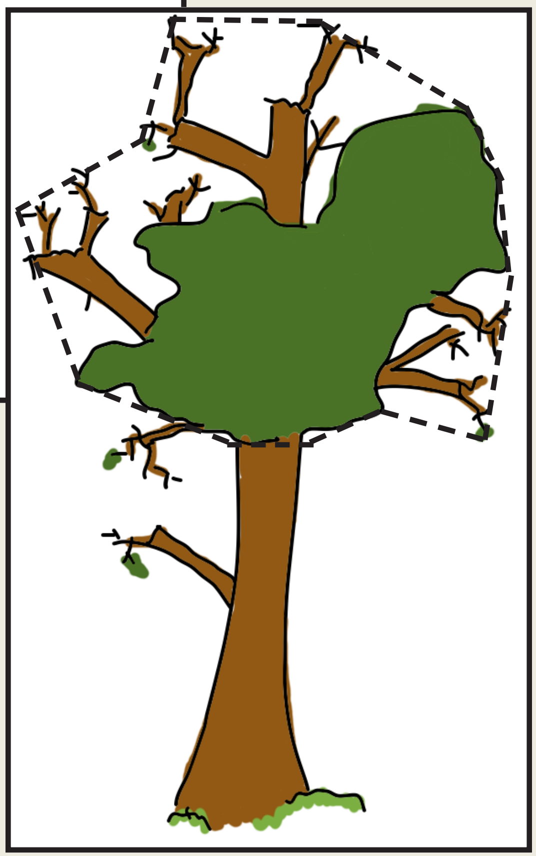
Crown Dieback is a categorical, visually-assessed variable that should be determined by at least two observers looking at the tree from multiple angles. Observers should mentally draw an outline around the outermost branches or crown perimeter visible from that angle and estimate the percent of the canopy area (including dieback area) that is missing (see box on next page). This is most easily done if one can look at the tree with a clear patch of sky as background (e.g., ***Figure V8***). Observers should only include in the visually-estimated percent of dieback those dead branches that are on the tops and outside of the tree. Exclude any dead branches on the underside of the canopy of within the live canopy. The visually-estimated percent dieback is transformed into a categorical rating and recorded in categories of 20% intervals according to the values in ***Table V8***).

If two observers looking at the tree from different angles obtain

Estimating *Crown Dieback* (V8)



The tree at the left has approximately 15% die-back in the canopy, and would be given a *Crown Dieback* rating of 1.



The tree at the right has approximately 50% dieback in the canopy, and would be given a *Crown Dieback* rating of 3. Note that the dead branch underneath the canopy and the branch off the main trunk are excluded from the total crown area.

different *Crown Dieback* ratings, the observers should average their individual estimates of percent dieback and record the *Crown Dieback* rating corresponding to the average percent die-back.

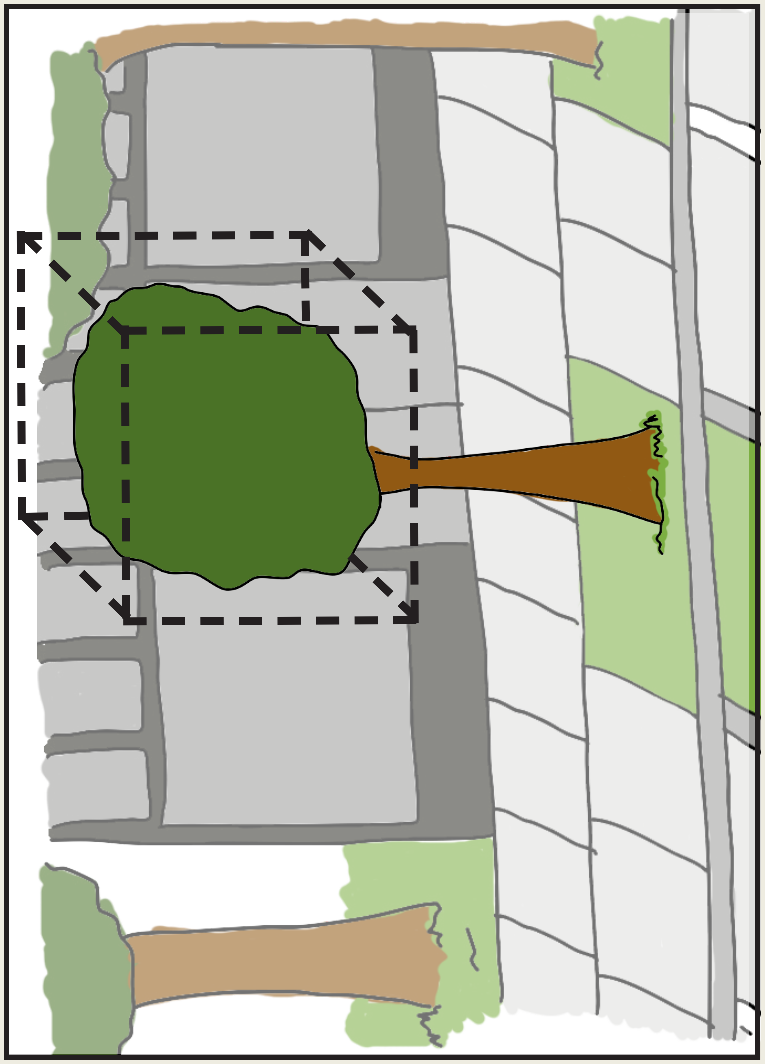
V9 Crown Exposure

Crown Exposure measures how open the canopy of the tree is to sunlight. Specifically, *Crown Exposure* estimates the number of sides of the crown that would be exposed to sunlight if the sun were directly overhead. Crown exposure indicates how shaded a tree is by buildings or other trees and how much a tree might be competing for or limited by aboveground growing space. Shading and space competition impact the potential for photosynthesis and growth.

Table V9. Explanation of *Crown Exposure* values. Observers should look at tree from more than one angle and imagine a box with four sides and a top fitted over the canopy with the sun directly overhead.

Level of Crown Exposure	Explanation
0	Tree receives no light on any sides, because it is shaded by other trees/vegetation, buildings or other infrastructure.
1	Tree receives light from the top or only one side.
2	Tree receives light from two sides but not the top, or from the top and one side.
3	Tree receives light from three sides but not the top, or from the top and two sides.
4	Tree receives light from the top and three sides.
5	Tree receives light from all four sides and the top.

Estimating *Crown Exposure* (V9)



Imagine a box or cube positioned around the canopy of a tree and the sun positioned directly overhead. *Crown Exposure* is the number of sides of the crown (as indicated by the box) that would be at least one-third exposed to sunlight. In this diagram, sunlight on the back and right side of the tree would be blocked by the building and tree, so *Crown Exposure* rating is 3.

Crown Exposure is a categorical variable that is visually assessed by at least two observers looking at the tree from different angles. Observers should imagine fitting a box with four sides and a top over the crown of the tree, and assess how many sides of the box would be at least one-third exposed to sunlight were the sun directly over the tree (see box at left). *Crown Exposure* should be recorded as a whole number between 0 and 5, according to the values described in ***Table V9.***

V10 Chlorosis

Leaf Chlorosis is chronic yellowing between the veins of a leaf. Pictures of leaf chlorosis on individual leaves are presented in ***Figure V10.*** Chlorosis is a relatively easy leaf condition metric to measure. Chlorosis is an indicator of several types of tree stress, most commonly nutrient deficiencies. In very severe cases, leaf chlorosis can be a precursor to crown dieback or tree mortality.

Leaf Chlorosis is recorded as a presence/absence variable,[7] where a 1 indicates the presence of extensive chlorosis and a 0 indicates an absence according to ***Table V10.*** For the purposes of this Protocol, we define "extensive" as chlorosis on more than 25% of the

Table V10. Explanation of leaf *Chlorosis* values.

Chlorosis value	Explanation
0	No leaf chlorosis present or chlorosis present on less than 25% of leaf surface area of the entire tree.
1	Evidence of leaf chlorosis on at least 25% of leaf surface of the entire tree.

7 There are many presence/absence variables in the Protocol, all of which should be recorded as 1/0 in an electronic database for easy analysis.

total leaf surface area of the tree. The leaf surface area is defined as the sum total of the surface area of all individual leaves. Note that the presence of *Chlorosis* is defined as 25% of the leaf *surface area*, *not* 25% of the leaves by number (see the box at right).

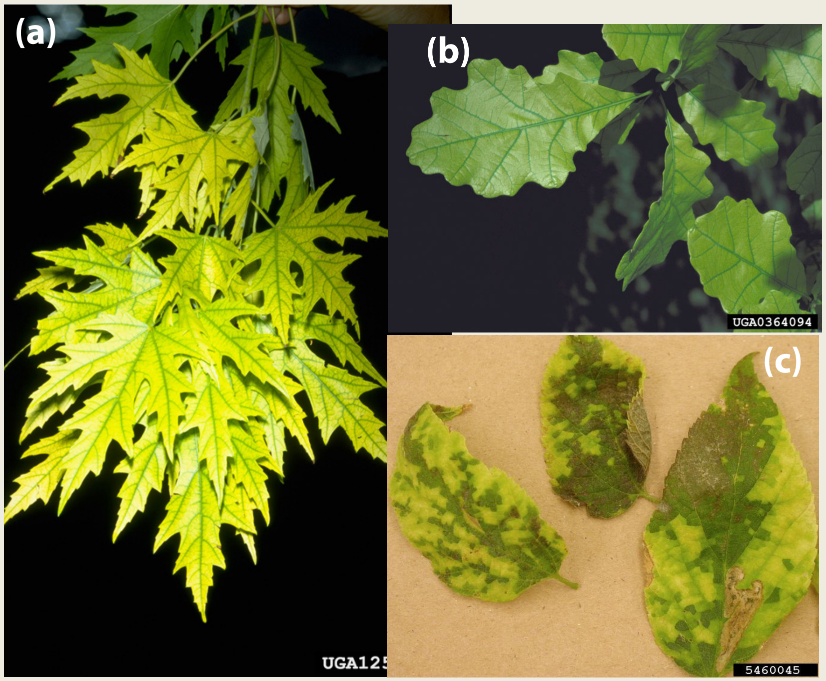


Figure V10. Examples of leaf chlorosis. (a) Severe chlorosis on silver maple leaves. **(b)** Mild chlorosis on an oak tree. **(c)** Chlorosis on hackberry leaves.

<u>Images obtained from ForestryImages.org. Citations:</u> (a) William M. Ciesla, Forest Health Management International, Bugwood.org; (b) Robert L. Anderson, USDA Forest Service, Bugwood.org; (c) Anette Phibbs, DATCP, Bugwood.org

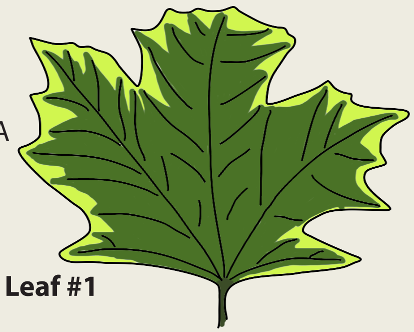
Calculating *Chlorosis* (V10) by Leaf Surface Area

Leaf surface area (LSA) is the sum total of the surface area of all individual leaves.

<u>Example #1:</u> Imagine a tree with chlorosis on only the very edges of many leaves - say, 10% of the area of each individual leaf for 99% of leaves on the tree (leaf #1 below). This tree would not be considered to be exhibiting extensive chlorosis because 10% of nearly every individual leaf is less than 25% of the total leaf surface area of the tree.

