CITY FOREST CREDITS

Appendix B

# Quantification Methods for Tree Planting Projects

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This Appendix B on Quantification for Tree Planting Projects consists of two Parts. Part 1 contains a description of the science and methods underlying quantification of $CO_2$ and co-benefits in city trees.

Part 2 contains a Summary of Quantification Steps, followed by a longer section entitled Quantification Methods and Examples, which provides a more detailed walk-though of quantification methods using examples.

The principal author of this Appendix B on Quantification is Dr. E.G. McPherson. Dr. McPherson also led the science teams that developed quantification methods for the State of California Air Resources Board Urban Forest Carbon Protocol in 2011 and the Climate Action Reserve Urban Forest Protocols in 2014.

**Note that quantification methods for Tree Preservation Projects, as distinct from Tree Planting Projects, are contained within the Tree Preservation Protocol.**

# Part 1

## Quantifying Carbon Dioxide Storage and Co-Benefits for Urban Tree Planting Projects

### Introduction

Ecoservices provided by trees to human beneficiaries are classified according to their spatial scale as global and local (Costanza 2008) (citations in Part 1 are listed in References at page 16). Removal of carbon dioxide ($CO_2$) from the atmosphere by urban forests is global because the atmosphere is so well-mixed it does not matter where the trees are located. The effects of urban forests on building energy use is a local-scale service because it depends on the proximity of trees to buildings. To quantify these and other ecoservices City Forest Credits (CFC) has relied on peerreviewed research that has combined measurements and modeling of urban tree biomass, and effects of trees on building energy use, rainfall interception, and air quality. CFC has used the most current science available on urban tree growth in its estimates of $CO_2$ storage (McPherson et al., 2016a). CFC's quantification tools provide estimates of co-benefits after 25 years in Resource Units (i.e., kWh of electricity saved) and dollars per year. Values for co-benefits are first-order approximations extracted from the i-Tree Streets (i-Tree Eco) datasets for each of the 16 U.S. reference cities/climate zones (https://www.itreetools.org/tools/i-tree-eco) (Maco and McPherson, 2003). Modeling approaches and error estimates associated with quantification of $CO_2$ storage and co-benefits have been documented in numerous publications (see References below) and are summarized here.

## Carbon Dioxide Storage

There are three different methods for quantifying carbon dioxide (CO2) storage in urban forest carbon projects:

- Single Tree Method - planted trees are scattered among many existing trees, as in street, yard and school plantings, individual trees are tracked and randomly sampled
- Tree Canopy Method for Park-like Projects- planted trees are relatively contiguous in park-like settings and change in canopy is tracked
- Tree Canopy Method for Riparian Projects – trees are planted very close together, significant mortality is expected, and change in canopy is tracked. The two main goals are to create a forest ecosystem and generate canopy.

In all cases, the estimated amount of $CO_2$ stored 25-years after planting is calculated. The forecasted amount of $CO_2$ stored during this time is the value from which the Registry issues credits in the amounts of 10%, 40% and 30% at Years 1, 4, and 6 after planting, respectively. A 20% mortality deduction is applied before calculation of Year 1 Credits in the Single Tree and Canopy Methods. A 5% buffer pool deduction is applied in all three methods before calculation of any crediting, with these funds going into a program-wide pool to insure against catastrophic loss of trees. At the end of the project, in year 25, Operators will receive credits for all $CO_2$ stored, minus credits already issued.

In the Single Tree Method, the amount of $CO_2$ stored in project trees 25-years after planting is calculated as the product of tree numbers and the 25-year $CO_2$ index (kg/tree) for each tree-type (e.g., Broadleaf Deciduous Large = BDL). The Registry requires the user to apply a 20% tree mortality deduction before calculation of Year 1 Credits. Year 4 and Year 6 Credits depend on sampling and mortality data. A 5% buffer pool deduction is applied as well before calculation at any stage.

In the Tree Canopy Method for Park-like Projects, the amount of $CO_2$ stored after 25-years by planted project trees is based on the anticipated amount of tree canopy area (TC). Because different tree-types store different amounts of $CO_2$ based on their size and wood density, TC is weighted based on species mix. The estimated amount of TC area occupied by each tree-type is the product of the total TC and each tree-type's percentage TC. This calculation distributes the TC area among tree-types based on the percentage of trees planted and each tree-type's crown projection area. Subsequent calculations reduce the amount of $CO_2$ estimated to be stored after 25 years based on the 20% anticipated mortality rate and the 5% buffer pool deduction.

In the Tree Canopy Approach for Riparian Projects, the forecasted amount of $CO_2$ stored at 25-years is the product of the amount of TC and the $CO_2$ Index (CI, t $CO_2$ per acre). This approach recognizes that forest dynamics for riparian projects are different than for park projects. In many cases, native species are planted close together and early competition results in high mortality and rapid canopy closure. Unlike urban park plantings, substantial amounts of carbon can be stored in the riparian understory vegetation and forest floor. To provide an accurate and complete accounting, we use the USDA Forest Service General Technical Report NE-343, with biometric data for 51 forest ecosystems derived from U.S. Forest Inventory and Assessment plots (Smith et al., 2006). The tables provide carbon stored per hectare for each of six carbon pools as a function of stand age. We use values for 25-year old stands that account for carbon in down dead wood and forest floor material, as well as the understory vegetation and soil. If local plot data are provided, values for live wood, dead standing and dead down wood are adjusted following guidance in GTR NE-343. More information on methods used to prepare the tables and make adjustments can be found in Smith et al., 2006. See Attachment A at the end of this Appendix for more information on the Riparian Canopy Method.

## Source Materials for Single Tree Method and Canopy for Park-like Projects Methods

Estimates of stored (amount accumulated over many years) and sequestered $CO_2$ (i.e., net amount stored by tree growth over one year) are based on the U.S. Forest Service's recently published technical manual and the extensive Urban Tree Database (UTD), which catalogs urban trees with their projected growth tailored to specific geographic regions (McPherson et al. 2016a, b). The products are a culmination of 14 years of work, analyzing more than 14,000 trees across the United States. Whereas prior growth models typically featured only a few species specific to a given city or region, the newly released database features 171 distinct species across 16 U.S. climate zones. The trees studied also spanned a range of ages with data collected from a consistent set of measurements. Advances in statistical modeling have given the projected growth dimensions a level of accuracy never before seen. Moving beyond just calculating a tree's diameter or age to determine expected growth, the research incorporates 365 sets of tree growth equations to project growth.

Users select their climate zone from the 16 U.S. climate zones (Fig. 1). Calculations of $CO_2$ stored are for a representative species for each tree-type that was one of the predominant street tree species per reference city (Peper et al., 2001). The "Reference city" refers to the city selected for intensive study within each climate zone (McPherson, 2010). About 20 of the most abundant species were selected for sampling in each reference city. The sample was stratified into nine diameter at breast height (DBH) classes (0 to 7.6, 7.6 to 15.2, 15.2 to 30.5, 30.5 to 45.7, 45.7 to 61.0, 61.0 to 76.2, 76.2 to 91.4, 91.4 to 106.7, and >106.7 cm). Typically 10 to 15 trees per DBH class were randomly chosen. Data were collected for 16 to 74 trees in total from each species. Measurements included: species name, age, DBH [to the nearest 0.1 cm (0.39 in)], tree height [to the nearest 0.5 m (1.64 ft.)], crown height [to the nearest 0.5 m (1.64 ft.)], and crown diameter in two directions [parallel and perpendicular to nearest street to the nearest 0.5 m (1.64 ft.)]. Tree age was determined from local residents, the city's urban forester, street and home construction dates, historical planting records, and aerial and historical photos.

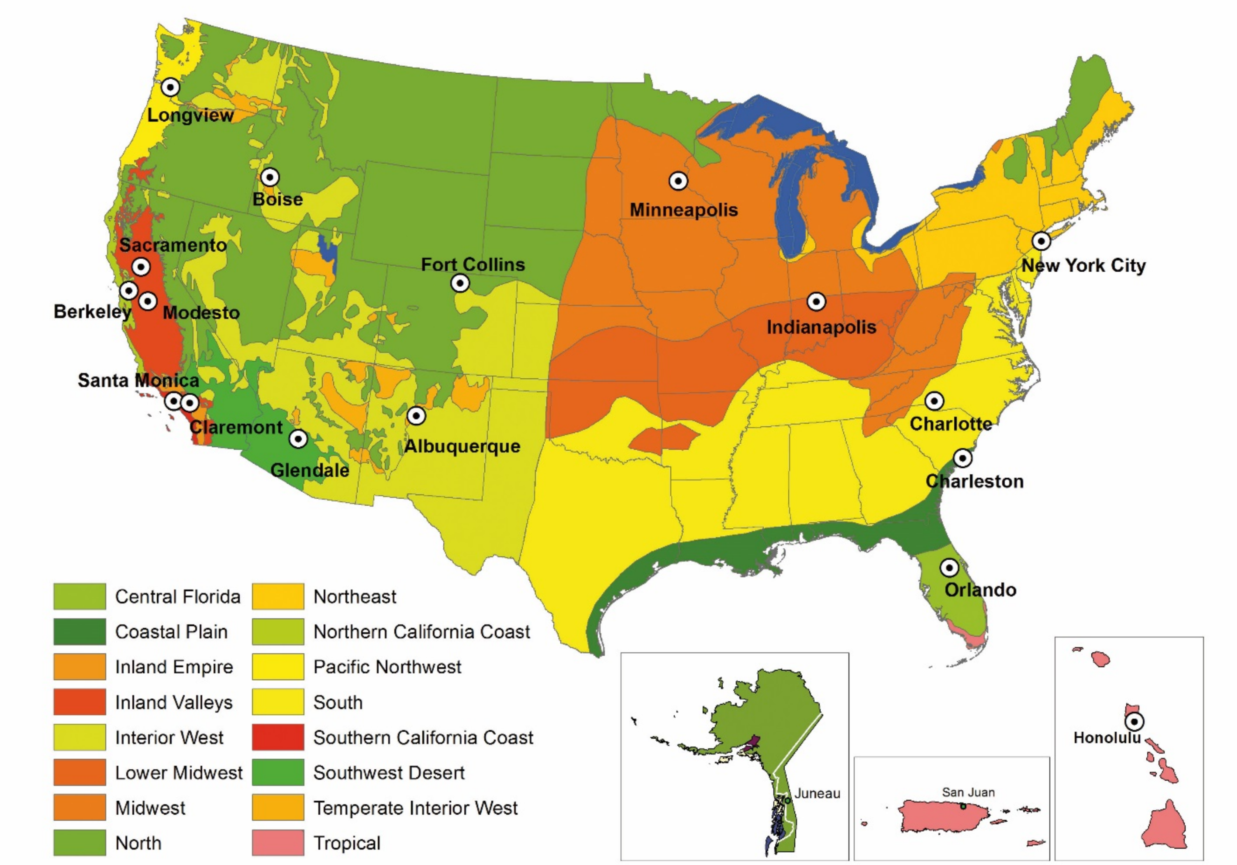


Fig. 1. Climate zones of the United States and Puerto Rico were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree data were collected. Sacramento, California was added as a second reference city (with

Modesto) to the Inland Valleys zone. Zones for Alaska, Puerto Rico and Hawaii are shown in the insets (map courtesy of Pacific Southwest Research Station).

## Species Assignment by Tree-Type

Representative species for each tree-type in the South climate zone (reference city is Charlotte, NC) are shown in Table 1. They were chosen because extensive measurements were taken on them to generate growth equations, and their mature size and form was deemed typical of other trees in that tree-type. Representative species were not available for some tree-types because none were measured. In that case, a species of similar mature size and form from the same climate zone was selected, or one from another climate zone was selected. For example, no Broadleaf Evergreen Large (BEL) species was measured in the South reference city. Because of its large mature size, *Quercus nigra* was selected to represent the BEL tree-type, although it is deciduous for a short time. *Pinus contorta*, which was measured in the PNW climate zone, was selected for the CES tree-type, because no CES species was measured in the South.