10% * 99% = 0.10 * 0.99
= 0.099
= 9.9% of LSA

***Chlorosis* = 0**



Leaf #1

<u>Example #2:</u> Imagine, a tree with a lot of chlorosis on only some leaves - say, 90% of the area of each individual leaf for a third of all leaves on the tree (leaf #2 below). This tree would be considered to be exhibiting extensive chlorosis because 90% of one-third of leaves on the tree is greater than 25% of the total leaf surface area.

90% * 1/3 = 0.90 * 0.33
= 0.30
= 30% of LSA

***Chlorosis* = 1**

Leaf #2

V11 Root Flare

The root flare is the gradual taper of the trunk of a tree as it enters the ground. Whether a tree's root flare is visible can indicate how deeply the tree was planted and any stresses the tree may face now or in the future because of being planted too deeply. The absence of a root flare indicates a tree was planted too deeply. Trees planted too deeply are at risk of developing girdling or encircling roots that can strangle the tree and increase the risk that the trunk of the tree will break off at the base. Also, roots of deeply planted trees may not have adequate access to oxygen, which may cause additional stress symptoms.

Root Flare is recorded as a presence/absence variable, where 1 indicates the presence of a root flare and 0 the absence of a root flare. Examine the base of the tree and note the shape of the trunk as it enters the soil. A tree with a "present" *Root Flare* should have a larger diameter and circumference where the trunk meets the soil than it has at 15 cm (6") above the ground level where *Caliper* (V5) is measured. Specifically, look for evidence of a first lateral root extending outwards from the trunk of the tree just beneath

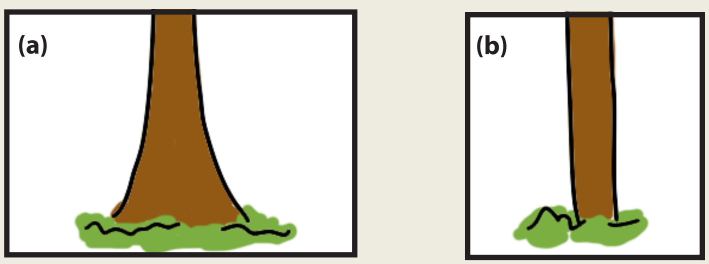


Figure V11. Presence and absence of a *Root Flare*. (a) A tapered or flared base of the trunk indicates presence of root flare. **(b)** A tree entering the ground like a telephone pole indicates absence of a root flare.

the surface of the soil. A smooth taper as the tree enters the soil or a visible first lateral root indicates presence of a *Root Flare* (panel a of ***Figure V11***). A trunk that enters the soil like a telephone pole, with no visible flare, indicates the absence of a *Root Flare* (panel b of ***Figure V11***). Examination may include minimal removal of any mulch around the base of the tree that can be done easily by hand, but do not dig into soil.

Finding a root flare can be tricky for extremely small trees or for trees exhibiting a prominent grafting union. For visibly grafted trees, a root flare should be a more gradually sloped, less bulge-like taper than the graft union (refer to panel b of ***FigureV5*** which displays both a grafting bulge and a root flare).

V12 Lower Trunk Damage

Lower Trunk Damage is damage near the base of the tree in the form of peeling or broken bark or damaged wood. Damage can be caused by lawn mowers, weed-whackers, vehicles, or even animals. Substantial lower trunk damage can increase risk of tree infection by fungus or disease, and repeated damage over time on all sides of the lower trunk, as from a lawn mower, can girdle and eventually kill a tree by severing the vascular tissue.

Lower Trunk Damage is recorded as a presence/absence variable, where 1 indicates the presence of damage and 0 the absence of damage (***Table V12***). Look for damage on the lower trunk (<45 cm or 18" from ground). Examine the base of the tree and look for any evidence of damage by a lawn mower, weed-whacker, car, animal, etc. in the form of scars or missing bark. The most common damage occurs about 15-20 cm (6-8") above the ground, the approximate height of a lawn mower, and looks like a horizontal strip of broken outer bark. Damage should be very visible, and more than a single minor scrape, such as broken outer bark. Evidence of wound occlusion (healing) may be apparent, but healing *Lower Trunk Damage* should still be recorded "present."

Table V12. Explanation of *Lower Trunk Damage* values.

Lower Trunk Damage value	Explanation
0	Absence; no evidence of damage is visible on lower 45 cm (18") of trunk.
1	Presence of damage on lower trunk.

Tree Condition

V13 Other Damage

Other Damage is damage on parts of the tree (upper trunk, branches, canopy) aside from the lower trunk. Damage on a tree can affect the overall health and growth of the tree. Any damage that strips a tree of bark or leaves an open wound opens the tree to infection by a fungus or disease. Damage such as a snapped branch that removes leaves can also decrease photosynthesis and growth potential.

Other Damage is recorded as a presence/absence variable, where 1 indicates the presence of damage elsewhere than the lower trunk and 0 the absence of damage (***Table V13***). Examine the whole tree and look for evidence of vandalism or other human-initiated damage (or negligence). This may include, but is not limited to: a dog rope tied to the tree, broken branches left unpruned, leaves stripped off branches (usually at pedestrian height), bark peeled off the tree, something choking or girdling the tree, car damage, or even a tree pulled out of the ground.

Table V13. Explanation of *Other Damage* values.

Other Damage value	Explanation
0	Absence; no evidence of damage is visible on the tree excluding any Lower Trunk Damage (V12).
1	Presence of damage on the tree above any Lower Trunk Damage (V12), such as snapped branches or vandalism, car damage, etc.

V14 Overall Tree Condition

Overall Tree Condition is a measure of the vigor of a tree and an important indicator of the overall health of the tree. A healthy, vigorous deciduous tree has a full canopy of dark green leaves that are not undersized (appropriate for the current season) and no dieback or decay. Leaves should be dark green in summer, and should not turn to fall colors early (except under conditions of extreme drought). Tree condition also considers the growth form of a tree. Trees in good condition exhibit proper form for the species and do not have dead branches or excessive suckering (water sprouts, or thin branches growing from the base of the tree or out of the main trunk). Tree condition influences how well a tree is growing, and poor condition can be an indicator of a tree's impending mortality. Tree condition also impacts the provision of benefits by a tree. Trees in worse condition may have less canopy volume and leaf area to photosynthesize and sequester carbon and provide shade. Trees in worse condition also provide fewer aesthetic benefits and may even contribute negatively to the appearance and property value of a home or business.

Overall Tree Condition is recorded as a rating ranging from Good to Dead, or categories for Stumps, Sprouts or Absent trees (***Table V14***). Ratings take into account the health of the canopy, any trunk wounds present, wood decay, evidence of insects or disease, and the overall form and shape of the tree. It is important to look at the tree from all angles and from top to bottom when assessing *Overall Condition*.

Table V14. Explanation of *Overall Tree Condition* Ratings. Observers should look at the tree from more than one angle and examine trunk, branches and canopy. Tree must exhibit most of the characteristics indicated to be given that rating.

Rating	Explanation
Good	Full canopy, minimal to no mechanical damage to trunk, no branch dieback over 5 cm (2”) in diameter, no suckering (root or water sprouts), form is characteristic of species.
Fair	Thinning canopy, new growth in medium to low amounts, tree may be stunted, significant mechanical damage to trunk (new or old), insect/disease is visibly affecting the tree, form not representative of species, premature fall coloring on foliage, needs training pruning.
Poor	Tree is declining, visible dead branches over 5 cm (2”) in diameter in canopy, significant dieback of other branches in inner and outer canopy, severe mechanical damage to trunk usually including decay from damage, new foliage is small, stunted or minimum amount of new growth, needs priority pruning of dead wood.
Dead	Standing dead tree, no signs of life with new foliage, bark may be beginning to peel.
Sprouts	Only a stump of a tree is present, with one or more water sprouts of 45 cm (18”) or greater in height growing from the remaining stump and root system.
Stump	Only a stump remains, no water sprouts greater than 45 cm (18”) high present.
Absent	No tree present, not even a stump remains visible in the location where the tree should have been; this category should also be used for trees that have obviously been replaced (are the incorrect species, much smaller than they should be given the planting date, etc.) and there is no evidence of the original tree.

V15 - V21 Interference with Infrastructure

Interference with infrastructure is a series of seven variables that indicate any conflict between the tree and the local built infrastructure. Interference can tell us something about the local growing conditions and aboveground space available for a tree. Houses, buildings, fences, signs, utility poles and wires, street and sidewalk light posts, and even automobile and pedestrian traffic can all interact with a planted tree, hindering its ability to grow freely and often necessitating pruning or maintenance to manage the interference. Infrastructure interference may also help your organization rethink site location strategies.

In this Protocol, we consider seven main types of urban infrastructure with which a planted tree may interfere: aboveground *Utility* wires or poles, *Buildings*, *Fences*, street or other *Signs*, *Lighting*, *Pedestrian* or foot traffic, and *Road* or automobile traffic. Conflict with each of these types of infrastructure is recorded as a presence/absence variable, where 1 indicates the presence of *current* conflict with that type of infrastructure and 0 the absence of current conflict (***Table V15-21***).

V22 - V23 Ground Cover At Base and Under Canopy

Ground Cover At Base and *Ground Cover Under Canopy* capture the dominant ground cover types at the base of the trunk and under the canopy of the tree. The type of ground cover tells us the potential for competition with other plants for water and nutrients, the permeability of the area immediately surrounding the tree, the amount of organic material potentially decomposing and

Table V15-21. Explanation of Interference with Infrastructure variables. Only presence (1) values are explained; absence (0) should be recorded for trees that do not meet the definition of present conflict with infrastructure.

Interference type	Explanation of presence (1) value
V15 Utility	Current conflict with above-ground utility wires or poles; tree branches of any size are touching wires or poles.
V16 Building	Current conflict with a building (including a foundation, wall, deck or porch-like structure, in-ground structure, etc.); tree branches of any size are touching the building.
V17 Fences	Current conflict with fences (except concrete wall-like fences, which are considered a type of building); tree branches of any size are touching the fence.
V18 Signs	Current conflict with traffic, business or street signs of any type; tree branches of any size are touching the sign *or* tree branches/canopy are *not* touching the sign but are blocking it from normal view.
V19 Lighting	Current conflict with street or pedestrian lights and light posts; tree branches of any size are touching the light or light post.
V20 Pedestrian Traffic	Current conflict on the sidewalk side of the tree with potential pedestrian traffic; branches at or below 2.4 m (8 ft) above a sidewalk or walkway; when walking on the sidewalk, a person could reach straight up and touch the tree.
V21 Road Traffic	Current conflict on the street side of the tree with potential automobile traffic, *not including traffic in any parking lane along the street*; branches of more than 1 cm (1/2”) in diameter at or below 4.3 m (14 ft) *above active traffic lanes.*

Table V22-23. Explanation of *Ground Cover at Base of Tree and Under Canopy* values.

Type of Ground Cover	Explanation
Soil	Bare soil, exposed dirt; includes very old mulch where so few mulch pieces are visible that it no longer serves a purpose as mulch.
Organic mulch	Organic (biodegradable in the short term) mulching material, such as bark or wood chips, shredded wood waste, even saw dust or intentionally placed leaves or pine needles.
Inorganic mulch	Inorganic (man-made and non-biodegradable in the short term) mulching material, such as rubber or plastic pellets.
Grass	Turf grass.
Perennial	Perennial plants, flowers, shrubs; live more than one growing season; most bushes are perennial plants.
Annual	Annual plants or flowers; only live one growing season; examples include most food plants, impatiens, begonias, petunias, most geranium flowers.
Gravel	Small pebbles, gravel, or landscaping rocks.
Weeds	Weeds, nuisance plants, grass, etc. greater than 30 cm (1 ft) in height.
Pavement	Pavement, cement, asphalt, paving stones, etc.; may be broken and cracked but should still be in large, identifiable pieces to qualify as pavement (small, gravel-sized pieces would be gravel).
Other, permeable	Any other ground covering not mentioned above that is *permeable* (water would run through the substance and reach the soil below).
Other, impermeable	Any other ground covering not mentioned above that is impermeable (water runs off in the direction of gravity or pools on the top but does not reach the soil immediately below).

providing nutrients to the tree, or even the likelihood of soil disturbance in the tree root zone (e.g., due to planting and replanting of annual plants). All of these factors can influence the growth and survival of a recently planted tree.