Table 1. Nine tree-types and abbreviations. Representative species assigned to each tree-type in the South climate zone are listed. The biomass equations (species, urban general broadleaf [UGB], urban general conifer [UGC]) and dry weight density (kg/m$^3$) used to calculate biomass are listed for each tree-type.

| Tree-Type | Tree-Type Abbreviation | Species Assigned | DW Density | Biomass Equations |
|---|---|---|---|---|
| Brdlf Decid Large (>50 ft) | BDL | *Quercus phellos* | 600 | *Quercus macrocarpa* [1.] |
| Brdlf Decid Med (30-50 ft) | BDM | *Pyrus calleryana* | 600 | UGB [2.] |
| Brdlf Decid Small (<30 ft) | BDS | *Cornus florida* | 545 | UGB [2.] |
| Brdlf Evgrn Large (>50 ft) | BEL | *Quercus nigra* | 797 | UGB [2.] |
| Brdlf Evgrn Med (30-50 ft) | BEM | *Magnolia grandiflora* | 523 | UGB [2.] |

| | | | | |
|---|---|---|---|---|
| Brdlf Evgrn Small (<30 ft) | BES | *Ilex opaca* | 580 | UGB [2.] |
| Conif Evgrn Large (>50 ft) | CEL | *Pinus taeda* | 389 | UGC [2.] |
| Conif Evgrn Med (30-50 ft) | CEM | *Juniperus virginiana* | 393 | UGC [2.] |
| Conif Evgrn Small (<30 ft) | CES | *Pinus contorta* | 397 | UGC [2.] |
| [1.] from Lefsky, M., & McHale, M.,2008. | | | | |
| [2] from Aguaron, E., & McPherson, E. G., 2012 | | | | |

## Calculating Biomass and Carbon Dioxide Stored

To estimate $CO_2$ stored, the biomass for each tree-type was calculated using urban-based allometric equations because open-growing city trees partition carbon differently than forest trees (McPherson et al., 2017a). Input variables included climate zone, species, and DBH. To project tree size at 25-years after planting, we used DBH obtained from UTD growth curves for each representative species.

Biomass equations were compiled for 26 open-grown urban trees species from literature sources (Aguaron and McPherson, 2012). General equations (Urban Gen Broadleaf and Urban Gen Conifer) were developed from the 26 urban-based equations that were species specific (McPherson et al., 2016a). These equations were used if the species of interest could not be matched taxonomically or through wood form to one of the urban species with a biomass equation. Hence, urban general equations were an alternative to applying species-specific equations, because many species did not have an equation.

These allometric equations yielded aboveground wood volume. Species-specific dry weight (DW) density factors (Table 1) were used to convert green volume into dry weight (7a). The urban general equations required looking up a dry weight density factor (in Jenkins et al. 2004 first, but if not available then the Global Wood Density Database). The amount of belowground biomass in roots of urban trees is not well researched. This work assumed that root biomass was 28% of total tree biomass

(Cairns et al., 1997; Husch et al., 2003; Wenger, 1984). Wood volume (dry weight) was converted to C by multiplying by the constant 0.50 (Leith, 1975), and C was converted to $CO_2$ by multiplying by 3.667.

## Error Estimates and Limitations

The lack of biometric data from the field remains a serious limitation to our ability to calibrate biomass equations and assign error estimates for urban trees. Differences between modeled and actual tree growth adds uncertainty to $CO_2$ sequestration estimates. Species assignment errors result from matching species planted with the tree-type used for biomass and growth calculations. The magnitude of this error depends on the goodness of fit in terms of matching size and growth rate. In previous urban studies the prediction bias for estimates of $CO_2$ storage ranged from -9% to +15%, with inaccuracies as much as 51% RMSE (Timilsina et al., 2014). Hence, a conservative estimate of error of ± 20% can be applied to estimates of total $CO_2$ stored as an indicator of precision.

It should be noted that estimates of $CO_2$ stored using the Tree Canopy Approach have several limitations that may reduce their accuracy. They rely on allometric relationships for open-growing trees, so storage estimates may not be as accurate when trees are closely spaced. Also, they assume that the distribution of tree canopy cover among tree-types remains constant, when in fact mortality may afflict certain species more than others. For these reasons, periodic "truing-up" of estimates by field sampling is suggested.

## Co-Benefit: Energy Savings

Trees and forests can offer energy savings in two important ways. In warmer climates or hotter months, trees can reduce air conditioning bills by keeping buildings cooler through reducing regional air temperatures and offering shade. In colder climates or cooler months, trees can confer savings on the fuel needed to heat buildings by reducing the amount of cold winds that can strip away heat.

Energy conservation by trees is important because building energy use is a major contributor to greenhouse gas emissions. Oil or gas furnaces and most forms of electricity generation produce $CO_2$ and other pollutants as by-products. Reducing the amount of energy consumed by buildings in urban areas is one of the most effective methods of combatting climate change. Energy consumption is also a costly burden on many low-income families, especially during mid-summer or mid-winter. Furthermore, electricity consumption during mid-summer can sometimes over-extend local power grids leading to rolling brownouts and other problems.

Energy savings are calculated through numerical models and simulations built from observational data on proximity of trees to buildings, tree shapes, tree sizes, building age classes, and meteorological data from McPherson et al. (2017) and McPherson and Simpson (2003). The main parameters affecting the overall amount of energy savings are crown shape, building proximity, azimuth, local climate, and season. Shading effects are based on the distribution of street trees with respect to buildings recorded from aerial photographs for each reference city (McPherson and Simpson, 2003). If a sampled tree was located within 18 m of a conditioned building, information on its distance and compass bearing relative to a building, building age class (which influences energy use) and types of heating and cooling equipment were collected and used as inputs to calculate effects of shade on annual heating and cooling energy effects. Because these distributions were unique to each city, energy values are considered first-order approximations.

In addition to localized shade effects, which were assumed to accrue only to trees within 18 m of a building, lowered air temperatures and windspeeds from increased neighborhood tree cover (referred to as climate effects) can produce a net decrease in demand for winter heating and summer cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances). Climate effects on energy use, air temperature, and wind speed, as a function of neighborhood canopy cover, were estimated from published values for each reference city. The percentages of canopy cover increase were calculated for 20-year-old large, medium, and small trees, based on their crown projection areas and effective lot size (actual lot size plus a portion of adjacent street and other rights-of-way) of 10,000 $ft^2$ (929 $m^2$), and one tree on average was assumed per lot. Climate effects were estimated by simulating effects of wind and air-temperature reductions on building energy use.

In the case of urban Tree Preservation Projects, trees may not be close enough to buildings to provide shading effects, but they may influence neighborhood climate. Because these effects are highly site-specific we conservatively apply an 80% reduction to the energy effects of trees for Preservation Projects.

Energy savings are calculated as a real-dollar amount. This is calculated by applying overall reductions in oil and gas usage or electricity usage to the regional cost of oil and gas or electricity for residential customers. Colder regions tend to see larger savings in heating and warmer regions tend to see larger savings in cooling.

## Error Estimates and Limitations

Formulaic errors occur in modeling of energy effects. For example, relations between different levels of tree canopy cover and summertime air temperatures are not well-researched. Another source of error stems from differences between the airport climate data (i.e., Los Angeles International Airport) used to model energy effects and the actual climate of the study area (i.e., Los Angeles urban area). Because of the uncertainty associated with modeling effects of trees on building energy use, energy estimates may be accurate within ± 25 percent (Hildebrandt & Sarkovich, 1998).

## Co-Benefit: $CO_2$ Avoided

Energy savings result in reduced emissions of $CO_2$ and criteria air pollutants (volatile organic hydrocarbons [VOCs], $NO_2$, $SO_2$, $PM_{10}$) from power plants and space-heating equipment. Cooling savings reduce emissions from power plants that produce electricity, the amount depending on the fuel mix. Electricity emissions reductions were based on the fuel mixes and emission factors for each utility in the 16 reference cities/climate zones across the U.S. The dollar values of electrical energy and natural gas were based on retail residential electricity and natural gas prices obtained from each utility. Utility-specific emission factors, fuel prices and other data are available in the Community Tree Guides for each region (https://www.fs.fed.us/psw/topics/urban_forestry/products/tree_guides.shtml). To convert the amount of $CO_2$ avoided to a dollar amount in the spreadsheet tools, City Forest Credits uses the price of $20 per metric ton of $CO_2$.

## Error Estimates and Limitations

Estimates of avoided CO2 emissions have the same uncertainties that are associated with modeling effects of trees on building energy use. Also, utility-specific emission factors are changing as many utilities incorporate renewable fuels sources into their portfolios. Values reported in CFC tools may overestimate actual benefits in areas where emission factors have become lower.

## Co-Benefit: Rainfall Interception

Forest canopies normally intercept 10-40% of rainfall before it hits the ground, thereby reducing stormwater runoff. The large amount of water that a tree crown can capture during a rainfall event makes tree planting a best management practice for urban stormwater control.

City Forest Credits uses a numerical interception model to calculate the amount of annual rainfall intercepted by trees, as well as throughfall and stem flow (Xiao et al., 2000). This model uses species-specific leaf surface areas and other parameters from the Urban Tree Database. For example, deciduous trees in climate zones with longer "in-leaf" seasons will tend to intercept more rainfall than similar species in colder areas shorter foliation periods. Model results were compared to observed patterns of rainfall interception and found to be accurate. This method quantifies only the amount of rainfall intercepted by the tree crown, and does not incorporate surface and subsurface effects on overland flow.

The rainfall interception benefit was priced by estimating costs of controlling stormwater runoff. Water quality and/or flood control costs were calculated per unit volume of runoff controlled and this price was multiplied by the amount of rainfall intercepted annually.

## Error Estimates and Limitations

Estimates of rainfall interception are sensitive to uncertainties regarding rainfall patterns, tree leaf area and surface storage capacities. Rainfall amount, intensity and duration can vary considerably within a climate zone, a factor not considered by the model. Although tree leaf area estimates were derived from extensive measurements on over 14,000 street trees across the U.S. (McPherson et al., 2016a), actual leaf area may differ because of differences in tree health and management. Leaf surface storage capacity, the depth of water that foliage can capture, was recently found to vary threefold among 20 tree species (Xiao & McPherson, 2016). A shortcoming is that this model used the same value (1 mm) for all species. Given these limitations, interception estimates may have uncertainty as great as ± 20 percent.

## Co-Benefit: Air Quality

The uptake of air pollutants by urban forests can lower concentrations and affect human health (Derkzen et al., 2015; Nowak et al., 2014). However, pollutant concentrations can be increased if the tree canopy restricts polluted air from mixing with the surrounding atmosphere (Vos et al., 2013). Urban forests are capable of improving air quality by lowering pollutant concentrations enough to significantly affect human health. Generally, trees are able to reduce ozone, nitric oxides, and particulate matter. Some trees can reduce net volatile organic compounds (VOCs), but others can increase them through natural processes. Regardless of the net VOC production, urban forests usually confer a net positive benefit to air quality. Urban forests reduce pollutants through dry deposition on surfaces and uptake of pollutants into leaf stomata.

A numerical model calculated hourly pollutant dry deposition per tree at the regional scale using deposition velocities, hourly meteorological data and pollutant concentrations from local monitoring stations (Scott et al., 1998). The monetary value of tree effects on air quality reflects the value that society places on clean air, as indicated by willingness to pay for pollutant reductions. The monetary value of air quality effects were derived from models that calculated the marginal damage control costs of different pollutants to meet air quality standards (Wang and Santini 1995). Higher costs were associated with higher pollutant concentrations and larger populations exposed to these contaminants.

## Error Estimates and Limitations

Pollutant deposition estimates are sensitive to uncertainties associated with canopy resistance, resuspension rates and the spatial distribution of air pollutants and trees. For example, deposition to urban forests during warm periods may be underestimated if the stomata of well-watered trees remain open. In the model, hourly meteorological data from a single station for each climate zone may not be spatially representative of conditions in local atmospheric surface layers. Estimates of air pollutant uptake may be accurate within ± 25 percent.