Both ground cover variables are recorded as the representative type of ground cover adjacent to where the trunk of the tree enters the ground (*Ground Cover At Base*) or within the dripline of the tree canopy (*Ground Cover Under Canopy*). Where more than one type of ground cover exists, assign the type of *Ground Cover* that constitutes the largest proportion of the area under the canopy or adjacent to the base of the tree. To assess *Ground Cover At Base*, imagine a small ring with a 15 cm (6") width adjacent to the base of trunk where the tree enters the ground and determine the predominant ground cover type within this ring. For a tree in a tree grate, look under the grate if possible. To assess *Ground Cover Under Canopy*, imagine a cylinder extending downward from the dripline (outer lateral extent of branches in the tree canopy) to the ground, and determine the predominant type of ground cover within the ground area encompassed by this cylinder. See ***Table V22-23*** for possible values for *Ground Cover At Base* and *Ground Cover Under Canopy*.

Planting Area Characteristics

V24 Planting Area Type

The *Planting Area Type* (sometimes called the planting space or planting spot) is a name for the contiguous, permeable physical place within which the tree is planted. The tree may be planted in an area filled with soil or a soil-substitute. Urban trees are usually planted in a space covered with a permeable substrate, such as grass or mulch. The type of planting area can tell us about the available growing space and soil conditions for the tree. Planting area may also give a clue as to who may be responsible for maintaining the tree, although this is not always the case.

Table V24. Explanation of *Planting Area Types*. See *Figure V24* for diagrams.

Planting Area Type	Explanation
Tree lawn	Tree is planted in the strip of permeable surface (usually grass) between the sidewalk and the street.
Median	Tree is planted in a median, or strip of land between two or more lanes of traffic.
Shoulder	Tree is planted in a large road shoulder, either sloping up or down from street level; generally for trees planted in the right-of-way of wide, busy streets or roads in more rural areas.
Tree grate	Tree is planted in a pit along a street or sidewalk and planting area is covered by a metal tree grate.
Tree pit	Tree is planted in a relatively small pit-like area, bordered by pavement or similar in close proximity on all four sides, but without a tree grate accompanying the pit.
Bumpout	Tree is located in a bumpout or cutout along the sidewalk or street, bordered by pavement or similar in close proximity on three sides; common where on-street parking occurs.
Front yard	Tree is located in the front yard of a house or building, between the building and the sidewalk or street.
Side yard	Tree is located on the side of a house or building, between two buildings.
Open area	Tree is located in a larger, park-like open area (e.g., a grassy open area near a pond or the middle of a small pocket park).

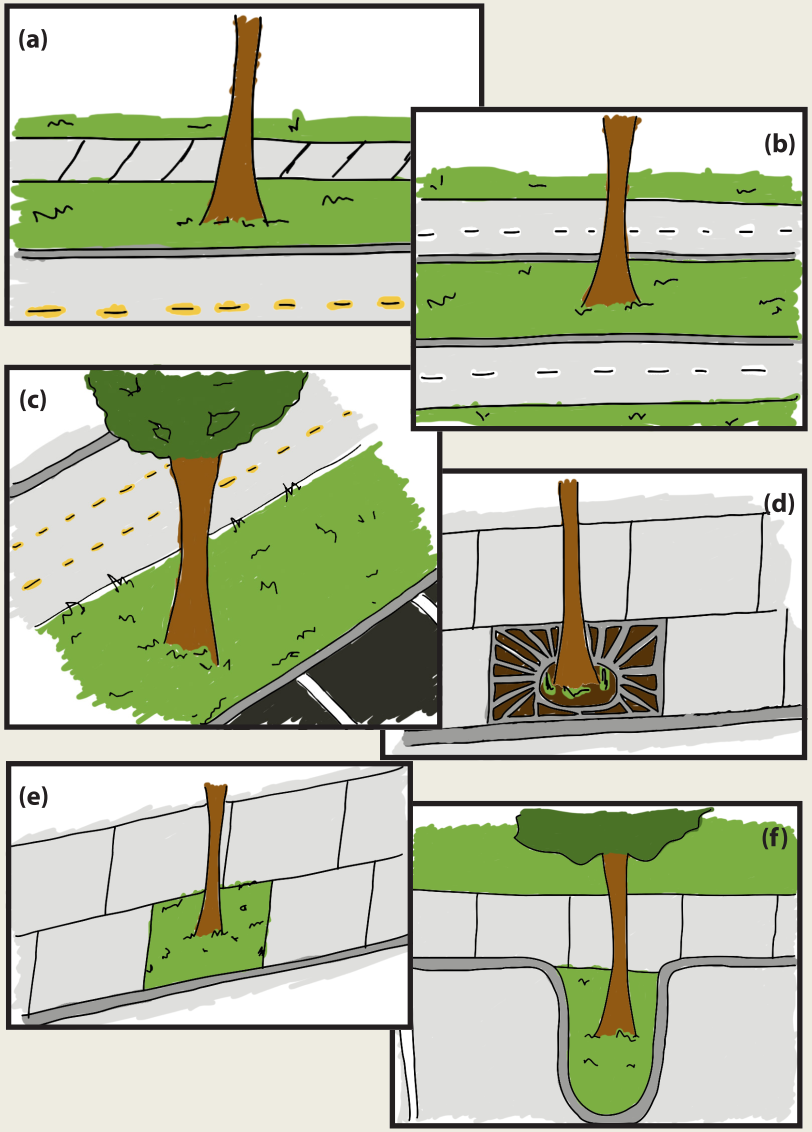


Figure V24. Diagrams of *Planting Area Types*. (a) Tree lawn. **(b)** Median. **(c)** Shoulder. **(d)** Tree grate. **(e)** Tree pit. **(f)** Bumpout. (*Continued next page.)*

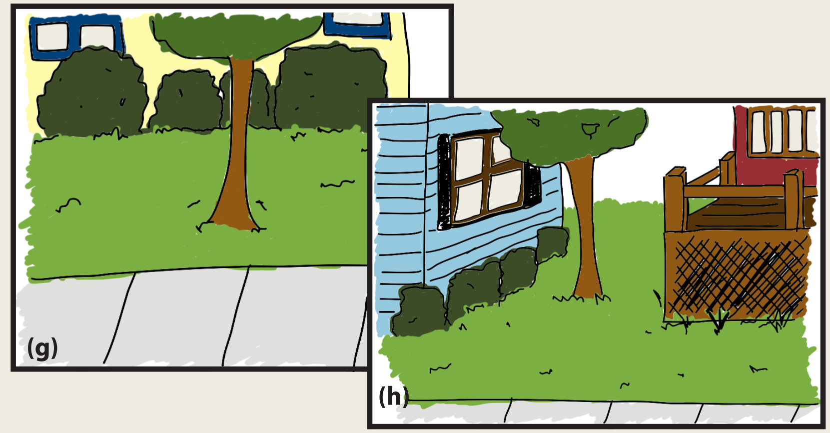


Figure V24. Diagrams of *Planting Area Types*. *(Continued from previous page)* **(g)** Front yard. **(h)** Side yard. [Note that Open area type is not shown.)

Planting Area Type is recorded as a categorical variable, picking from the options in ***Table V24.*** Types of planting areas include areas in the public right-of-way such as the tree lawn, median, tree grate, tree pit, or a curb bump-out, in private front or back yards, or an open area. See ***Table V24*** for definitions of each *Planting Area Type* and ***Figure V24*** for diagrams of each type.

V25 Planting Area Relative to Road

The position of the *Planting Area Relative to Road* refers to whether the area in which the tree is planted is elevated above, below, or approximately even with the surface of the road. When combined with *Curb Presence* (see V28 below), *Planting Area Relative to Road* can tell us about the potential quantity and quality of any runoff into the area where the tree is planted. For instance, a road surface above a planting area that lacks a curb means greater infiltration of surface runoff into the planting area.

Planting Area Relative to Road is recorded as a categorical variable with three values: above, even, or below (***Table V25***).

Table V25. Explanation of values for planting area position *Relative to Road*.

Relative to Road value	Explanation
Above	Planting area is elevated higher, or above, the surface of the road. Most common planting areas adjacent to roads with curbs are slightly above the level of the road surface.
Even	Planting area is approximately level with the road surface.
Below	Planting area is lower than the surface of the road. Planting areas adjacent to elevated roads or highways are often lower than the surface of the road.

V26 Planting Area Width

Planting Area Width is the narrowest dimension of the planting area in a direction perpendicular to an edge of the planting area that best describes the entire planting area (***Figure V26-27***). For most planting areas, this is the distance between two parallel impervious surfaces, for example, the curb of a road and the sidewalk for a tree lawn, or two curbs of the road for a median. If we assume that the size of a planting area approximates the available belowground rooting volume (which is a fairly sound assumption for most urban tree planting spaces and particularly for street trees), the width of the planting area can tell us something about the most constricting dimension for tree root growth. *Planting Area Width* and *Planting Area Length* (see V27 below) multiplied together give the surface area of the available belowground rooting volume for rectangular planting areas and an approximate area for irregularly shaped planting areas. Available rooting volume affects the size of the belowground portion of the tree (roots), which is related to the growth and maximum possible size of the aboveground portion of the tree (trunk, canopy).

Table V26. Description of where to measure *Planting Area Width* (V26) for different *Planting Area Types* (V24).

Planting Area Type	Where to measure width
Tree lawn or Shoulder	Measure the distance between the sidewalk or parking lot and the street from pavement to curb (or where a curb would be if a curb is absent).
Median	Measure the distance between the two lanes of traffic, from curb to curb.
Tree grate or Tree pit	Measure the width of the tree grate or pit in the narrowest direction (may be parallel or perpendicular to the street).
Bumpout	Measure the width of the bumpout in the narrowest direction, usually parallel to the road.
Front yard	Measure the distance between the house or front porch and the sidewalk or street (whichever is closest type of pavement).
Side yard	Measure the distance from wall to wall (or porch) for the two structures between which the tree is located.
Open area	Measure, in the narrowest dimension, the distance between the walls or impervious surfaces bordering the common area. It is okay if this is a large number if the open area is quite large.

Planting Area Width is measured with either a hypsometer/range finder (if using) or with a meter tape (such as that on one side of most DBH tapes). Width should be recorded to the nearest 0.1 m or 10 cm (or, if using English units, to the nearest 3”). Widths over 30 m (98 ft) can be recorded less precisely, to the nearest meter (or 3 ft). ***Table V26*** describes where to measure *Planting Area Width* for each *Planting Area Type*. See also ***Figure V26-27***.

V27 Planting Area Length

Planting Area Length is the widest or longest dimension of the planting area in a direction perpendicular to an edge of the planting area (***Figure V26-27***). For most planting areas, this is the dimension perpendicular to the width, such as the distance between two driveways or walkways for a tree lawn planting area. Planting area length and width, as mentioned above, can together give a loose approximation of the available rooting volume for the tree, and therefore aboveground growth potential.

Planting Area Length is measured with either a hypsometer/range finder (if using) or with a meter tape (such as that on one side of most DBH tapes). *Length*, like *Width*, should be recorded to the nearest 0.1 m or 10 cm (or, if using English units, to the nearest 3"). Lengths over 30 m (98 ft) can be recorded less precisely, to the nearest meter (or 3 ft).