## Conclusions

Our estimates of carbon dioxide storage and co-benefits reflect an incomplete understanding of the processes by which ecoservices are generated and valued (Schulp et al., 2014). Our choice of co-benefits to quantify was limited to those for which numerical models were available. There are many important benefits produced by trees that are not quantified and monetized. These include effects of urban forests on local economies, wildlife, biodiversity and human health and well-being. For instance, effects of urban trees on increased property values have proven to be substantial (Anderson & Cordell, 1988). Previous analyses modeled these “other” benefits of trees by applying the contribution to residential sales prices of a large front yard tree (0.88%) (McPherson et al., 2005). We have not incorporated this benefit because property values are highly variable. It is likely that co-benefits reported here are conservative estimates of the actual ecoservices resulting from local tree planting projects.

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# Part 2
## Overview of Quantification in Planting Projects

Project Operators will select one of three different methods for quantifying $CO_2$ stored in their project trees:

- Single Tree Method (where planted trees are dispersed or scattered among many existing trees, such as street or yard tree plantings) or
- Canopy Method (where planted trees are relatively contiguous, such as in park plantings)
- Riparian Method (where trees are planted in riparian or similar areas, with the goal of generating canopy via closely-spaced planting and high expected mortality)

The Single Tree Method requires tracking and sampling of individual trees. The Canopy Method requires tracking of changes in the project's overall tree canopy area using data and the i-Tree tool.

The Riparian Method requires our scientists to apply GTR tables to data provided by the Project Operator on tree or forest type being planted, acres, climate zone, and other information. This is described in more detail in Attachment A at the end of this Appendix. Quantification for this Riparian method thus depends on data specific to each project and application of GTR tables. See Attachment A to this Appendix.

A Project Operator thus selects the appropriate quantification method. He or she then applies that method at different time periods. The Tools used are the Initial Credit Quantification Tool, the Management Credit Quantification Tool, and the Final Quantification Tool.

Thus there are six quantification Tools, three for the Single Tree Method and three for the Canopy Method. The three Tools for each method are used near the beginning of a project, in the early years of a project, and at the end of the project in Year 25.

Single Tree Method:

- Single Tree Initial Credit Quantification
- Single Tree Management Credit Quantification
- Single Tree Final Quantification

Canopy Method:

- Canopy Initial Credit Quantification
- Canopy Management Credit Quantification
- Canopy Final Quantification

The Tool used depends on the time at which the Project Operator seeks Credits. The Registry will issue credits on the following tiered schedule per Section 9 of the Planting Protocol:

- After planting of project trees: 10% of projected total $CO_2e$ stored by Year 26, minus a 20% mortality deduction and a 5% Buffer Pool deduction, subject to quantification conducted under the Registry's quantification methodology and verification by an approved third-party verifier;
- After Year 3: 40% of projected total $CO_2e$ stored by Year 26, minus a 5% Buffer Pool deduction, subject to data collection, sampling, mortality data based on the sampled data, and quantification conducted under the Registry's quantification methodology and verification by an approved third-party verifier;
- After year 5: 30% of projected total $CO_2e$ stored by Year 26, a 5% Buffer Pool deduction, subject to data collection, sampling, mortality data based on the sampled data, and quantification conducted under the Registry's quantification methodology and verification by an approved third-party verifier;
- At the end of the 25-year Project Duration: all remaining credits issued after final quantification and verification of carbon stored, minus a 5% Buffer Pool deduction. Thus, at the end of Year 25, the Project Operator will conduct a

final quantification with data collection, sampling, approval of the quantification methods by the Registry, and third-party verification. At that time, the Registry will issue “true-up” credits equaling the difference between credits already issued (which were based on projected $CO_2$e stored) and credits earned based on final quantification and verification of $CO_2$e stored;
- 5% of total credits earned and issued will be retained by the Registry for a Registry-wide Reversal Pool.

The Initial Credit Quantification Tool enables the Project Operator to calculate projected carbon stored in his or her project using planting data. The Tool applies a 20% mortality deduction as well as a 5% Buffer Pool deduction. The Project Operator can request to use an alternative value for the 20% mortality reduction. Justification for the value must be provided to the Registry based on historic mortality data for projects with similar species, planting stock, site quality and management regime.

The Management Credit Tool is used for Credits that can be issued in Year 4 and Year 6. The Management Credit Tool requires planting data, calculation of a sample number and sample sites, and then sampling of project trees to determine the presence of trees. This sampling produces a mortality adjustment that allows estimation of $CO_2$e storage after Years 4 and 6.

The Final Quantification Tool is used at the end of a project, in Year 25. It is the same basic Tool as the Credit Management Tool used in Years 4 and 6, except that it also requires measurement of dbh (diameter at breast height).

This Appendix B contains detailed examples of four of the six Tools - Single Tree Initial Credit Quantification Tool, Single Tree Management Credit Quantification Tool, Single Tree Final Quantification Tool, and Canopy Final Quantification Tool, with associated spreadsheet tables and calculations. The other Tools are available upon request.

Before describing those Tools in detail, here is a summary of the steps used in each of the three different processes.

# Illustrative Summary of Quantification Steps in Four of the Tools

This section summarizes the steps in three Single Tree Tools used to quantify carbon storage in tree planting projects. These steps are set out in instructions on each sheet of the Quantification Spreadsheets. The steps will be much clearer to many readers when viewed within the spreadsheets rather than read here without tables, fields, and inputs. The next section of this Appendix – entitled Quantification Methods and Examples – gives screen shots of the spreadsheets with explanatory text.

## Steps for Single Tree Initial Credit Quantification

1) For each planting site, collect this information
    a. Unique site number
    b. Unique tree number (may be several tree numbers at same site if remove & replace)
        i. Tree species planted
        ii. Date planted
    c. Tree number removed
        i. Date removed
    d. GPS coordinates (lat/long)
    e. Notes
2) Photograph tree site or provide imaging of sufficient resolution to discern individual trees
        i. If using photographs, take photos at the four outer corners of each site, and also at 50 foot intervals on diagonal lines running between corners

ii. Include time stamp and GPS coordinates

3) The Tool will deduct 20% for mortality and 5% for the program-wide Buffer Pool and then show projected CO2e storage and Credits
   a. The Project Operator can request to use an alternative value for the 20% mortality reduction. Justification for the value must be provided to the Registry based on historic mortality data for projects with similar species, planting stock, site quality and management regime.

## Steps for the Single Tree Management Credit Quantification

1) Collect the planting data described in 1 above, specifically,
   a. Unique site number
   b. Unique tree number (may be several tree numbers at same site if remove & replace)
      i. Tree species planted
      ii. Date planted
   c. GPS coordinates (lat/long)
   d. Notes
2) Use the Sample Size Calculator that we provide and the Stored $CO_2$ per Tree Look-Up Table to determine the number of tree sites to sample. We define a "tree site" as the location where a project tree was planted, and use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.
3) Randomly sample tree sites collecting data on species, status (alive, dead, removed, replaced).
4) With this sampled data, the Tool will then calculate projected CO2 storage and credits, and will set those out for Years 4 and 6, along with quantified Co-Benefits.

## Steps for the Single Tree Final Quantification

1) Collect the planting data described in 1 above, or use the data already collected, specifically,
    a. Unique site number
    b. Unique tree number (may be several tree numbers at same site if remove & replace)
        i. Tree species planted
        ii. Date planted
    c. GPS coordinates (lat/long)
    d. Notes
2) Use the Sample Size Calculator that we provide and the Stored $CO_2$ per Tree Look-Up Table to determine the number of tree sites to sample. We define a "tree site" as the location where a project tree was planted, and use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.
3) Randomly sample tree sites collecting data on species, status (alive, dead, removed, replaced), diameter at breast height (dbh) (to nearest inch), and photo of tree site (may be with or without the tree planted) with geocoded location and date.
4) Fill in the table provided showing the number of live trees sampled in each 1" dbh class by tree-type.
5) Combine data from the step 5 table with the $CO_2$ Stored by DBH Look-Up Table for your climate zone to calculate $CO_2$ stored by sampled trees for each tree-type.
6) Fill in the table provided showing number of sites planted, sites sampled and status of sampled tree sites by tree-type. This table calculates Extrapolation Factors.
7) Combine data from tables in step 7 (Extrapolation Factors) and step 6 to scale-up $CO_2$ stored from the sample to the population of trees planted.

8) Fill in the table provided to incorporate error estimates of ±15% to $CO_2$ stored by the entire tree population.
9) Fill in the table provided to incorporate estimates of co-benefits.

## Steps for the Canopy Final Quantification Method

1) Describe the project (i.e., dates trees planted, locations and climate zone).
2) Create a planting list that contains data on the numbers of trees planted by species (with tree-type for each species obtained from the table provided).
3) Fill-in the table provided using data from the Stored $CO_2$ per Unit Canopy Look-Up Table for 25 years after planting and numbers of trees planted by tree-type to calculate the Project Index.
4) Use i-Tree Canopy to calculate total project area and area in tree canopy.
5) In the table provided, multiply the area in tree canopy by the Project Index to calculate total $CO_2$ stored by trees planted in the project area.
6) Fill-in the table provided to incorporate error estimates of ±15% to $CO_2$ stored by the entire tree population.
7) Fill-in the table provided to incorporate estimates of co-benefits.

# Quantification Methods and Examples

## Data Collection for all Single Tree Quantification and Tools

At planting, Project Operators must collect the data listed below. Project Operators can update that data as the Project proceeds.

**Directions**

Create a data sheet with the same fields seen in the example below.

At the time of data collection soon after planting, record the following information:

- Date of data collection.
- Names of the crew that collected that data.

At the time of data collection soon after planting record the following information on each tree:

- Date planted
- Site Id#, a unique number assigned to each spot a tree is planted at.
- Species name (botanical name)
- Tree Id#, the unique number that coincides with each tree that was planted at the site. When each tree has just been planted, and there are not any dead or missing trees, the tree id#s will all be the same as the site#s. As trees get replaced, the list of tree id#s will increase. In the example below, site# 1 has a replacement tree planted in it, therefore what was originally tree #1 is now tree #4. If tree #4 is the next one at the project
- latitude and longitude or x and y coordinates of where each tree is located. These data are used to accurately locate the site for remeasurement.

**Example Data Collection Table**

Data Collection Date: 04/24/2018 Crew: Julie and Ed

| date planted | site id# | species | tree id # | x coord | y coord | live (orig/replace #1/replace #2) | standing dead or vacant site | image#1 | image#2 | date removed | date replaced | notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/15/2016 | 1 | Celtis reticulata | 1 | 33.96872 | -117.344 | | | | | | | |
| 9/15/2016 | 2 | Pistacia chinensis | 2 | 32.96752 | -117.263 | | | | | | | |
| 9/15/2016 | 3 | Platanus racemosa | 3 | 32.87346 | -116.84 | | | | | | | |
| | | | | | | | | | | | | |
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| | | | | | | | | | | | | |

# Single Tree Initial Credit Quantification and Tool

The steps above summarized the quantification Tools for four Tools described in this Appendix. Below is a detailed walk-through of the Single Tree Quantification. Project operators will use this process and Tools to request Credits in projects where trees are not planted contiguously.

The Registry will provide the Tools that contains look-up tables and calculations built in to the spreadsheet so that projects can enter their project data and then walk through the sheets to quantify $CO_2$ and co-benefits.

# Overview

**Single Tree Projects Initial Credit Quantification Tool for the Southern California Coast Climate Zone**

The analyst can use this method to calculate the amount of CO2 (in metric tonnes, t) estimated to be stored by live project trees after 25 years. Credits based on the estimated CO2 storage can be issued at three points in time – 10% within one year after planting, 40% after year 3, and 30% after year 5, minus 5% that will go into a program-wide buffer pool to insure against catastrophic loss of trees. At the end of the project, in year 25, Operators will receive credits for all CO2 stored, minus credits already issued.

Project Operators will follow the Steps listed below to obtain an initial estimate that assumes 20% mortality. Basic tree planting data on all trees planted needs to be collected at the time of planting. Users will submit this spreadsheet to the Registry with other documentation so that the verifier can verify the planting before initial credits are issued. Sampled data will be used to obtain credits at subsequent points in time.