Note that because the planting area is considered to be the entire contiguous area within which the tree is planted, this may mean that *Planting Area Length* is a large number. For instance, if an entire city block has a single unbroken tree lawn between the street and sidewalk, the *Planting Area Length* will be the entire length of the block. It is likely that lengths longer than a particular threshold are biologically indistinguishable from completely unrestricted rooting space for the tree; however, as always, the greatest level of detail possible should be collected for all variables while in the field.

V28 Curb Presence

Curb Presence tells us whether there is a curb or barrier at the edge of a planting area. This variable tells us more information about the type of the planting area where the tree is planted. Curbs affect the quality and quantity of stormwater runoff from the road that may or may not be infiltrating the planting area.

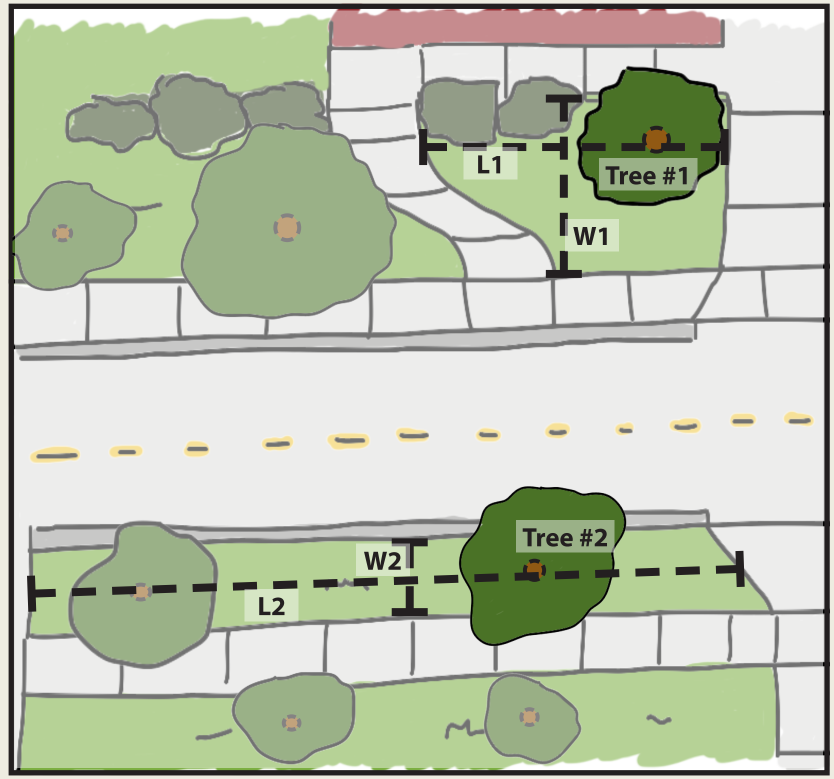


Figure V26-27. Examples of *Planting Area Width* (V26) and *Length* (V27). The diagram above shows examples of where to measure *Planting Area Width* (W1 and W2) and *Planting Area Length* (L1 and L2) for two sample trees.

Curbs also act as a barrier to vehicles that may drive off the road and injure a tree. Curbs may be located on the boundary of the permeable planting area and the pavement adjacent to many types of planting areas, including along the edges of streets, plazas, parking lots, sidewalks, and more.

Curb Presence is recorded as a presence/absence variable, where 1 indicates the presence of a curb and 0 the absence of a curb, with the addition of a third possible value of "damaged" (***Table V28***).

Damaged indicates the presence of a curb that is old and degraded or so substantially damaged that it no longer functions as a barrier between a street/parking lot and the tree planting area. Look for a curb on the edge of the planting area that is closest to the base of the planted tree.

Table V28. Explanation of *Curb Presence* values.

Curb Presence value	Explanation
0	No curb present; planting area surface is flush or nearly flush with the road or parking lot surface.
1	An intact curb is present; planting surface is separated from a road and/or parking lot by a raised barrier of concrete or pavement.
Damaged or Partial	An intact curb was likely present at one time and remnants are still clearly visible; curb is partially present in the form of broken chunks of concrete but no longer forms an effective barrier separating the planting area from adjacent road/parking lot.

Proximity to Other Things

V29 - V31 Number of Trees In... 10-m Radius, 20-m Radius, & Same Planting Area

The *Number of Trees In 10-m Radius*, the *Number of Trees in 20-m Radius*, and the *Number of Trees in Same Planting Area* are all count variables indicating the number of other trees (*excluding the focal tree*) close by. The number of trees in close proximity to the focal tree can tell us about the amount of potential competition occurring. The number of trees within a 10- and 20-m radius can tell us about potential shading and space competition experienced by the tree above ground. The number of other trees in the same planting area can tell us how many trees may be competing for the same water, nutrients, and rooting space below ground.

We expect trees that are experiencing more competition from a greater number of neighboring trees to have reduced growth and survival than trees lacking competitor trees.

Number of Trees In 10-m Radius (V29), *Number of Trees In 20-m Radius* (V30), and *Number of Trees In Same Planting Area* (V31) are all recorded as an integer (1, 2, 3...), where the number of trees counted for each variable *does not include the focal tree*. An example of the *Number of Trees In 10-* and *20-m Radii* and *Same Planting Area* is shown in ***Figure V29-31***. Only count trees with a DBH greater than 2 cm (3/4”). To count the *Number of Trees In 10-* and *20-m Radii*, stand as close to the trunk of the focal tree as possible, and using a hypsometer or meter tape, measure the distance between the focal tree and neighboring trees, starting with the nearest tree. Note that trees counted as part of the 10-m radius are included in the count of trees in a 20-m radius. For the example in ***Figure V29-31***, *Number of Trees In 10-m Radius* is one (1) and *Number of Trees in 20-m Radius* is five (5). To count the *Number of Trees In Same Planting Area*, count the number of additional trees within the same contiguous pervious planting area. For the example in ***Figure V29-31,*** there is one (1) other tree in the same planting area.

V32 - V33 Distance To...Road & Building

The *Distance To Road* (V32) and the *Distance To Building* (V33) are the linear distances between the tree and the road or between the tree and the nearest building, respectively. These variables can tell us important information about the above ground growing conditions for the tree. The distance between the tree and the road can tell us about the tree’s potential exposure to factors that may decrease health and condition. Factors include how likely the tree may be to be injured by an automobile, or how much road spray contaminated with fuel oils, road salts and other particles may reach the tree. The distance between the tree and

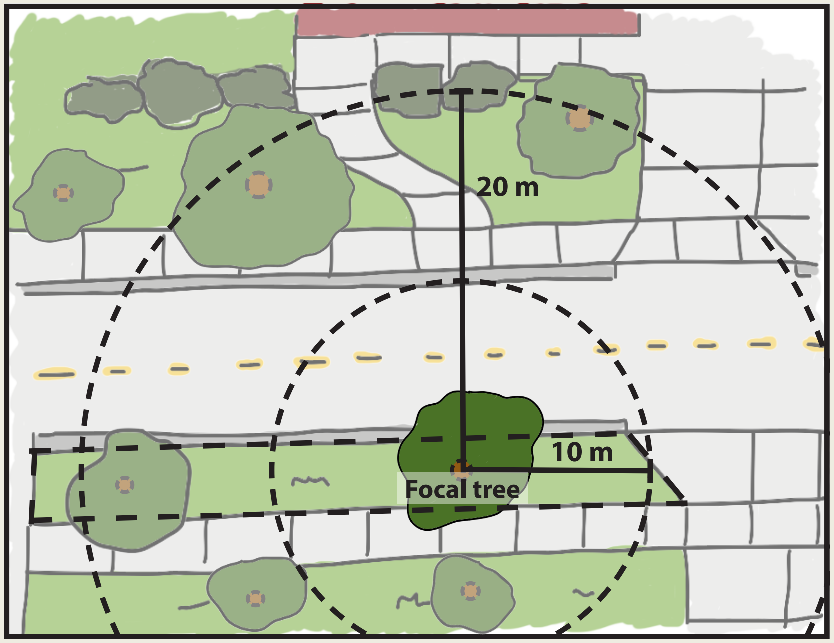


Figure V29-31. Example of *Number of Trees In 10-m Radius* (V29), *20-m Radius* (V30), and *Same Planting Area* (V30). Above is an aerial view of a typical street, containing tree lawns, sidewalks, driveways, a building, and trees. Tree locations are indicated by green irregular shapes outlining the extent of their canopy and brown circles representing trunk location. The focal (study) tree is at the center of the 10- and 20-m radius dotted line circles. (Assume there are no trees greater than 2 cm (3/4") DBH outside the extent of the frame.) The planting area is outlined in a dashed line. According to this example, there is 1 tree in a 10-m radius, 5 trees in a 20-m radius, and 1 additional tree in the same planting area.

the nearest building can tell us about the tree's exposure to radiant building heat and also to shading from the building. Because roads and buildings also have a below ground presence, both of these variables can also tell us about the potential for interference with tree root growth in one or more directions.

Distance To Road (V32)and *Distance To Building* (V33) are measured using the hypsometer or a meter tape. Measure the distance between the trunk of the tree and the edge of the nearest road or the wall of the nearest building, and record to the nearest 0.1 m or 10 cm (or if using English units to the nearest 3"). Distances over 30 m (98 ft) can be recorded less precisely, to the nearest meter (or 3 ft). See ***Figure V32-33*** for an example of measuring *Distance To Road* (V32) and *Distance To Building* (V33). Note that

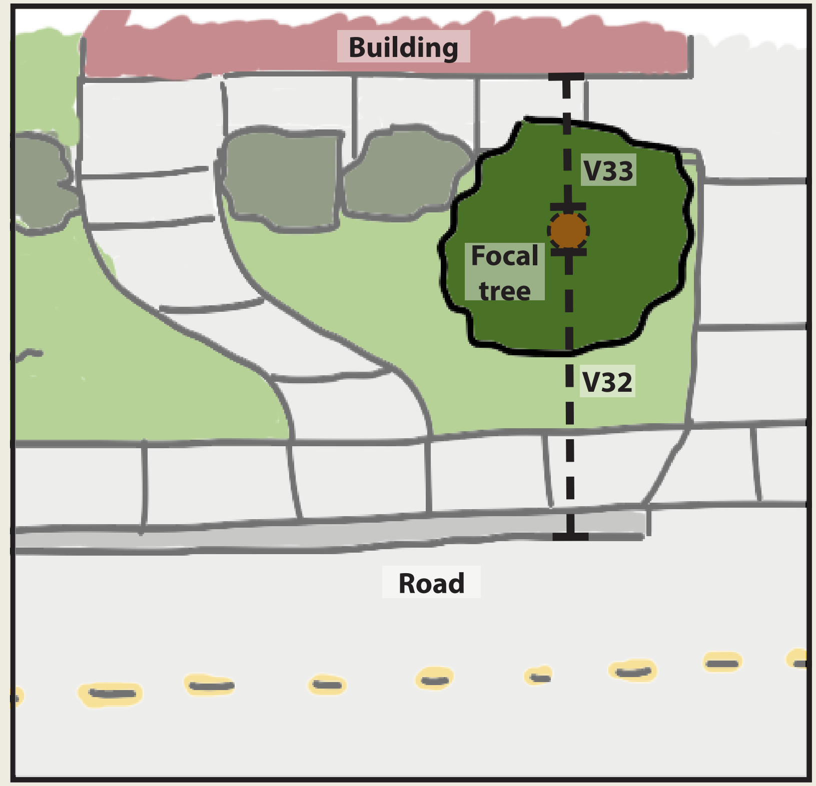


Figure V32-33. Measuring *Distance To Road* (V32) and *Distance To Building* (V33). The diagram above show an example of where to measure *Distance To Road* (V32) and *Distance To Building* (V33) for a focal tree.

even for trees in front or side yard planting areas, distance to the nearest road should still be recorded, even though there may be a sidewalk or other paved surface between the tree and the road and thus the nearest road may not necessarily also be the nearest pavement or impervious surface.

Management Variables

The set of *Management Variables* in the Protocol includes maintenance practices evident on the tree.

Evidence of Maintenance

Pruning

V34 *Pruning* is defined as a visible effort made by a human to remove branches from the canopy or trunk of a tree. Pruning or trimming the branches of a tree can improve the overall growth form, structure, stability, and appearance of a tree. Pruning is usually a well-intentioned effort to care for a tree, whether or not the pruning is done correctly. Still, by definition, pruning reduces the amount of leaves on the tree and thus reduces the tree's capacity for photosynthesis and growth. Pruning also leaves a wound on the tree, leaving the tree open to disease and pathogens. Evidence of pruning and whether pruning was done correctly may be an important indicator of future health of the tree as well as an indicator of whether or not the tree is being actively maintained and cared for by someone.

Pruning is recorded as a categorical variable, with possible values of correct, incorrect, or none (***Table V34***). Examine the trunk and main branches of the tree and look for signs of pruning that has occurred since planting. Evidence of pruning (correct or incorrect) consists of a flat cut, as if done with a handsaw, knife or other implement that would yield a flat tip of a branch. Broken-off branches do not count as pruning because it is impossible

Table V34. Explanation of *Pruning* values.

Pruning value	Explanation
Correct	Evidence of tree pruning exists and this pruning was done correctly, according to ***Figure V34, panel a.***
Incorrect	Evidence of tree pruning exists, but pruning is not done correctly. See ***Figure V34, panel b.***
None	No evidence of pruning visible.

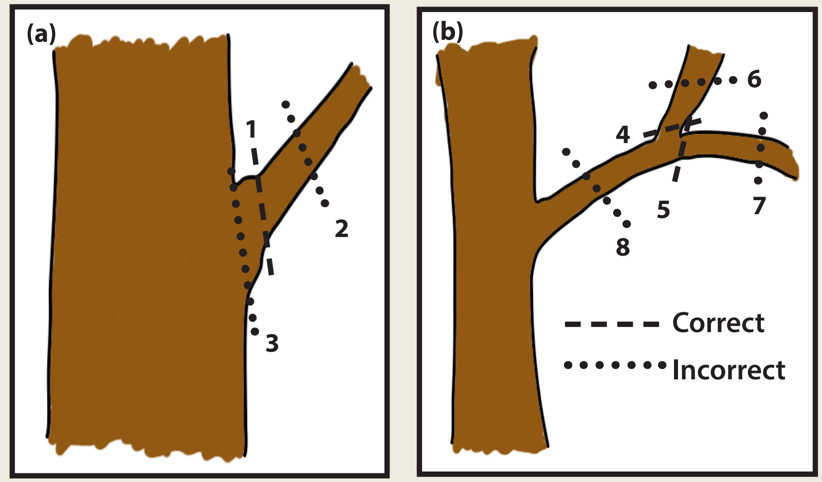


Figure V34. Diagram of the location of correct and incorrect *Pruning*. (a) For pruning of branches on the main trunk of the tree, correct pruning cuts occur just outside the branch collar (cut 1). Incorrect pruning leaves too much of the branch above the branch collar (cut 2) or cuts too deeply into the branch collar (cut 3). **(b)** For pruning of secondary branches in the crown, correct pruning should occur just after the branching (cuts 4 *or* 5, *but not both on the same branch*), while incorrect pruning again leaves too much of the original branch (cuts 6, 7, 8), slowing wound healing.

to determine whether these were intentionally or unintentionally broken by a human or other animal. "Correct" *Pruning* occurs just outside the branch collar, a slight bulge of differently-textured bark where the smaller branch diverges from a larger branch. Look for cut branches with the lighter color of the inner wood visible, pruning scars, open wounds, a branch collar not completely healed over, etc. Any pruning scars that are mostly or completely healed over do not count as recent pruning because such pruning is likely to have occurred at the nursery and to not have been performed by an individual responsible for the recently planted tree.

If there is more than one recently pruned branch on a tree, consider all pruned branches when determining correct or incorrect *Pruning*, and record "correct" or "incorrect" based on the majority of pruning cuts evident.

V35 Maintenance: Mulching

Mulching is defined as any effort to place organic or inorganic materials around the base of the tree to prevent weed growth or water loss. Mulch is usually an organic material made of shredded or chipped tree or shrub trimmings, such as wood chips or shredded bark. Inorganic mulching materials such as rubber or plastic pellets are also sometimes used. (For more descriptions of mulch see ***Table V22-23*** on ground cover types.) Correctly mulched trees may better withstand drought because moisture is retained in the mulched soil. Mulch also provides protection from mower damage that might otherwise occur during cutting the grass surrounding the base of the tree. Mulching, like pruning, is usually a well-intentioned effort to care for the tree, whether or not it is done correctly. Evidence of mulching and whether any mulching appears to have been done correctly may be an important indicator that the tree is being actively maintained and cared for by someone.

Mulching is recorded as a categorical variable, with possible values of correct, incorrect, and none (***Table V35***). Examine the base of the trunk and ground underneath the tree and look for organic mulch (e.g., wood chips, shredded bark, and even saw dust or intentionally placed leaves or pine needles) and inorganic mulch (e.g., plastic or rubber pellets). "Correct" *Mulching* is defined as no more than 5 cm (2") of mulch distributed in a 'donut' shape within the dripline, pulled 5-15 cm (2-6") away from the base of the trunk so as not to suffocate the tree and encourage adventitious roots growing into the mulch from the aboveground portion of the trunk (***Figure V35***). "Incorrect" *Mulching* is defined as mulch piled up around the base of the trunk in a 'volcano' formation (***Figure V35***) or excess depth of mulch (i.e., over 5 cm or 2"). Note that correct versus incorrect mulching does not consider the type of mulch used (this is captured by V22, *Ground Cover At Base*) but simply the amount and placement of mulch. Mulch so old that only a few pieces of larger bark shreds or wood chips remain visible is considered to be no mulch (*Mulching* equals a value of "none").

Table V35. Explanation of *Mulching* values.

Mulching value	Explanation
Correct	Mulch less than 5 cm (<2") deep is approximately evenly distributed in a 'donut' shape around the base of the tree and under the canopy. See Figure V35, panel a.
Incorrect	Mulch is greater than 5 cm (>2") deep piled up around the base of the tree in a 'volcano' formation. See Figure V35, panel b.
None	Mulch is not present, or is very old and visible only in the form of a few remaining wood chips or bark fragments.

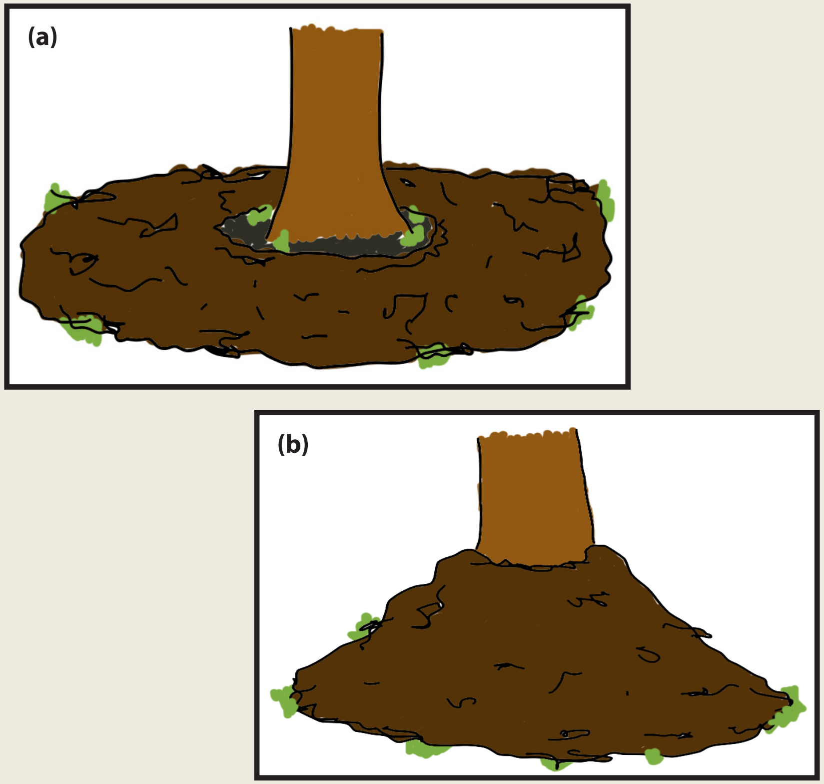


Figure V35. Diagram of the location of correct and incorrect *Mulching*. (a) Correct mulch is evenly distributed around the base of the tree and under the canopy, but is pulled 5-15 cm (2-6”) away from root flare, forming a ‘donut’ shape. **(b)** Incorrect mulch is piled up around the base and trunk of the tree in a ‘volcano’ formation.

V36

Maintenance: Staking

Staking is defined as an effort to hold a tree in place and keep it from being knocked down or blown over. There are many methods of staking, including some that only use ropes to hold the tree upright and no stakes at all. Staking, like mulching and pruning, is usually a well-intentioned effort to care for the tree, whether or not it is done correctly. Correct staking on a recently

planted tree may be an indicator that the tree is being cared for and maintained. Incorrect staking, however, such as a stake not removed at the proper time, may be an indicator that the tree is not actively being cared for.

Staking is recorded as a categorical variable, with possible values of correct, incorrect, and none (***Table V36***). Look for one or more stakes holding the tree upright. “Correct” *Staking* implies that the stake or ropes are not pulling the tree over in one direction or the other and the stake line is not girdling the tree because it is tied too tight or the tree has out-grown the line. “Incorrect” *Staking* occurs when stake line is girdling the tree, a stake is pulling the tree over, the stake is placed too close to the trunk of the tree (the tree may be growing into the stake), the staking line is snapped but still tied to the tree, or when other staking methods harm the tree. Note that a stake with nothing tying it to the tree (and nothing around the tree that might have been tied to the stake) should be noted in notes, but enter “none” for *Staking*.

Table V36. Explanation of *Staking* values.

Staking value	Explanation
Correct	Stake and line are correctly attached to the tree, providing support but not pulling the tree over in one direction or the other or otherwise injuring the tree.
Incorrect	Tree is staked, but incorrectly (tree may be pulled over by the stake, a stake line or rope girdling the tree or digging into the bark, etc.). Note that a leaning tree does not necessarily indicate incorrect staking, because the stake may in fact be an attempt to correct the lean.
None	No evidence of staking. No remaining stake or staking line around the tree *OR* Present stake but nothing remains tying the stake to the tree and the stake is out of the way of trunk growth.

Community

The set of *Community* variables in the Protocol includes indicators of an ethic of tree care in the people near the tree.

Evidence of Care

V37 - V41 Evidence of Care

The evidence of care variables are other actions individuals can take that indicate an ethic of care for the tree and surrounding area, outside of the tree-specific maintenance practices described in the previous section. Evidence of care for a tree may indicate a sense of ownership and responsibility that someone may have for that tree, and may be related to improved tree condition, survival and growth rate. The five variables included in this Protocol were adapted from the Site Assessment Tools used by the New York City Parks & Recreation Department in their Young Street Tree Mortality study.[8] Once collected, these variables could be summed together (*Water Bag* + *Bench* + *Bird Feeder* + *Yard Art* - *Trash/Debris*) to get an index of care.