**Steps**

1) Compile data on the numbers of trees planted by species to fill in the Planting List (Table 1). When planting project trees collect the following data on each planted tree: species, site id#, tree id# and location (latitude and longitude). We use the term “site” instead of “tree” because some planted trees may no longer be present in the sites where they were planted.

2) If the anticipted mortality rate in 25 years is NOT the default 20% of planted sites, the value is entered into row 6 on the Credits sheet. Justification for the value must be provided to the Registry based on historic mortality data for projects with similar species, planting stock, site quality and management regime.

3) Initial Credits will be automatically calculated and presented in Tables 3 and 4 (column H), incorporating anticipated tree losses and the 5% buffer pool deduction.

5) For planning purposes only, users can enter a low and high price of $CO_2$ ($ per t) in Table 5. Table 6 incorporates error estimates of ±15% to calculate low and high amounts of $CO_2$ stored.

6) Table 7 automatically provides estimates of co-benefits for live trees after 25 years in Resource Units (e.g., kWh) per year and $ per year.

# Planting List

Enter the species and number planted as shown in Table 1 below.

**Directions**

1) In Table 1 record the number of sites planted for each tree species.
2) If species are not listed, add them to the bottom of Table 1.

**Table 1. Planting List**

| ScientificName | CommonName | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|---|
| Acacia baileyana | Bailey acacia | BES | |
| Acacia decurrens | green acacia | BEM | |
| Acacia longifolia | Sydney golden wattle | BES | |
| Acacia melanoxylon | black acacia | BEL | |
| Acer palmatum | Japanese maple | BDS | |
| Acer rubrum | red maple | BDL | |
| Acer saccharinum | silver maple | BDL | |
| Acer species | maple | BDL | |
| Agonis flexuosa | peppermint tree; Australian willow myrtle | BES | |
| Albizia julibrissin | mimosa | BDS | 16 |
| Alnus cordata | Italian alder | BDM | |
| Alnus rhombifolia | white alder | BDL | |
| Annona cherimola | cherimoya | BES | |
| Araucaria bidwillii | bunya bunya | CEL | |
| Araucaria columnaris | coral reef araucaria | CEL | |
| Araucaria heterophylla | Norfolk Island pine | CEL | |
| Arbutus unedo | strawberry tree | BES | |
| Archontophoenix cunninghamian | king palm | PES | |
| Arecastrum romanzoffianum | queen palm | PES | |
| Bauhinia variegata | mountain ebony | BDS | |
| Betula pendula | European white birch | BDM | |
| Betula species | birch | BDM | 94 |
| Brachychiton populneus | kurrajong | BEM | |
| Brahea armata | Mexican blue palm | PES | |
| Brahea edulis | Guadalupe palm | PES | |
| Brahea species | brahea palm | PES | |
| Broadleaf Deciduous Large | broadleaf deciduous large | BDL | 140 |
| Broadleaf Deciduous Medium | broadleaf deciduous medium | BDM | |
| Broadleaf Deciduous Small | broadleaf deciduous small | BDS | |
| Broadleaf Evergreen Large | broadleaf evergreen large | BEL | |
| Broadleaf Evergreen Medium | broadleaf evergreen medium | BEM | |
| Broadleaf Evergreen Small | broadleaf evergreen small | BES | |
| Broussonetia papyrifera | paper mulberry | BDM | |
| Butia capitata | jelly palm | PES | |
| Calliandra tweedii | Trinidad flame bush | BES | |
| Callistemon citrinus | lemon bottlebrush | BES | |
| Callistemon viminalis | weeping bottlebrush | BES | |
| Calocedrus decurrens | incense cedar | CEL | |

**Table 2. Summary of Planting Sites**

| Tree-Type | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|
| Brdlf Decid Large (>50 ft) | BDL | 140 |
| Brdlf Decid Med (30-50 ft) | BDM | 94 |
| Brdlf Decid Small (<30 ft) | BDS | 16 |
| Brdlf Evgrn Large (>50 ft) | BEL | 0 |
| Brdlf Evgrn Med (30-50 ft) | BEM | 0 |
| Brdlf Evgrn Small (<30 ft) | BES | 0 |
| Conif Evgrn Large (>50 ft) | CEL | 0 |
| Conif Evgrn Med (30-50 ft) | CEM | 0 |
| Conif Evgrn Small (<30 ft) | CES | 0 |
| | Total Sites Planted | 250 |

# Initial Credits

This sheet calculates the Credits that can be issued in Year 1. It uses a default mortality of 20%. Project Operators may adjust that mortality deduction if they demonstrate to the Registry justification based on historic mortality data for projects with similar species, planting stock, site quality and management regime. Credits issued in Years 4 and 6 will depend on mortality based on sampling of trees in those years.

**Directions**

Enter the default 20% anticipted mortality rate (% of planted sites without trees in 25 years) into cell D6. Using the information you provide and background data, the tool calculates the amount of Credits that could be issued at years 1 (10%), 4 (40%) and 6 (30%) after planting. The mortality deductions (% loss) is applied to account for anticipated tree losses. A 5% buffer pool deduction is applied that will go into a program-wide pool to insure against catastrophic loss of trees.

Mortality Deduction (%): 20%

**Table 3. Credits are based on 10%, 40% and 30% at Years 1, 4 and 6 after planting, respectively, of the projected CO2 stored by live trees 25-years after planting. These values account for anticipated tree losses and the 5% buffer pool deduction.**

| | | | | | | 10% | 40% | 30% |
|---|---|---|---|---|---|---|---|---|
| | No. Sites Planted | No. Live Trees | Mortality Deduction (%) | 25-yr $CO_2$ stored (kg/tree) | Tot. 25-yr $CO_2$ stored w/ losses and 5% deduction (t) | Initial $CO_2$ (t) | 4 Years $CO_2$ (t) | 6 Years $CO_2$ (t) |
| **BDL** | 140 | 112 | 0.20 | 1,794.13 | 190.9 | 19.09 | 76.36 | 57.27 |
| **BDM** | 94 | 75 | 0.20 | 629.52 | 45.0 | 4.50 | 17.99 | 13.49 |
| **BDS** | 16 | 13 | 0.20 | 422.19 | 5.1 | 0.51 | 2.05 | 1.54 |
| **BEL** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| **BEM** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| **BES** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CEL** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CEM** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CES** | 0 | 0 | 0.20 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 |
| | 250 | 200 | | 2,845.8 | 241.0 | 24.10 | 96.40 | 72.30 |

## Total $CO_2$

In Table 4 the tool infers the amount of $CO_2$ stored after 25 years based on the anticipated population of live trees. Values in column H account for anticipated tree losses and the 5% buffer pool deduction.

**Table 4. Grand Total $CO_2$ Stored after 25 years (all live trees, includes tree losses and buffer pool deduction)**

| Tree-Type | No. Sites Planted | Mortality Deduction (%) | Total Live Trees After Mortality | 25-yr CO2 stored (kg/tree) | CO2 Tot. - No Deductions (t) | Grand Total CO2 w/ Deductions (t) |
|---|---|---|---|---|---|---|
| **Brdlf Decid Large (>50 ft)** | 140 | 0.20 | 112 | 1,794.13 | 251.2 | 190.9 |
| **Brdlf Decid Med (30-50 ft)** | 94 | 0.20 | 75 | 629.52 | 59.2 | 45.0 |
| **Brdlf Decid Small (<30 ft)** | 16 | 0.20 | 13 | 422.19 | 6.8 | 5.1 |
| **Brdlf Evgrn Large (>50 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| **Brdlf Evgrn Med (30-50 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| **Brdlf Evgrn Small (<30 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| **Conif Evgrn Large (>50 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| **Conif Evgrn Med (30-50 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| **Conif Evgrn Small (<30 ft)** | 0 | 0.20 | 0 | 0.00 | 0.0 | 0.0 |
| | 250 | | 200 | 2,845.8 | 317.1 | 241.00 |

## $CO_2$ Summary

| Directions |
|---|
| In Table 5, enter the low and high price of $CO_2$ in $ per tonne (t). |

Table 6 incorporates error estimates of ±15% to the high and low estimates of the total CO2 (t) stored by the live tree population after 25 years. For planning purposes only, it calculates dollar values.

**Table 5. $CO_2$ value**

| | $CO_2$ $ per tonne |
|---|---|
| **Low** | $20.00 |
| **High** | $40.00 |

**Table 6. Summary of $CO_2$ stored after 25 years (all live trees, includes tree losses)**

| Tree-Type | Total $CO_2$ (t) at 25 years | Low $ value | High $ value |
|---|---|---|---|
| **Brdlf Decid** | 241.00 | $4,820.04 | $9,640.09 |
| **Brdlf Evgrn** | 0.00 | $0.00 | $0.00 |
| **Conif Evgrn** | 0.00 | $0.00 | $0.00 |
| **Total** | 241.00 | $4,820.04 | $9,640.09 |
| | **$CO_2$ (t)** | **Total $** | **Total $** |
| **Grand Total $CO_2$ (t) at 25 years:** | 241.00 | $4,820.04 | $9,640.09 |
| **High Est. with Error:** | 277.15 | $5,543.05 | $11,086.10 |
| **Low Est. with Error:** | 204.85 | $4,097.04 | $4,097.04 |
| ± 15% error = ± 10% formulaic ± 3% sampling ± 2% measurement | | | |

Co-Benefits

Using the information you provide and background data, the tool provides estimates of co-benefits after 25 years in Resource Units per year and $ per year.

**Table 10. Co-Benefits per year after 25 years (all live trees, includes tree losses)**

| Ecosystem Services | Res Units Totals | Res Unit/site | Total $ | $/site |
|---|---|---|---|---|
| Rain Interception (m3/yr) | 734.20 | 2.94 | $1,512.86 | $6.051 |
| CO2 Avoided (t, $20/t/yr) | 16.86 | 0.07 | $337.17 | $1.349 |
| Air Quality (t/yr) | | | | |
| O3 | 0.0998 | 0.0004 | $1,100.35 | $4.401 |
| NOx | 0.0244 | 0.0001 | $686.65 | $2.747 |
| PM10 | 0.0517 | 0.0002 | $1,072.53 | $4.290 |
| Net VOCs | 0.0010 | 0.0000 | $10.34 | $0.041 |
| Air Quality Total | 0.1768 | 0.0007 | $2,869.86 | $11.48 |
| Energy (kWh/yr & kBtu/yr) | | | | |
| Cooling - Elec. | 39,554.23 | 158.22 | $4,612.02 | $18.45 |
| Heating - Nat. Gas | 18,835.65 | 75.34 | $234.40 | $0.94 |
| Energy Total ($/yr) | | | $4,846.42 | $19.39 |
| Grand Total ($/yr) | | | $9,566.31 | $38.27 |

# Single Tree Management Credit Quantification and Tool

## Overview

Follow these directions, and also update the Data Collection Sheet that you completed at time of planting. See page 10 above.

**Single Tree Project Management Credit Quantification Tool for the Tropical Climate Zone**

The analyst can use this method to calculate the amount of CO2 (in metric tonnes, t) estimated to be stored by live project trees for Years 4 and 6 crediting. These credits are based on sample data that revise the estimated CO2 storage 25 years after planting from the anticipated value that assumed 20% mortality. Credits are issued at the rates of 40% in Year 4, and 30% in Year 6, minus 5% that will go into a program-wide buffer pool to insure against catastrophic loss of trees. This tool calculates benefits assuming trees are 25-years old with average dbh's of 20", 16" and 10" for large, medium and small tree-types, respectively.

To summarize the Tool briefly, Project Operators will sample trees from a random selection within the project area. They will record if each sample tree is alive, dead or missing. They will also photo-sample each sampling site and submit the images geocoded & time stamped. This tool then calculates CO2 stored, co-benefits, and the number of Credits that may be issued at Years 4 and 6. Users will submit this spreadsheet to the Registry with photo images so that the Registry can verify the process and sampled data. It is important to note that co-benefits to human health, satisfaction, attendance/absenteeism, and quality of life are not quantified by this tool, but can be compelling reasons for partners to invest in local projects.

**Steps**

1) Plant project trees and collect the following data on each planted tree using the data collection table included in this workbook: species, site id#, tree id# and location (latitude and longitude). We use the term “site” instead of “tree” because some planted trees may no longer be present in the sites where they were planted.