Evidence of care variables are recorded as presence/absence variables, where 1 indicates the presence of a particular type of care and 0 its absence (***Table V37-41***). Care variables include presence of the following: a *Water Bag* (V37; e.g., Gator Bag, irrigation bag) around the trunk of the tree, a *Bench* (V38) or chair near the tree, a *Bird Feeder* (V39) or birdhouse hung in the tree, *Yard Art* (V40; e.g., lawn gnomes, spinning fans, decorative rocks or shells, statues or icons, lights in the tree, etc.) near the tree, or *Trash/Debris* (V41) in or near the tree. Note that the *Water Bag* variable (V37) actually has three possible values: Present, filled; Present, dry; or Absent.

8 http://www.nycgovparks.org/trees/ystm

Table V37-41. Explanation of evidence of care variables. Only presence (1) values are explained; absence (0) should be recorded for trees that do not meet the definition of present evidence of this particular type of care. Note that "presence" for *Water Bag* has two possible options: Present, filled or Present, dry.

Care variable	Explanation of presence (1) value
V37 Water Bag	Water bags, also called irrigation bags or Gator Bags, are plastic or canvas bags around the trunk and/or base of the tree. When filled, they slowly release water to the roots of the tree through a porous bottom. A water bag can either be filled or partially filled with water ("Present, filled"), i.e., not dry, or not filled with any water ("Present, dry").
V38 Bench	A bench or chair or similar is attached to or very near (within ~1 m [3 ft] of) the tree.
V39 Bird Feeder	A bird feeder, house or water dish is in or near the tree; may be hung from a branch of the tree or on a separate post very near (within ~1 m [3 ft] of) the tree.
V40 Yard Art	Yard art is in or near the tree; yard art includes but is not limited to lawn gnomes, ornaments, spinning fans, decorative rocks or shells, statues or icons, lights in the tree, etc.
V41 Trash/Debris	Trash or debris can be at or near the base of the tree or in the canopy itself.

Additional Notes

The *Additional Notes* field is an important place to record information about the tree that is not captured by any of the 41 variables discussed above. Additional notes on a tree become particularly important when the tree does not fit any of the possible values of a categorical variables (e.g., when "Other, permeable" is chosen for *Ground Cover At Base* or *Ground Cover Under Canopy*). Additional notes can also be a place for data collectors to write important notes to whomever will be analyzing and interpreting the tree inventory data.

V.

Suggestions for Summarizing Data

Once you have inventoried your trees, you should organize the data into an Excel spreadsheet with data for each variable in a single column (much like the sample paper data sheets on the previous pages of this booklet). Each row is data on one tree with a unique *Tree ID#.* All of the trees that you have gathered data on are now part of the re-inventoried tree sample. There are many ways that the data can be summarized and displayed. The following section suggests just a few useful metrics and figures to present your data. For examples of statistics and figures, we use re-inventory data that the Bloomington Urban Forestry Research Group gathered on a sample of trees planted by Keep Indianapolis Beautiful, Inc. through their NeighborWoods program.[9] All metrics and figures were created using Microsoft Excel. If you are interested in more sophisticated statistical analyses, we recommend partnering with local university faculty who can perform these types of analyses for you (see page 77).

Tree Outcome Variables

Survival and Mortality Rates

The *survival rate* for a sample of trees is simply the proportion of all trees planted that are still living at re-inventory. Conversely, the *mortality rate* for a sample of trees is the proportion of all trees planted that are dead (or missing/absent) at the time of sampling. The survival rate plus the mortality rate should equal 1.

9 NeighborWoods is a national program of the Alliance for Community Trees.

Survival and mortality rates can be calculated from *Overall Tree Condition* (V14), according to ***Equations [1]*** and ***[2]***.

$$\text{Survival rate} = \frac{\text{\# trees in "Good", "Fair" or "Poor" } \underline{\textit{Overall Tree Condition} \text{ categories}}}{\text{Total \# of trees in re-inventory sample}} \quad [1]$$

$$\text{Mortality rate} = 1 - \text{Survival rate} \quad [2]$$

Survival rate or mortality rate can be calculated for the entire sample of trees, as well as for individual planting projects, neighborhoods, planting years, species, or other variables of interest. ***Figure 3*** shows survival rates by neighborhood for the re-inventoried sample of KIB trees.

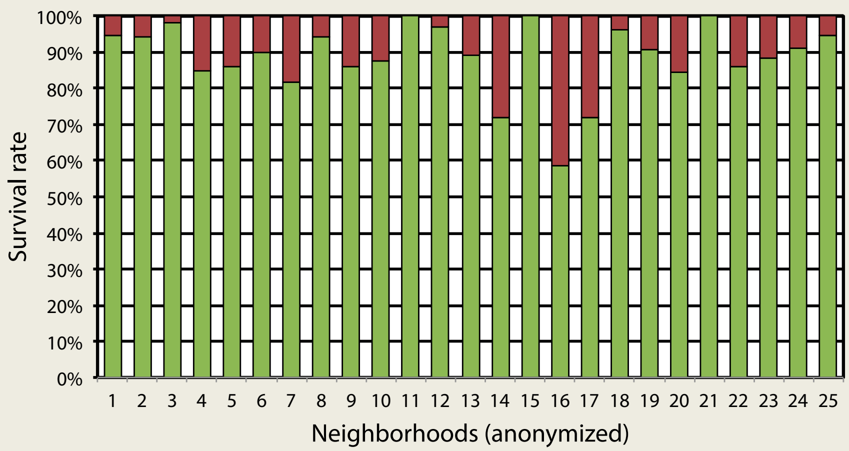


Figure 3. Survival rate by neighborhood for a sample of Keep Indianapolis Beautiful, Inc. tree plantings.

Calculating survival rates also allows you to separate out a sub-sample of only living trees that can be used to assess tree growth and condition. This living sub-sample (the number of trees in alive *Overall Tree Condition* categories, or where V14 = "Good", "Fair" or "Poor"[10]) will be used in all analyses of living trees that are presented from here on.

Size and Growth Rate

Average size of the re-inventoried tree population can be presented in terms of *average tree height* or average tree diameter at breast height (*average DBH*). Average metrics like these can be calculated for the entire population, just for a particular neighborhood or tree planting project, for a single planting year, a single species of tree, or for particular types of planting areas. ***Table 2*** displays the average DBH and height for trees by planting year for a sample re-inventory of KIB trees.

Table 2. Average tree size by year for a sample of Keep Indianapolis Beautiful, Inc. tree plantings.

Planting year	Avg tree DBH (cm)	Avg tree height (m)
2006	6.94	3.8
2007	6.24	3.7
2008	4.74	3.3
2009	3.37	2.7
2010	2.10	2.1

The size of the sampled trees can also be presented in a frequency or distribution chart. A DBH distribution chart divides trees into size categories by DBH. For instance, by counting up the number of trees in 2-cm DBH categories (e.g., # of trees between 2 and 4 cm, # of trees between 4 and 6 cm, etc.) a DBH distribution chart such as that in ***Figure 4*** can be created.

If your organization recorded tree size at planting in terms of DBH, caliper or height, you can calculate the average annual growth rate of trees in the sample. *Annual growth rate since planting* for each individual tree can be calculated according to

10 Note that although trees receiving a Condition rating of "Sprouts" are technically still alive, because these are not a tree form as planted, they are not included in the sample of alive trees.

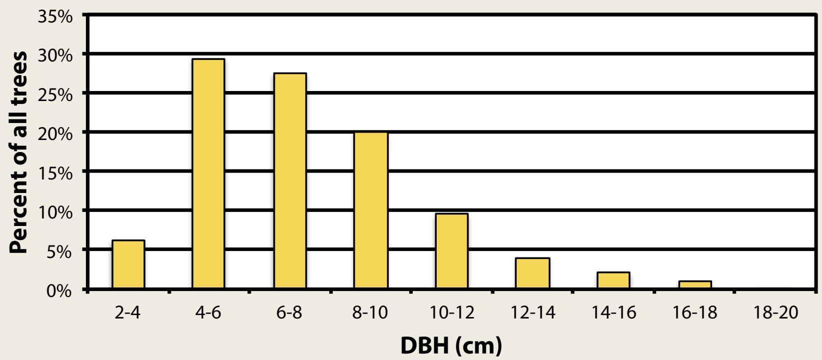


Figure 4. Distribution of sample Keep Indianapolis Beautiful, Inc. trees by 2-cm diameter at breast height (DBH) categories.

Equation [3], where size is height, DBH, or caliper. Years since planting should be measured in the most accurate form possible, ideally number of days since planting divided by 365.[11] This ensures that growth rate is accurately calculated.

$$\text{Annual growth rate since planting} = \frac{\text{current size} - \text{size at planting}}{\text{years since planting}} \qquad [3]$$

Make sure that the same size metric is used for both current size and size at planting (e.g., re-inventoried caliper and caliper at planting). Annual growth rate can be displayed in similar ways to average size. ***Figure 5*** displays the average annual caliper growth rate (and standard deviation) by genus for sample KIB trees.

Condition

Overall tree condition can be displayed by itself (e.g., as a pie chart; ***Figure 6***) or sorted by category, like planting project,

11 Microsoft Excel can easily calculate the number of days since planting by using a formula that subtracts the planting date from the date of data collection. Divide by 365 to calculate years since planting.

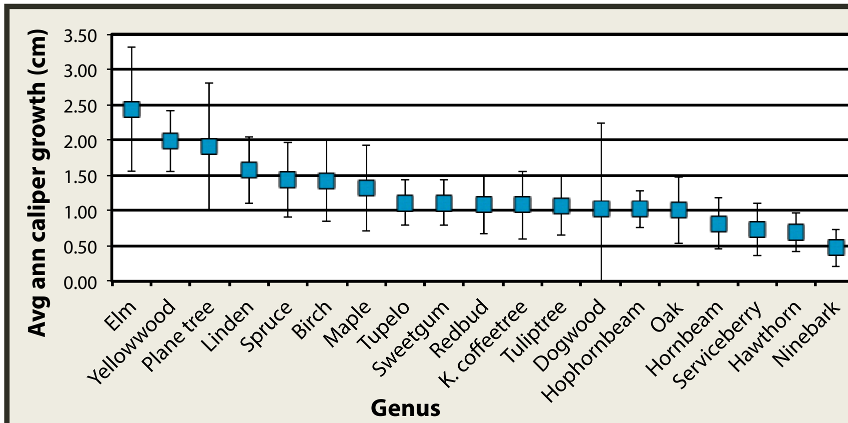


Figure 5. Average annual caliper growth rate (cm) by genera for a sample of Keep Indianapolis Beautiful, Inc. trees. Error bars show 1 standard deviation above and below the average. Standard deviation is a measure of variation around the average.

neighborhood, species, planting area type, etc. ***Figure 7*** displays overall tree condition class ratings by planting area types for sample KIB trees. The x-axis currently displays data by planting area type. This could be replaced with any of the other variables of interest. Overall condition should usually be displayed only for those living trees in the sample.

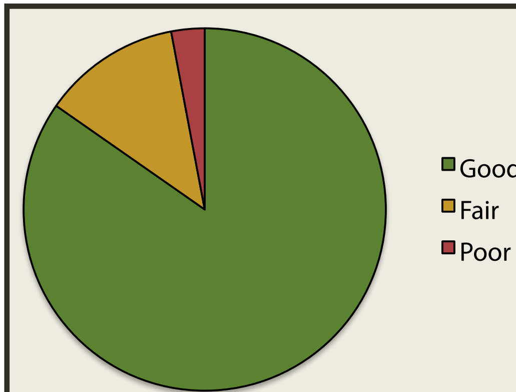


Figure 6. Overall tree condition for a sample of Keep Indianapolis Beautiful, Inc. trees.