2) Compile data on the numbers of trees planted by species from the Data Collection table and use this information to fill in the Planting List (Table 1).

3) The Sample Size Calculator will automatically determine the number of sites to sample (Table 3).

4) Create a random sample of sites to visit. For further instructions see the Random Sampling sheet. Note that if you choose to collect data at more than one of the allowed time steps (immediately after planting, after year 3, and after year 5), DIFFERENT random samples must be drawn at each of those times to avoid any sampling bias.

5) Collect data at each sample site using the Data Collection table included in this workbook. For further instructions see the Data Collection sheet.

6) Enter data on the number of live trees and vacant sites from the Data Collection table into Table 5 on the Sample Data sheet.

7) Credits will be automatically calculated in Table 6.

8) Table 7 automatically infers the amount of $CO_2$ stored after 25 years from the sample to the population of live trees.

9) For planning purposes only, users can enter a low and high price of $CO_2$ ($ per t) in Table 8. Table 9 incorporates error estimates of ±15% to calculate low and high amounts of $CO_2$ stored.

10) Table 10 automatically provides estimates of co-benefits for live trees after 25 years in Resource Units (e.g., kWh) per year and $ per year.

**Single Tree Projects Initial Credit Quantification Tool for the Southern California Coast Climate Zone**

The analyst can use this method to calculate the amount of CO2 (in metric tonnes, t) estimated to be stored by live project trees after 25 years. Credits based on the estimated CO2 storage can be issued at three points in time – 10% within one year after planting, 40% after year 3, and 30% after year 5, minus 5% that will go into a program-wide buffer pool to insure against catastrophic loss of trees. At the end of the project, in year 25, Operators will receive credits for all CO2 stored, minus credits already issued.

Project Operators will follow the Steps listed below to obtain an initial estimate that assumes 20% mortality. Basic tree planting data on all trees planted needs to be collected at the time of planting. Users will submit this spreadsheet to the Registry with other documentation so that the verifier can verify the planting before initial credits are issued. Sampled data will be used to obtain credits at subsequent points in time.

Steps

1) Compile data on the numbers of trees planted by species to fill in the Planting List (Table 1). When planting project trees collect the following data on each planted tree: species, site id#, tree id# and location (latitude and longitude). We use the term “site” instead of “tree” because some planted trees may no longer be present in the sites where they were planted.

2) If the anticipted mortality rate in 25 years is NOT the default 20% of planted sites, the value is entered into row 6 on the Credits sheet. Justification for the value must be provided to the Registry based on historic mortality data for projects with similar species, planting stock, site quality and management regime.

3) Initial Credits will be automatically calculated and presented in Tables 3 and 4 (column H), incorporating anticipated tree losses and the 5% buffer pool deduction.

5) For planning purposes only, users can enter a low and high price of $CO_2$ ($ per t) in Table 5. Table 6 incorporates error estimates of ±15% to calculate low and high amounts of $CO_2$ stored.

6) Table 7 automatically provides estimates of co-benefits for live trees after 25 years in Resource Units (e.g., kWh) per year and $ per year.

# Planting List

**Directions**

1) In Table 1 record the number of sites planted for each tree species.
2) If species are not listed, add them to the bottom of Table 1.

**Table 1. Planting List**

| ScientificName | CommonName | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|---|
| Acacia baileyana | Bailey acacia | BES | |
| Acacia decurrens | green acacia | BEM | |
| Acacia longifolia | Sydney golden wattle | BES | |
| Acacia melanoxylon | black acacia | BEL | |
| Acer palmatum | Japanese maple | BDS | |
| Acer rubrum | red maple | BDL | |
| Acer saccharinum | silver maple | BDL | |
| Acer species | maple | BDL | |
| Agonis flexuosa | peppermint tree; Australian willow myrtle | BES | |
| Albizia julibrissin | mimosa | BDS | 16 |
| Alnus cordata | Italian alder | BDM | |
| Alnus rhombifolia | white alder | BDL | |
| Annona cherimola | cherimoya | BES | |
| Araucaria bidwillii | bunya bunya | CEL | |
| Araucaria columnaris | coral reef araucaria | CEL | |
| Araucaria heterophylla | Norfolk Island pine | CEL | |
| Arbutus unedo | strawberry tree | BES | |
| Archontophoenix cunninghamian | king palm | PES | |
| Arecastrum romanzoffianum | queen palm | PES | |
| Bauhinia variegata | mountain ebony | BDS | |
| Betula pendula | European white birch | BDM | |
| Betula species | birch | BDM | 94 |
| Brachychiton populneus | kurrajong | BEM | |
| Brahea armata | Mexican blue palm | PES | |
| Brahea edulis | Guadalupe palm | PES | |
| Brahea species | brahea palm | PES | |
| Broadleaf Deciduous Large | broadleaf deciduous large | BDL | 140 |
| Broadleaf Deciduous Medium | broadleaf deciduous medium | BDM | |
| Broadleaf Deciduous Small | broadleaf deciduous small | BDS | |
| Broadleaf Evergreen Large | broadleaf evergreen large | BEL | |
| Broadleaf Evergreen Medium | broadleaf evergreen medium | BEM | |
| Broadleaf Evergreen Small | broadleaf evergreen small | BES | |
| Broussonetia papyrifera | paper mulberry | BDM | |
| Butia capitata | jelly palm | PES | |
| Calliandra tweedii | Trinidad flame bush | BES | |
| Callistemon citrinus | lemon bottlebrush | BES | |
| Callistemon viminalis | weeping bottlebrush | BES | |
| Calocedrus decurrens | incense cedar | CEL | |

**Table 2. Summary of Planting Sites**

| Tree-Type | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|
| **Brdlf Decid Large (>50 ft)** | **BDL** | 140 |
| **Brdlf Decid Med (30-50 ft)** | **BDM** | 94 |
| **Brdlf Decid Small (<30 ft)** | **BDS** | 16 |
| **Brdlf Evgrn Large (>50 ft)** | **BEL** | 0 |
| **Brdlf Evgrn Med (30-50 ft)** | **BEM** | 0 |
| **Brdlf Evgrn Small (<30 ft)** | **BES** | 0 |
| **Conif Evgrn Large (>50 ft)** | **CEL** | 0 |
| **Conif Evgrn Med (30-50 ft)** | **CEM** | 0 |
| **Conif Evgrn Small (<30 ft)** | **CES** | 0 |
| | **Total Sites Planted** | 250 |

# Data Collection – Calculating your Sample Size

**Table 3. Sample Size Calculator**

| Description | | Value |
|---|---|---|
| 1) | Margin of Error (15% required) | 15% |
| 2) | Confidence level (95% required) | 95% |
| 3) | Total number of project sites | 250 |
| 4) | Mean stored $CO_2$ per tree (kg) | 1189 |
| 5) | Standard deviation of stored $CO_2$ (kg) | 978 |
| 6) | Expected proportion of tree survival (75% required) | 75% |
| | Calculated sample size | 115 |

Use the Sample Size Calculator that we provide to determine the number of sites to sample. We use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.

**Directions**

1) Margin of error, the default value of 15% is used.
2) Confidence level, the default value of 95% is used.
3) The total number of original sites is automatically filled in from the Planting List tab.
4) Mean stored $CO_2$ for all tree types 25 years after planting is automatically filled in from Table 4 below.
5) Standard deviation of the average $CO_2$ stored for all tree types 25 years after planting is automatically filled in from the Table 4.
6) Expected proportion of tree survival – for sampling purposes we conservatively estimate that 75% of the planted trees are expected to survive. This value is used as the default in the Sample Size Calculator.

**Table 4. Stored $CO_2$ (kg) by tree type for years after planting in the Tropical climate zone.**

| Age | BDL | BDM | BDS | BEL | BEM | BES | CEL | CEM | CES | Avg. | Std. Dev. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 380 | 66 | 45 | 103 | 58 | 102 | 13 | 30 | 47 | | |
| 10 | 1,282 | 249 | 152 | 354 | 185 | 281 | 203 | 127 | 167 | | |
| 15 | 2,444 | 550 | 338 | 724 | 376 | 453 | 964 | 317 | 315 | | |
| 20 | 3,638 | 957 | 610 | 1,175 | 615 | 588 | 2,021 | 621 | 475 | | |
| **25** | **4,719** | **1,450** | **976** | **1,673** | **883** | **695** | **2,021** | **1,059** | **640** | **1,189** | **978** |
| 30 | 5,627 | 2,009 | 1,442 | 2,191 | 1,162 | 812 | 2,021 | 1,647 | 807 | | |
| 35 | 6,364 | 2,610 | 2,013 | 2,711 | 1,434 | 992 | 2,021 | 2,402 | 974 | | |
| 40 | 6,977 | 3,231 | 2,695 | 3,222 | 1,684 | 1,316 | 2,021 | 3,337 | 974 | | |

# Data Collection – Identifying your Random Sample of Planting Sites

**Directions**

Use this tool to create a random list of site IDs to sample.

| No. Sites to Sample | Random List of Site IDs |
|---|---|
| 1 | 69 |
| 2 | 97 |
| 3 | 134 |
| 4 | 200 |
| 5 | 170 |
| 6 | 116 |
| 7 | 133 |
| 8 | 236 |
| 9 | 195 |
| 10 | 104 |
| 11 | 21 |
| 12 | 139 |
| 13 | 215 |
| 14 | 186 |

1) In Column A create a numbered row for each of the sites to be sampled (110) in example.

2) In cell B6, replace the XXXX in the following formula with the total number of planted sites, =RANDBETWEEN(1,XXXX).

2) Replace the XXXX in the following formula with the total number of sites, =LARGE(ROW($1:$XXXX)*NOT(COUNTIF($B$5:B5,ROW($1:$XXXX))),RANDBETWEEN(1,(XXXX+2-1)-ROW(B5)))

3) Copy and paste that formula into cell B7. You will get a #NUM! error in that cell. Double click that cell and then press CTRL+SHIFT+ENTER to enter this as an array formula.

4) Copy cell B7 down for as many rows as you are required to sample, the resulting values should all be unique.

5) Starting in cell B6 you have a list of random site numbers where you will collect data.

6) Note that DIFFERENT random samples must be drawn each time crediting is sought to avoid any sampling bias.

# Data Collection – Field Sample Data Collection Sheet

**Directions**

Create a data sheet with the same fields seen in the example below.

To request Credits, consult the Sample Size Calculator to determine the required number of random samples.

Use the Random Sampling Tool to create a random list of site IDs to sample.

If the tree is alive, record if it is the original one planted (original) or a replacement (replace#1, replace#2).

Record if the tree is dead (standing) or missing (vacant site).

image#1, the unique number for the first image of this site.

image#2, the unique number for the second image of this site taken at 90 degrees to the first.

Date removed, the date when the tree was removed.

Date replaced, the date when the replacement tree was planted.

Notes, information concerning tree status, health, etc.

During subsequent field sampling sessions you may find it helpful to take a copy of your original data sheets along for reference when attempting to locate each tree.

**Example Data Collection Table**

Data Collection Date: 08/11/2018 Crew: Julie and Ed

| date planted | site id# | species | tree id # | x coord | y coord | live (orig/replace #1/replace #2) | standing dead or vacant site | image#1 | image#2 | date removed | date replaced | notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/15/2016 | 1 | Celtis reticulata | 4 | 33.968715 | -117.343649 | R#1 | | 1 | 2 | 3/1/2017 | 4/5/2017 | Original tree (#1) removed & replaced (#4) |
| 9/15/2016 | 2 | Pistacia chinensis | 2 | 32.967521 | -117.263458 | | vacant | 3 | 4 | 2/21/2017 | | Dead tree (#2) removed , not replaced |
| 9/15/2016 | 3 | Platanus racemosa | 3 | 32.873459 | -116.839654 | Orig | | 5 | 6 | | | Originally planted tree (#3) alive |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

# Sample Data

**Directions**

1) In Table 5 Cols. D-F enter the number of live trees sampled (originally planted, 1st and 2nd replacements) by tree type.