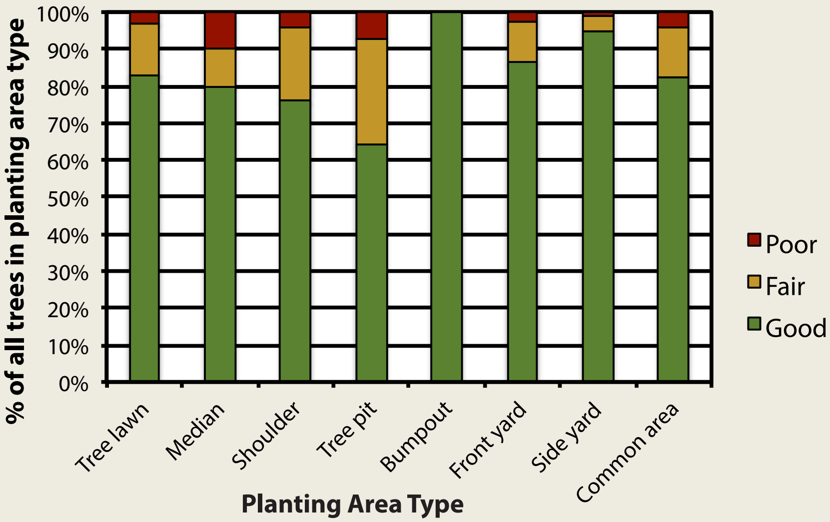


Figure 7. Overall tree condition by planting area type for a sample of Keep Indianapolis Beautiful, Inc. trees.

How are Tree Outcomes Related to Other Variables?

The key question this Protocol enables organizations to answer is this: "How are tree outcomes - namely survival, growth, and condition - related to other variables, including local environmental factors, management efforts, and social factors?" As demonstrated above, we can compare tree survival rates, annual growth rates, and condition class ratings between different categories of a variable. For instance, we can compare average annual growth rates for trees that exhibit evidence of correct pruning with those trees that exhibit evidence of incorrect pruning, or no pruning. Or we could compare survival rates between trees with gator bags and those without. Or we could compare the proportion of trees in "good" condition between trees with and without mulch. The possibilities are endless once you have the data collected!

Make Partnerships with Local Universities

Once you have a dataset for your re-inventoried trees, instead of summarizing the data yourself, you could contact a local university or university extension office to establish a partnership. A partnership with a university has many advantages. University partnerships can provide you with sophisticated analysis and reports about your trees, often for very little or even no cost to your organization. Professors may be looking for service-learning opportunities for their classes or they might be looking for data for a research project. Students may be looking for data for class projects or they may be interested in an internship opportunity with your organization analyzing tree data. Researchers at universities can also provide you with a comparison of your organization's trees to trees in other cities presented in the literature. A partnership with a research university may also be a way for your organization to leverage additional funding, including grant and contract opportunities, as well as new fundraising sources. Ultimately, a collaborative partnership with a university or extension office benefits both you and the university.

A Final Cautionary Note on Inventories

Caution is always advised in interpreting tree data, and we do not advise making program or management changes based on the findings of an inventory alone. You should always consider the data from an inventory in the context of your organization's entire tree planting and management program and in the context of the local community and neighborhood in which trees are planted.

VI.

Additional Resources & References

Bond, Jerry, and Beth Buchanan. 2006. **Best Management Practices: Tree Inventories.** Champaign, IL: International Society of Arboriculture.

Available for purchase at the ISA Web Store: http://www.isa-arbor.com/store/product.aspx?ProductID=137.

Clark, James R., Nelda P. Matheny, Genni Cross, and Victoria Wake. 1997. **"A Model of Urban Forest Sustainability."** *Journal of Arboriculture* 23 (1): 17–30.

PDF available for download at the *Arboriculture & Urban Forestry/ Journal of Arboriculture* website: http://auf.isa-arbor.com/articles.asp?JournalID=1&VolumeID=23&IssueID=1

Fischer, Burnell C., Michael Steinhoff, Sarah Mincey, and Lance Dye. 2007. The 2007 Bloomington Street Tree Report: An Analysis of Demographics and Ecosystem Services. Bloomington Urban Forestry Report 01-07. 30 pp.

PDF available for download at: http://www.indiana.edu/~cipec/research/bufrg_publications.php.

Iakovoglou, Valasia, Janette Thompson, Lee Burras, and Rebecca Kipper. 2001. **"Factors Related to Tree Growth Across Urban-rural Gradients in the Midwest, USA."** *Urban Ecosystems* 5: 71–85.

International Union of Forest Research Organizations (IUFRO), International Society of Arboriculture (ISA), United States Forest Service (USFS), and Urban Natural Resources Institute (UNRI). 2010. **Standards for Urban Forestry Data Collection: A Field Guide, Draft 2.0.** Urban Natural Resources Institute.

PDF available for download at: http://www.unri.org/standards/wp-content/uploads/2010/08/Version-2.0-082010.pdf.

Kozlowski, Theodore T., & Stephen G. Pallardy. (1997). ***Growth Control in Woody Plants***. San Diego, CA: Academic Press, Inc.

New York City (NYC) Parks & Recreation, United States Department of Agriculture Forest Service Northern Research Station (USFS-NRS), Rutgers University, and The New School For Design Parsons. 2010. New York City's Young Street Tree Mortality Study Site Assessment Tools Description. New York City, NY.

PDF available for download at: http://www.nycgovparks.org/sub_your_park/trees_greenstreets/images/how_to_assess_your_citys_st_survival_10-6-2010.pdf.

Ostrom, Elinor. 2009. **"A General Framework for Analyzing Sustainability of Social-ecological Systems."** *Science* 325 (5939): 419–422. doi:10.1126/science.1172133.

Ostrom, Elinor, & Michael Cox. 2010. **"Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis."** *Environmental Conservation* 37(4): 451–463. doi:10.1017/S0376892910000834

Appendix A:

Sources of Variable Collection Methods

The methods for collecting some of the variables in the Protocol were modified from other tree inventory methods and protocols. The table below provides citations to these sources (including page numbers), if applicable. Complete source citations are provided in References.

Variable	Name	Modified from... *(if applicable)*
V1	*Tree ID#*	
V2	*Location*	
V3	*Species*	IUFRO et al. 2010: p. 1
V4	*DBH*	IUFRO et al. 2010: p. 2-3
V5	*Caliper*	
V6	*Total Height*	IUFRO et al. 2010: p. 3
V7	*Height to Crown*	IUFRO et al. 2010: p. 3-4
V8	*Crown Dieback*	IUFRO et al. 2010: p. 8
V9	*Crown Exposure*	IUFRO et al. 2010: p. 4-5
V10	*Chlorosis*	
V11	*Root Flare*	IUFRO et al. 2010: p. 23
V12	*Lower Trunk Damage*	
V13	*Other Damage*	
V14	*Overall Tree Condition*	Fischer et al. 2007, appendix
V15	*Utility Interference*	IUFRO et al. 2010: p. 9
V16	*Building Interference*	IUFRO et al. 2010: p. 9
V17	*Fences Interference*	IUFRO et al. 2010: p. 9
V18	*Sign Interference*	IUFRO et al. 2010: p. 9
V19	*Lighting Interference*	IUFRO et al. 2010: p. 9

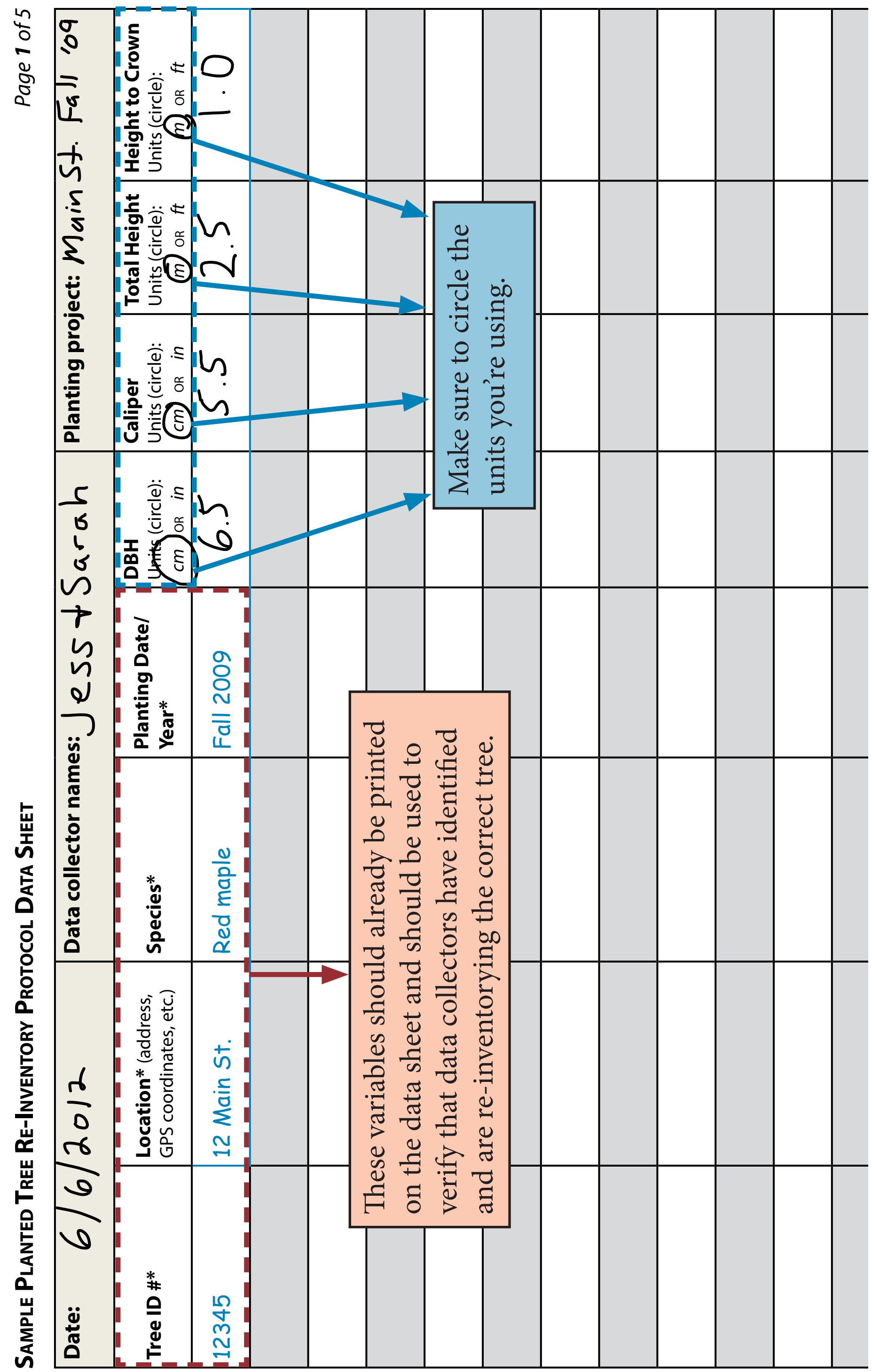
Variable	Name	Modified from... *(if applicable)*
V20	*Pedestrian Traffic Interfer-ence*	IUFRO et al. 2010: p. 9
V21	*Road Traffic Interference*	IUFRO et al. 2010: p. 9
V22	*Ground Cover At Base*	IUFRO et al. 2010: p.14
V23	*Ground Cover Under Can-opy*	IUFRO et al. 2010: p. 14
V24	*Planting Area Type*	
V25	*Planting Area Relative to Road*	
V26	*Planting Area Width*	IUFRO et al. 2010: p. 15-16
V27	*Planting Area Length*	
V28	*Curb Presence*	NYC et al. 2010: p. 20
V29	*Number of Trees In 10-m Radius*	Iakovoglou et al. 2001: p. 75
V30	*Number of Trees In 20-m Radius*	Iakovoglou et al. 2001: p. 75
V31	*Number of Trees In Same Planting Area*	
V32	*Distance To Road*	IUFRO et al. 2010: p. 16
V33	*Distance To Building*	IUFRO et al. 2010: p. 9
V34	*Pruning*	NYC et al. 2010: p. 22
V35	*Mulching*	
V36	*Staking*	
V37	*Water Bag*	NYC et al. 2010: p. 22
V38	*Bench*	NYC et al. 2010: p. 22
V39	*Bird Feeder*	NYC et al. 2010: p. 22
V40	*Yard Art*	NYC et al. 2010: p. 22
V41	*Trash/Debris*	

Appendix B:

Sample Data Collection Sheets

The following pages provide snapshots of sample paper data collection sheets for all variables in the Protocol. The top row of each data sheet is filled out with a sample data collection entry for a hypothetical tree, and important characteristics of the data sheet are highlighted and explained.