2) In Table 5 Cols. H-I enter the number of vacant sites sampled (original tree not replaced, 1st replacement removed and not replaced, 2nd replacement removed and not replaced) by tree type.

**Table 5. Sample Data on Tree Numbers**

| Sample Data | Number of Sites Originially Planted | Sampled - No. Live Original Planting | Sampled - No. Live 1st Replacements | Sampled - No. Live 2nd Replacements | Total Sites Sampled - Live Trees | Sampled Dead - Original Planting Not Replaced | Sampled - Dead - 1st Replacements, Not Replaced | Sampled - Dead - 2nd Replacements, Not Replaced | Total Sites Sampled - Vacant / Dead Trees | Total Sites Sampled | Original Planting Survival (%) | Current Survival w/ Replacements (%) | Extrap-olation Factor | Total Number Live Trees Inferred from Sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brdlf Decid Large (>50 ft)** | 140 | 39 | 4 | 1 | 44 | 12 | 1 | 0 | 13 | 57 | 68 | 77 | 2.46 | 108 |
| **Brdlf Decid Med (30-50 ft)** | 94 | 26 | 1 | 1 | 28 | 12 | 3 | 0 | 15 | 43 | 60 | 65 | 2.19 | 61 |
| **Brdlf Decid Small (<30 ft)** | 16 | 6 | 1 | 0 | 7 | 3 | 0 | 0 | 3 | 10 | 60 | 70 | 1.60 | 11 |
| **Brdlf Evgrn Large (>50 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **Brdlf Evgrn Med (30-50 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **Brdlf Evgrn Small (<30 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Large (>50 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Med (30-50 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Small (<30 ft)** | 0 | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| | 250 | 71 | 6 | 2 | 79 | 27 | 4 | 0 | 31 | 110 | 65 | 72 | | 180 |

## Credits at Years 4 and 6 After Planting

| Directions |
|---|
| Using the information you provide and background data, the tool calculates the amount of Credits that could be issued at years 1 (10%), 4 (40%) and 6 (30%) after planting. A mortality deduction (% loss) is applied to account for tree losses based on sampling results. |

**Table 6. Credits are based on 10%, 40% and 30% at Years 1, 4, and 6 after planting, respectively, of the projected CO2 stored by live trees 25-years after planting. These values account for tree losses based on sampling results and 5% buffer pool deduction.**

| | | | | | | 10% | 40% | 30% |
|---|---|---|---|---|---|---|---|---|
| | **No. Sites Planted** | **No. Live Trees** | **Mortality Deduction (%)** | **Tot. 25-yr $CO_2$ stored w/ mortality (t)** | **Tot. 25-yr $CO_2$ stored minus 5% deduction (t)** | **Initial $CO_2$ (t)** | **4 Years $CO_2$ (t)** | **6 Years $CO_2$ (t)** |
| **BDL** | 140 | 108 | 0.23 | 510.0 | 484.5 | 48.45 | 193.80 | 145.35 |
| **BDM** | 94 | 61 | 0.35 | 88.8 | 84.3 | 8.43 | 33.73 | 25.30 |
| **BDS** | 16 | 11 | 0.30 | 10.9 | 10.4 | 1.04 | 4.15 | 3.11 |
| **BEL** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| **BEM** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| **BES** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CEL** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CEM** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| **CES** | 0 | 0 | 0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 |
| | 250 | 180 | 0.28 | 609.7 | 579.2 | 57.92 | 231.68 | 173.76 |

## Total $CO_2$

In Table 7 the tool infers the amount of $CO_2$ stored after 25 years from the sample to the population of live trees.

**Table 7. Grand Total $CO_2$ Stored after 25 years (all live trees, includes tree losses)**

| Tree-Type | No. Sites Planted | Extrap. Factor | Total Live (Original + Replaced Trees) Sampled | Total Number Live Trees Inferred from Sample | Sample $CO_2$ Stored (kg) End of Year 25 (w/ mortality) | CO2 (t) Stored at the End of Year 25 Minus 5% Buffer Deduction |
|---|---|---|---|---|---|---|
| **Brdlf Decid Large (>50 ft)** | 140 | 2.46 | 44 | 108 | 207,641.2 | 484.50 |
| **Brdlf Decid Med (30-50 ft)** | 94 | 2.19 | 28 | 61 | 40,607.5 | 84.33 |
| **Brdlf Decid Small (<30 ft)** | 16 | 1.60 | 7 | 11 | 6,830.3 | 10.38 |
| **Brdlf Evgrn Large (>50 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| **Brdlf Evgrn Med (30-50 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| **Brdlf Evgrn Small (<30 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| **Conif Evgrn Large (>50 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| **Conif Evgrn Med (30-50 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| **Conif Evgrn Small (<30 ft)** | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| | 250 | | 79 | 180 | 255,079.1 | 579.21 |

## $CO_2$ Summary

**Table 8. $CO_2$ value**

| | **$CO_2$ $ per tonne** |
|---|---|
| **Low** | $20.00 |
| **High** | $40.00 |

**Table 9. Summary of $CO_2$ stored after 25 years (all live trees, includes tree losses)**

| **Tree-Type** | **Total $CO_2$ (t) at 25 years** | **Low $ value** | **High $ value** |
|---|---|---|---|
| **Brdlf Decid** | 579.21 | $11,584.20 | $23,168.39 |
| **Brdlf Evgrn** | 0.00 | $0.00 | $0.00 |
| **Conif Evgrn** | 0.00 | $0.00 | $0.00 |
| **Total** | 579.21 | $11,584.20 | $23,168.39 |
| | **$CO_2$ (t)** | **Total $** | **Total $** |
| **Grand Total $CO_2$ (t) at 25 years:** | 579.21 | $11,584.20 | $23,168.39 |
| **High Est. with Error:** | 666.09 | $13,321.82 | $26,643.65 |
| **Low Est. with Error:** | 492.33 | $9,846.57 | $9,846.57 |
| ± 15% error = ± 10% formulaic ± 3% sampling ± 2% measurement | | | |

Co-Benefits

| Using the information you provide and background data, the tool provides estimates of co-benefits after 25 years in Resource Units per year and $ per year. | | | | |
|---|---|---|---|---|
| **Table 7. Co-Benefits per year after 25 years (all live trees, includes tree losses)** | | | | |
| **Ecosystem Services (Resource Units)** | **Resource Units (Totals)** | **Resource Unit/site** | **Total $** | **$/site** |
| **Rain Interception (m3/yr)** | 1,038.93 | 4.16 | $502.26 | $2.009 |
| **CO2 Avoided (t, $20/t/yr)** | 10.46 | 0.04 | $209.18 | $0.837 |
| **Air Quality (t/yr)** | | | | |
| **O3** | 0.0819 | 0.0003 | $2,966.76 | $11.867 |
| **NOx** | 0.0367 | 0.0001 | $1,330.25 | $5.321 |
| **PM10** | 0.0465 | 0.0002 | $5,258.16 | $21.033 |
| **Net VOCs** | -0.1759 | -0.0007 | -$1,295.22 | -$5.181 |
| **Air Quality Total** | -0.0109 | 0.0000 | $8,259.96 | $33.04 |
| **Energy (kWh/yr & kBtu/yr)** | | | | |
| **Cooling - Elec.** | 23,486.42 | 93.95 | $3,823.82 | $15.30 |
| **Heating - Nat. Gas** | 14,510.13 | 58.04 | $188.82 | $0.76 |
| **Energy Total ($/yr)** | | | $4,012.64 | $16.05 |
| **Grand Total ($/yr)** | | | $12,984.04 | $51.94 |

# Single Tree Final Credit Quantification and Tool

Overview

Project Operators will use and update their Data Collection sheet created at planting. See page 10 above. The Tool described below will guide them through final quantification at Year 26.

The P.O. calculates the amount of $CO_2$ stored by live project trees 26 years after initial planting, based on sampling of the resource. The following steps are required and illustrated for a hypothetical planting of 250 street/front yard sites in Sacramento, with 95 trees sampled 26-years after planting.

| |
|---|
| This tool is used to support a request for final credits 26 years after planting when most trees have matured. The approach calculates the amount of $CO_2$ stored by live project trees in metric tonnes (t) on a tree-by-tree basis, based on sampling of a full inventory of the resource. |

| Steps |
|---|
| 1) Create a planting list that contains data on the numbers of trees planted by species. Other information to record includes tree location and date planted. |
| 2) Use the information gathered in step one to fill-in the Planting List (Table 1) by recording the number of sites planted for each tree species. We use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted. |
| 3) Use the Sample Size Calculator (Table 3) to determine the number of sites to sample. See directions on the sheet for more information. |
| 4) Create a random sample of sites to visit and collect data at each site. See the Random Sample sheet for more information. Use a DIFFERENT random sample each time credits are sought. |
| 5) Visit and collect data at each site. For further instructions see the data collection sheet. |
| 6) Enter the number of live trees sampled in each 1" dbh class by tree-type in the tables 5-7 on the Sampled Data sheet. Then enter the number of dead and not replaced (vacant) and dead that were replaced in tables 10-12. |
| 7) In the CO2 Summary sheet, Table 16, enter the low and high price of CO2 in $ per tonne (t). |

# Planting List

| Directions |
|---|
| 1) In Table 1 record the number of sites planted for each tree species. |
| 2) If species are not listed, add them to the bottom of Table 1. |

**Table 1. Planting List**

| ScientificName | CommonName | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|---|
| Acacia baileyana | Bailey acacia | BES | |
| Acacia decurrens | green acacia | BEM | |
| Acacia longifolia | Sydney golden wattle | BES | |
| Acacia melanoxylon | black acacia | BEL | |
| Acer palmatum | Japanese maple | BDS | |
| Acer rubrum | red maple | BDL | |
| Acer saccharinum | silver maple | BDL | |
| Acer species | maple | BDL | |
| Agonis flexuosa | peppermint tree; Australian willow myrtle | BES | |
| Albizia julibrissin | mimosa | BDS | 16 |
| Alnus cordata | Italian alder | BDM | |
| Alnus rhombifolia | white alder | BDL | |
| Annona cherimola | cherimoya | BES | |
| Araucaria bidwillii | bunya bunya | CEL | |
| Araucaria columnaris | coral reef araucaria | CEL | |
| Araucaria heterophylla | Norfolk Island pine | CEL | |
| Arbutus unedo | strawberry tree | BES | |
| Archontophoenix cunninghamian | king palm | PES | |
| Arecastrum romanzoffianum | queen palm | PES | |
| Bauhinia variegata | mountain ebony | BDS | |
| Betula pendula | European white birch | BDM | |
| Betula species | birch | BDM | 94 |
| Brachychiton populneus | kurrajong | BEM | |
| Brahea armata | Mexican blue palm | PES | |
| Brahea edulis | Guadalupe palm | PES | |
| Brahea species | brahea palm | PES | |
| Broadleaf Deciduous Large | broadleaf deciduous large | BDL | 140 |
| Broadleaf Deciduous Medium | broadleaf deciduous medium | BDM | |
| Broadleaf Deciduous Small | broadleaf deciduous small | BDS | |
| Broadleaf Evergreen Large | broadleaf evergreen large | BEL | |
| Broadleaf Evergreen Medium | broadleaf evergreen medium | BEM | |
| Broadleaf Evergreen Small | broadleaf evergreen small | BES | |
| Broussonetia papyrifera | paper mulberry | BDM | |
| Butia capitata | jelly palm | PES | |
| Calliandra tweedii | Trinidad flame bush | BES | |
| Callistemon citrinus | lemon bottlebrush | BES | |
| Callistemon viminalis | weeping bottlebrush | BES | |
| Calocedrus decurrens | incense cedar | CEL | |

**Table 2. Summary of Planting Sites**

| Tree-Type | Tree-Type Abbreviation | No. Sites Planted |
|---|---|---|
| Brdlf Decid Large (>50 ft) | BDL | 140 |
| Brdlf Decid Med (30-50 ft) | BDM | 94 |
| Brdlf Decid Small (<30 ft) | BDS | 16 |
| Brdlf Evgrn Large (>50 ft) | BEL | 0 |
| Brdlf Evgrn Med (30-50 ft) | BEM | 0 |
| Brdlf Evgrn Small (<30 ft) | BES | 0 |
| Conif Evgrn Large (>50 ft) | CEL | 0 |
| Conif Evgrn Med (30-50 ft) | CEM | 0 |
| Conif Evgrn Small (<30 ft) | CES | 0 |
| | Total Sites Planted | 250 |

## Data Collection - Sample Size

Table 3. Sample Size Calculator

| Description | | Value |
|---|---|---|
| 1) | Margin of Error (15% required) | 15% |
| 2) | Confidence level (95% required) | 95% |
| 3) | Total number of project sites | 250 |
| 4) | Mean stored $CO_2$ per tree (kg) | 1128 |
| 5) | Standard deviation of stored $CO_2$ (kg) | 642 |
| 6) Enter: | Expected proportion of tree survival | 70% |
| | Calculated sample size | 95 |

Use the Sample Size Calculator that we provide to determine the number of sites to sample. We use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.