A full-page PDF version of the set of data sheets as well as a modifiable and printable Microsoft Excel version are available on the Bloomington Urban Forestry Research Group (BUFRG) webpage: http://www.indiana.edu/~cipec/research/bufrg_protocol.



Sample Planted Tree Re-Inventory Protocol Data Sheet

Date: 6/6/2012		Data collector names: Jess + Sarah			Planting project: Main St. Fall '09		
Tree ID # (same as page 1)	**Crown Dieback** (0, 1, 2, 3, 4, 5, 6)	**Crown Exposure** (0, 1, 2, 3, 4, 5)	**Chlorosis** (1 = Present)	**Root Flare** (1 = Present)	**Lower Trunk Damage** (1 = Present)	**Other Damage** (1 = Present)	**Overall Tree Condition** (Good, Fair, Poor, Dead, Sprouts, Stump, Absent)
12345	0	4	0	1	1	0	Good

Tree ID#'s for all trees for which data is being collected should be printed in the far left hand column on every page.

For trees that are absent, only fill out the *Overall Tree Condition* variable. Write down a dashed line (--) or "n/a" (for not applicable) for all other variables, because you cannot assess the Protocol variables for absent or missing trees.

Sample Planted Tree Re-Inventory Protocol Data Sheet

Date: 6/6/2012		Data collector names: Jess + Sarah					Planting project: Main St. Fall '09		
Tree ID # (same as page 1)	**Interference with Infrastructure** (1 = Present)							**Ground Cover...**	
	Utility	**Building**	**Fences**	**Signs**	**Lighting**	**Pedestrian Traffic**	**Road Traffic**	**At Base**	**Under Canopy**
12345	0	0	0	1	0	1	0	Soil	Grass

Make sure to fill in the top portion of the data sheet with the date, data collectors names and planting project name *on every data sheet.*

Sample Planted Tree Re-Inventory Protocol Data Sheet

Date: 6/6/2012 | **Data collector names:** Jess + Sarah | **Planting project:** Main St. Fall '09

Tree ID # (same as page 1)	Planting Area — Units (circle): (m) OR ft				Curb Presence (1 = Present)	Number of Trees In...			Distance To... Units (circle): (m) OR ft	
	Type	Relative to Road	Width	Length		10 m	20 m	Same Planting Area	Road	Building
12345	Tree Lawn	above	3.0	5.5	1	1	3	1	1.6	15.5

Make sure to circle the units you're using.

Sample Planted Tree Re-Inventory Protocol Data Sheet

Date: 6/6/2012 | **Data collector names:** Jess + Sarah | **Planting project:** Main St. Fall '09

Tree ID # (same as page 1)	Maintenance (correct, incorrect, none)			Evidence of Care 1 (Present) or 0 (Absent)					Additional Notes
	Pruning	Mulching	Staking	Water Bag	Bench	Bird Feeder	Yard Art	Trash/ Debris	
12345	none	none	none	0	0	1	0	0	chlorosis ~10% LSA

In the final column, put any additional notes about the tree that might be useful later. This should be the last thing filled in by data collectors before moving on to the next tree on the list. The note above for the sample tree lets us know that at the time the inventory was conducted, approximately 10% of the leaf surface area (LSA) showed chlorosis.

Appendix C:

(Online)
Quick Field Reference

A Quick Field Reference, containing definitions and possible values for all variables in the Protocol, may be useful to carry with you during data collection. Full-page, color and black and white PDF versions of the Quick Field Reference are available on the Bloomington Urban Forestry Research Group (BUFRG) webpage: http://www.indiana.edu/~cipec/research/bufrg_protocol.

Glossary

This glossary provides definitions for select terms in the context of the Planted Tree Re-Inventory Protocol. Variables appear in italic text, with page number references to their complete descriptions in Section IV.

Biophysical environment: The physical and biological growing environment (soils, etc.) surrounding a tree. This is one of four systems in the "Urban Forests as Social-Ecological Systems Framework."

Branch collar: A slight bulge of differently-textured bark where a smaller branch grows from a larger branch.

***Caliper*:** (V5) The diameter of the trunk of a tree at 15 cm (6") above the first lateral root. Typically measured for small trees that are not yet tall enough for DBH measurement.

Canopy: see Crown.

***Chlorosis*:** (V10) Chronic yellowing of the portion of leaves in between the veins, usually caused by nutrient deficiencies.

Clinometer: A mechanical instrument that can be used to measure the height of an object.

Community: The community of resource users and beneficiaries is the individuals or groups that use and benefit from the urban forest. This is one of four systems in the "Urban Forests as Social-Ecological Systems Framework."

Coniferous tree: Trees with needles that retain these needles and remain green year round.

Crown: The branches and leaves that make up the green leafy tops of a deciduous tree, or the branches and needles comprising the top of a coniferous tree. Also known as a Canopy.

Deciduous tree: Trees that lose their leaves in the winter.

***Diameter at breast height (DBH)*:** (V4) The diameter, or width, of the main trunk of the tree at "breast height," officially 1.37 m (4.5 ft) from the base of the tree.

DBH tape: A specialized measuring tape that allows a data collector to measure the diameter of a round object like a tree by wrapping the tape around the circumference of the object. Sometimes called a "D-tape."

Dripline: The outer lateral extent of branches in the tree canopy. Imagine a cylinder extending from the outer extent of the canopy down to the ground, and the dripline is where this cylinder meets the ground.

Establishment phase: The first growing phase of a transplanted tree, during which below ground root growth dominates above ground trunk and canopy growth. The establishment phase is typically 2 years for trees 3-5 cm (1-2") in caliper at planting.

Girdling: Depriving a tree of its ability to transport water and nutrients up and down the tree from the roots to the canopy. Can occur when a lawnmower or weed whip damages both the outer and inner bark in a ring around the tree, or when a tree's own roots encircle the base of the tree, effectively strangling the tree.

Global positioning system (GPS): A global system of satellites that enables receivers positioned on the ground to determine the location of any GPS-capable device in the form of longitude and latitude (X and Y coordinates).

GPS unit: A piece of technology with GPS capabilities that provides accurate information about location in the form of longitude and latitude (X and Y coordinates).

Graft: A visible bulge at the base of a tree where a root stock was grafted onto a shoot. Grafting is done to join a root stock with reliable characteristics (e.g., of a cultivar or species that does well in the confined rooting spaces available in urban areas) to the above ground portion of the desired tree species.

Growing season: The summer months during which the tree's roots and above ground trunk are growing and the leaves are photosynthesizing.

Hypsometer: Also called a range finder. A digital version of a clinometer which measures angles, linear distances, and heights with the click of a button and can be used to measure dimensions in the local environment (e.g., distance to nearest road or building, etc.).

Institutions: Formal and informal rules and strategies that govern how people and groups of people interact with one another and with the physical world. This is one of four subsystems in the "Urban Forests as Social-Ecological Systems Framework."

Inventory: A set of methods used to take stock of the trees planted in a city. This Protocol provides methods for inventorying trees years after they have been planted, a *re-inventory*.

Lateral root: The highest root that extends outwards from the trunk of the tree just beneath the surface of the soil.

Permeable: A ground surface that water can pass through. Grassy areas or soil are permeable surfaces. Paved areas like sidewalks and roads are not permeable surfaces.

Photosynthesis: The conversion of light energy, carbon dioxide and water to sugar and oxygen by plants, including trees.

Planted Tree Re-Inventory Protocol: A set of guidelines and instructions for gathering data on urban trees. The protocol enables tree-planting organizations to monitor the survival, growth and condition of their trees.

Random sampling: A method of selecting units (trees) for study. In this process, trees are assigned a unique identification number and trees are selected at random until the number of selected trees is equal to the desired size of the sample.

Resolution: The scale in which numerical measurements are recorded, e.g., "to the nearest 0.5 m" or "to the nearest 0.1 cm."

Root zone: The below ground growing space for a tree's roots. Roots are densest in the top 6-18" (15-45 cm) of soil, and generally do not grow much deeper than about 3 ft or 1 m.

Species code: Standardized shorthand for plant identification developed by the United States Department of Agriculture (USDA). A full list of all species codes as used by the USDA can be found at the PLANTS Database website: http://plants.usda.gov.

Stratified sampling: A method of selecting units (trees) for a sample that selects the same number of units in each of two or more categories (e.g., X # of trees in each of Y # neighborhoods).

Systematic sampling: A method of selecting units (trees) for a sample that uses an interval. For example, one might sample every 10th planted tree along a street. In contrast to Random sampling.

Urban Forests as Social-Ecological Systems (UFs as SESs) Framework: A framework that models the urban forest by four interacting systems—the trees, the biophysical environment, the surrounding community, and the institutions and management that govern local tree maintenance.

About BUFRG

The Indiana University **Bloomington Urban Forestry Research Group** at CIPEC (BUFRG) has been conducting research on urban forests since Dr. Burnell C. Fischer collaborated with City of Bloomington Urban Forester Lee Huss in 2007 to conduct Bloomington's first complete street tree inventory. Since this time, Fischer has amassed a cast of Indiana University students who collaborate with each other and with urban forest researchers and practitioners across the country to study urban forests as social-ecological systems. BUFRG was formally organized in the fall of 2012, when the group received the 2012 inaugural Indiana University Campus Sustainability Award for Excellence in Research. BUFRG is housed within the Center for the Study of Institutions, Populations and Environmental Change (CIPEC), a research center of the Office of the Vice Provost for Research at Indiana University, Bloomington.

More information about BUFRG can be found on our website: http://www.indiana.edu/~cipec/research/bufrg_about.php.

More information about the Center for the Study of Institutions Populations and Environmental Change can be found at the CIPEC website: http://www.indiana.edu/~cipec/.

Bloomington Urban Forestry Research Group at CIPEC

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The following documents and supporting files related to the Planted Tree Re-Inventory Protocol can be found on the Bloomington Urban Forestry Research Group website:
(http://www.indiana.edu/~cipec/research/bufrg_protocol)

- A full-color, printable, PDF version of the Protocol;
- A black-and-white, printable, PDF version of the Protocol;
- Printable PDF and Microsoft Excel versions of the Sample Data Collection Sheets; and,
- A printable PDF version of the Quick Field Reference.

Please contact Burnell C. Fischer (bufische@indiana.edu) or Jessica Vogt (jessica.m.vogt@gmail.com) with questions or comments.

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ACTrees
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