**Directions**

1) Margin of error, the default value of 15% is used.
2) Confidence level, the default value of 95% is used.
3) The total number of original sites is automatically filled in from the Planting List tab.
4) Mean stored $CO_2$ for all tree types 25 years after planting is automatically filled in from Table 4 below.
3) Standard deviation of the average $CO_2$ stored for all tree types 25 years after planting is automatically filled in from the Table 4.
5) Expected proportion of tree survival – estimates of survival rates can be based on project experience or pre-sampling. Enter the proportion (%) of expected tree survival into the Sample Size Calculator (this can be calculated by dividing the expected or known number of trees that have survived by the total number of trees that were planted, input this number into Cell D9, which will multipy your value by 100 and display it as a percentage). Note: if you do not have an estimate for tree survival, 75 should be entered.

## Data Collection – Calculating a Random Sample of Planting Sites

Use this to create a random list of site IDs to sample.

| No. Sites to Sample | Random List of Sites |
|---|---|
| 1 | 129 |
| 2 | 48 |
| 3 | 64 |
| 4 | 148 |
| 5 | 188 |
| 6 | 201 |
| 7 | 97 |
| 8 | 26 |
| 9 | 65 |
| 10 | 233 |
| 11 | 205 |
| 12 | 167 |
| 13 | 95 |

**Random Sampling Steps**

1) Replace the XXXX in the following formula with the total number of sites, =RANDBETWEEN(1,XXXX). Enter this formula in cell B5.
2) Replace the XXXX in the following formula with the total number of sites, =LARGE(ROW($1:$XXXX)*NOT(COUNTIF($B$5:B5,ROW($1:$XXXX))),RANDBETWEEN(1,(XXXX+2-1)-ROW(B5)))
3) Copy and paste that formula into cell B6. You will get a #NUM! error in that cell. Double click that cell and then press CTRL+SHIFT+ENTER to enter this as an array formula.
4) Copy cell B6 down for the amount of rows that is equivilant to the amount of sites you are required to sample, the resulting values should all be unique.
5) Starting in cell B5 you have a list of random site numbers where you will collect data.
6) Note that DIFFERENT random samples must be drawn each time crediting is sought to avoid any sampling bias.

# Data Collection – Field Sample Data Collection Sheet

**Directions**

Create a data sheet with the same fields seen in the example below. Print the data sheet horizontal.

Soon after planting the trees for the project record the following information:

- Date of data collection.
- Names of the crew that collected that data.
- Site Id#, a unique number assigned to each spot a tree is planted.
- If the tree is the original one planted (original) or a replacement (replace#1, replace#2).
- If the tree is dead or missing (vacant site).
- Species (botanical name)
- Tree Id#, the unique number that conincides with each tree that was planted. When each tree has just been planted, and there are not any dead or missing trees, the tree id#s will all be the same as the site#s. As trees get replaced, the list of tree id#s will grow. In the example below, site# 1 has a replacement tree planted in it, therefore what was originally tree #1 is now tree #4. If tree #4 is the next one that gets replaced, that new tree will then be tree# 5.
- Diameter at breast height (dbh), this is typically taken at 1.37 meter from the ground. If you are unable to take the dbh measurement at this height please see the field guide found at, Roman, L., et al. Urban Tree Monitoring: Field Guide (In prep) General Technical Report, for further information. If a tree you are measuring has multiple stems (trunks) you will need to calculate the square root of the sum of squares of the diameters to calculate one value for the dbh:
  1) Measure the DBH of each stem.
  2) Square the DBH of each stem.
  3) Sum the squares of all the stems.
  4) Take the square root of the sum and use it as the DBH.
     Example: Given a tree with 3 stems that measure 10, 18, and 14 the combined DBH value is:
     sqrt(10^2 + 18^2 + 14^2) = 24.9
- Height (ht). These data are not used in this tool but can be helpful for other reasons such as, verifying you are collecting data at the same tree in subsequent monitoring sessions.
- Condition (cond), good, fair, poor, dead. These data are not used in this tool but can be helpful for other reasons such as, verifying you are collecting data at the same tree in subsequent monitoring sessions.
- x and y coordinates of where each tree is located. These data are used to accurately locate the site for remeasurement.
- image#1, the unique number for the first image of this site.
- image#2, the unique number for the second image of this site taken at 90 degrees to the first.
- Notes, information concerning tree status, health, etc.
- During subsequent monitoring sessions you will use the same data sheet format. During these sessions you may find it helpful to take a copy of your original data sheets along for reference when attempting to locate each tree.

**Example Data Collection Sheet**

Date: Crew:

| site id# | live (orig/replace #1/replace #2) | dead/vacant site | species | tree id # | dbh1 (cm) | dbh2 (cm) | dbh3 (cm) | dbh4 (cm) | dbh5 (cm) | ht (m) | cond | x coord | y coord | image#1 | image#2 | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | RP#1 | | Celtis reticulata | 4 | 5 | | | | | 15 | Good | | | | | Original tree (#1) removed & replaced (#4) |
| 2 | | vacant | Pistacia chinensis | 2 | | | | | | | | | | | | Dead tree (#2) removed , not replaced |
| 3 | Original | | Platanus racemosa | 3 | 10 | 18 | 14 | | | 30 | Fair | | | | | Originally planted tree (#3) alive |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

# Sample Data

**Table 14. Sample summary**

| Sample Data | Number of Sites Originially Planted | Sampled - No. Live Original Planting | Sampled - No. Live 1st Replacements | Sampled - No. Live 2nd Replacements | Total Sites Sampled - Live Trees | Sampled Dead - Original Planting Not Replaced | Sampled - Dead - 1st Replacements, Not Replaced | Sampled - Dead - 2nd Replacements, Not Replaced | Total Sites Sampled - Vacant / Dead Trees | Total Sites Sampled | Original Planting Survival (%) | Current Survival w/ Replacements (%) | Extrapolation Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brdlf Decid Large (>50 ft)** | 140 | 34 | 4 | 1 | 39 | 12 | 1 | 0 | 13 | 52 | 65 | 75 | 2.69 |
| **Brdlf Decid Med (30-50 ft)** | 94 | 23 | 1 | 1 | 25 | 12 | 3 | 0 | 15 | 40 | 58 | 63 | 2.35 |
| **Brdlf Decid Small (<30 ft)** | 16 | 4 | 1 | 0 | 5 | 3 | 0 | 0 | 3 | 8 | 50 | 63 | 2.00 |
| **Brdlf Evgrn Large (>50 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Brdlf Evgrn Med (30-50 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Brdlf Evgrn Small (<30 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Large (>50 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Med (30-50 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Conif Evgrn Small (<30 ft)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 250 | 61 | 6 | 2 | 69 | 27 | 4 | 0 | 31 | 100 | 61 | 69 | |

## Total $CO_2$ - Final Credits at 26 Years After Planting

In Table 15 the tool infers the amount of $CO_2$ stored from the sample to the population of live trees.

**Table 15. Grand Total $CO_2$ Stored (all live trees, includes tree losses)**

| Tree-Type | No. Sites Planted | Extrap. Factor | Total Live (Original + Replaced Trees) Sampled | Total Number Live Trees Inferred from Sample | Sample $CO_2$ Tot. (kg) | Grand Total $CO_2$ (t) |
|---|---|---|---|---|---|---|
| Brdlf Decid Large (>50 ft) | 140 | 2.69 | 39 | 105 | 54,858.89 | 147.70 |
| Brdlf Decid Med (30-50 ft) | 94 | 2.35 | 25 | 59 | 23,048.57 | 54.16 |
| Brdlf Decid Small (<30 ft) | 16 | 2.00 | 5 | 10 | 813.48 | 1.63 |
| Brdlf Evgrn Large (>50 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| Brdlf Evgrn Med (30-50 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| Brdlf Evgrn Small (<30 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| Conif Evgrn Large (>50 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| Conif Evgrn Med (30-50 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| Conif Evgrn Small (<30 ft) | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| | 250 | | 69 | 174 | 78,720.94 | 203.49 |

$CO_2$ Summary

You can enter a price per tonne to see dollar values of Credits.

**Table 16. $CO_2$ value**

| | CO2 $ per tonne |
|---|---|
| **Low** | $20.00 |
| **High** | $40.00 |

**Table 17. Summary of $CO_2$ stored**

| Tree-Type | Total $CO_2$ (t) at 25 years | Low $ value | High $ value |
|---|---|---|---|
| **Brdlf Decid** | 203.49 | $4,069.76 | $8,139.52 |
| **Brdlf Evgrn** | 0.00 | $0.00 | $0.00 |
| **Conif Evgrn** | 0.00 | $0.00 | $0.00 |
| **Total** | 203.49 | $4,069.76 | $8,139.52 |
| | **$CO_2$ (t)** | **Total $** | **Total $** |
| **Grand Total $CO_2$ (t) at 25 years:** | 203.49 | $4,069.76 | $8,139.52 |
| **High Est. with Error:** | 234.01 | $4,680.23 | $9,360.45 |
| **Low Est. with Error:** | 172.96 | $3,459.30 | $3,459.30 |
| ± 15% error = ± 10% formulaic ± 3% sampling ± 2% measurement | | | |

Co-Benefits

Using the information you provide and background data, the tool provides estimates of co-benefits in Resource Units per year and $ per year. Values include tree losses based on sampling results.

**Table 18. Co-Benefits (per year, tree losses included)**

| Ecosystem Services | Resource Units (Totals) | Resource Unit/site | Total $ | $/site |
|---|---|---|---|---|
| Rain Interception (m3/yr) | 379.18 | 1.52 | $781.31 | $3.13 |
| CO2 Avoided (t, $20/t/yr) | 9.30 | 0.04 | $186.05 | $0.74 |
| Air Quality (t/yr) | | | | |
| O3 | 0.0514 | 0.0002 | $567.06 | $2.27 |
| NOx | 0.0126 | 0.0001 | $354.77 | $1.42 |
| PM10 | 0.0268 | 0.0001 | $556.29 | $2.23 |
| Net VOCs | 0.0005 | 0.0000 | $5.65 | $0.02 |
| Air Quality Total | 0.0914 | 0.0004 | $1,483.78 | $5.94 |
| Energy (kWh/yr & kBtu/yr) | | | | |
| Cooling - Elec. | 21,825.56 | 87.30 | $2,544.86 | $10.18 |
| Heating - Nat. Gas | 7,565.78 | 30.26 | $94.15 | $0.38 |
| Energy Total ($/yr) | | | $2,639.01 | $10.56 |
| Grand Total ($/yr) | | | $5,090.14 | $20.36 |

# Canopy Initial Credit Quantification Method and Tool

The Registry will provide this Tool and its instructions upon request.

# Canopy Management Credit Quantification Method and Tool

The Registry will provide this Tool and its instructions upon request.

# Canopy Final Quantification Method

The PO calculates the amount of $CO_2$ currently stored by planted project trees in metric tonnes (t) based on the amount of tree canopy (TC) determined from remote sensing and an index ($CO_2$ per unit canopy area) that is weighted by the mix of species planted. The following steps are illustrated for a hypothetical planting of 500 tree sites along a creek in Sacramento, CA measured 25-years after planting.

**Step 1.** Describe the project, quantify the project area, acquire the following information: numbers of trees planted, date planted, species name and tree-type for each species, GPS locations and climate zone (Table 1).

The 500 trees were planted 25-years ago along the Bannon Creek Parkway bordered by Azevedo Dr. (west), Bannon Creek Elementary School (north and east) and West El Camino Ave. (south) (Figure 1). The Project Area, shown outlined in red using a Google image in the i-Tree Canopy application, covers 12.5 acres (5.1 ha). The numbers of trees originally planted are shown by species and tree-type in Table 1.


*Figure 1.* The Project Area where 500 trees were planted 25-years ago in Sacramento, CA.

*Table 1.* Planting list for trees planted 25-years ago in the Bannon Creek Parkway Project Area, Sacramento, CA (Inland Valley climate zone)

| Planting List (Species) | Common Name | Tree-Type | Number Planted | Tree-Type Subtotals |
|---|---|---|---|---|
| Celtis australis | European hackberry | BDL | 45 | |
| Quercus lobata | valley oak | BDL | 40 | |
| Ulmus species | elm | BDL | 35 | 120 |
| Jacaranda mimosifolia | jacaranda | BDM | 40 | |
| Melia azedarach | Chinaberry | BDM | 30 | 70 |
| Chitalpa tashkentensis | chitalpa | BDS | 30 | |
| Diospyros kaki | Japanese persimmon | BDS | 20 | 50 |
| Grevillea robusta | silk oak | BEL | 45 | |
| Quercus suber | cork oak | BEL | 35 | 80 |
| Acacia species | acacia | BEM | 30 | |
| Eucalyptus cinerea | silver dollar eucalyptus | BEM | 25 | 55 |
| Laurus nobilis | laurel de olor | BES | 30 | 30 |
| Cedrus atlantica | Atlas cedar | CEL | 25 | |
| Pinus halepensis | aleppo pine | CEL | 25 | 50 |
| Pinus pinea | Itailian stone pine | CEM | 20 | |
| Juniperus species | juniper | CEM | 25 | 45 |
| Total Sites Planted | | | 500 | 500 |

**Step 2.** For each tree-type, locate the Stored $CO_2$ by Age and Unit Canopy Look-Up Table (Table 2) for the Inland Valley climate zone at, in this case, 25-years after planting. Copy these values into the Project Index Table (Table 3).

*Table 2.* The Stored $CO_2$ by Age and Unit Canopy Look-Up Table contains values for each tree-type in the Inland Valley climate zone at 5-year intervals after planting. Values reflect a single tree's $CO_2$ per unit tree canopy (TC, $kg/m_2$) at selected years after planting (from McPherson et al. 2016). Values in the highlighted column for 25-year old trees are used in this example.

| r TC (kg/m2) | BDL | BDM | BDS | BEL | BEM | BES | CEL | CEM | CES |
|---|---|---|---|---|---|---|---|---|---|
| Age | ZESE | PYCA | PRCE | CICA | MAGR | ILOP | SESE | PIBR2 | PICO5 |
| 5 | 2.4 | 14.3 | 5.7 | 4.9 | 2.6 | 4.4 | 6.6 | 1.2 | 5.8 |
| 10 | 5.3 | 17.5 | 8.6 | 8.0 | 5.2 | 12.0 | 17.5 | 5.5 | 9.4 |
| 15 | 8.0 | 19.1 | 11.7 | 11.0 | 7.8 | 19.6 | 28.6 | 13.6 | 12.1 |
| 20 | 10.7 | 20.3 | 14.8 | 14.0 | 10.3 | 26.7 | 40.0 | 23.5 | 14.4 |
| 25 | 13.5 | 21.1 | 18.0 | 16.9 | 12.8 | 33.1 | 52.1 | 24.9 | 16.4 |
| 30 | 16.2 | 21.7 | 21.2 | 19.8 | 15.2 | 38.8 | 65.0 | 25.9 | 18.3 |
| 35 | 18.9 | 22.3 | 24.4 | 22.6 | 17.5 | 44.0 | 79.2 | 27.0 | 20.1 |
| 40 | 21.7 | 22.7 | 27.6 | 25.2 | 19.8 | 48.8 | 95.0 | 28.1 | 20.1 |

**Step 3.** The numbers of trees planted are multiplied by their respective per tree Stored $CO_2$ index to calculate Project Indices for each tree-type (last column Table 3). These values are summed (10,766 kg) and divided by the total number of trees planted (500) to derive the Stored $CO_2$ Project Index (21.53 kg/m$^2$). This value is the average amount of $CO_2$ stored per unit of tree canopy (TC), after weighting to account for the mix of species planted.

*Table 3.* This Project Index Table shows 25-year Project $CO_2$ indices that are calculated in the fourth column as the products of tree numbers planted (col. 2) and the per tree values for 25-Yr Stored $CO_2$ (col. 3) from Table 2.

| Tree-Type | Number Planted | 25-Yr Stored CO2 Indices (kg/m2 TC) | Project Indices (kg/m2 TC) |
|---|---|---|---|
| BDL | 120 | 13.5 | 1,614.7 |
| BDM | 70 | 21.1 | 1,475.8 |
| BDS | 50 | 18.0 | 899.4 |
| BEL | 80 | 16.9 | 1,355.8 |
| BEM | 55 | 12.8 | 704.2 |
| BES | 30 | 33.1 | 992.4 |
| CEL | 50 | 52.1 | 2,602.5 |
| CEM | 45 | 24.9 | 1,121.1 |
| CES | 0 | 16.4 | 0.0 |
| Total: | 500 | | 10,766.0 |
| | | Project Index: | 21.53 |

**Step 4.** Use i-Tree Canopy or another tool to classify tree cover and estimate the tree canopy (TC) area for the planted tree sites. If using point sampling, continue adding points until the standard error of the estimate is less than 5%.

Using i-Tree Canopy, 110 points were randomly located in the Project Area (PA) and classified as Tree or Non-Tree. The result was 44.9% tree canopy (TC) and 55.1% non-tree cover, both at ± 4.81% standard error (Std. Er., Table 4). By clicking on the gear icon next to the upper right portion of the image and selecting "Report By Area" the user can prompt i-Tree Canopy to provide an estimate of the area in Tree or Non-Tree cover. In this example, the PA is 12.5 acres.

*Table 4.* Results from the i-Tree Canopy analysis are percentages of tree and non-tree cover that are converted to area based on the size of the Project Area (PA, 12.5 acres)

| | Tree Cover | Non-Tree Cover | Total PA | Std Er. |
|---|---|---|---|---|
| Percent (%) | 44.9 | 55.1 | 100 | 4.81 |
| Area (ac) | 5.6 | 6.9 | 12.5 | |
| Area (m2) | 22,713 | 27,873 | 50,585 | |

**Step 5.** To estimate the amount of stored $CO_2$ in the project tree canopy (TC), multiply the Project Index (from Table 3) by the TC area ($m^2$). Divide by 1,000 to convert from kg to t.

The product of the Project Index (21.53 kg/$m^2$ TC) and TC (22,713 $m^2$) is 489,050 kg or 489.1 t $CO_2$ (Table 5).

*Table 5.* This table shows that an estimated 22,713 $m^2$ of tree canopy (TC) stores 489.1 t of $CO_2$.

| | Amounts |
|---|---|
| Tree Canopy Area (m2) | 22,713 |
| Project Index | 21.53 |
| Stored CO2 (kg) | 489,050 |
| Stored CO2 (t) | 489.1 |

**Step 6.** Incorporate error estimates and prices to illustrate range of amount stored and value (Table 6).

*Table 6.* This summary table shows that with 15% of the 489.1 t of $CO_2$ stored added and subtracted to 489.1 t (see Appendix 1) the actual amount of $CO_2$ stored is likely to range between 415 t and 562 t. The estimated value, assuming prices of $20 and $40 per tonne, ranges from $8,314 to $22,496.

| | CO2 (t) | $ 20.00 | $ 40.00 |
|---|---|---|---|
| Total CO2 (t): | 489.1 | $ 9,781 | $ 19,562 |
| High Est.: | 562.4 | $ 11,248 | $ 22,496 |
| Low Est.: | 415.7 | $ 8,314 | $ 16,628 |
| ± 15% error = ± 10% formulaic ± 3% sampling | | | |
| ± 2% measurement (see Appendix 1) | | | |

**Step 7.** Calculate co-benefits (Table 7).

Co-benefits are shown in Table 7 and based on the ecosystem services produced annually per unit TC. Given the 22,713 $m^2$ of TC after 25 years, total annual services are valued at $8,831, or $18 per site (500 tree sites planted). Estimated energy savings ($5,354) are primarily associated with reductions in air conditioning use due to tree shading and climate effects. Rainfall interception and associated stormwater management savings have an estimated value of $2,565. Uptake of air pollutants by trees is somewhat offset by BVOC emissions, resulting in a net benefit of $532. Avoided $CO_2$ emissions associated with energy savings is valued at $380 assuming a $CO_2$ price of $20 per t. These co-benefits are first-order approximations and dollar values may not reflect the most current prices for local environmental and utility services.

*Table 7.* Co-benefits estimated for the 22,713 $m^2$ of TC at 25 years after planting 500 trees and calculated using the Inland Valley data found in the i-Tree Streets and Design software. i-Tree prices were used, except for $CO_2$, which was $20 per tonne.

| Ecosystem Services | Res Units | Total $ | $/site |
|---|---|---|---|
| Energy (kWh & kBtu) | | | |
| Cooling - Elec. | 44,565 | $5,196 | $10.39 |
| Heating - Nat. Gas | 12,679 | $158 | $0.32 |
| Energy Total | | $5,354 | $10.71 |
| CO2 Avoided (t, $20/t) | 19 | $380 | $0.76 |
| Air Quality (t) | | | |
| O3 | 0.11 | $244 | $0.49 |
| NOx | 0.03 | $168 | $0.34 |
| PM10 | 0.07 | $292 | $0.58 |
| Net VOCs | -0.08 | -$171 | -$0.34 |
| Air Quality Total | 0.12 | $532 | $1.06 |
| Rain Interception (m3) | 1,245 | $2,565 | $5.13 |
| Grand Total | | $8,831 | $17.66 |

# References and Resources

The look-up tables in both examples were created from allometric equations in the Urban Tree Database, now available on-line at: http://www.fs.usda.gov/rds/archive/Product/RDS-2016-0005/. A US Forest Service General Technical Report provides details on the methods and examples of application of the equations and is available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr253/psw_gtr253.pdf.

The citations for the archived UTD and the publication are as follows.

McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. 2016. Urban tree database. Fort Collins, CO: Forest Service Research Data Archive. http://dx.doi.org/10.2737/RDS-2016-0005

McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. 2016. Urban tree database and allometric equations. General Technical Report PSW-253. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. http://www.fs.fed.us/psw/publications/documents/psw_gtr253/psw_gtr253.pdf

The i-Tree Canopy Tools is available online at: http://www.itreetools.org/canopy/.

Features of ten software packages for tree inventory and monitoring are evaluated in this comprehensive report from Azavea: https://www.azavea.com/reports/urban-tree-monitoring/.

# Error Estimates in Carbon Accounting

Our estimates of error include 3 components that are additive and applied to estimates of total $CO_2$ stored:

Formulaic Error (± 10%) + Sampling Error (± 3%) + Measurement Error (± 2%)

We take this general approach based on data from the literature, recognizing that the actual error will vary for each project and is extremely difficult to accurately quantify. We limit the amount of sampling error by providing guidance on the minimum number of trees to sample in the single-tree approach and the minimum number of points to sample using i-Tree Canopy. If sample sizes are smaller than recommended these error percentages may not be valid. Project Operators are encouraged to provide adequate training to those taking measurements, and to double-check the accuracy of a subsample of tree dbh measurements and tree canopy cover classification. A synopsis of the literature and relevant sources are listed below.

## Formulaic Error

A study of 17 destructively sampled urban oak trees in Florida reported that the aboveground biomass averaged 1201 kg. Locally-derived biomass equations predicted 1208 kg with RMSE of 427 kg. Tree biomass estimates using the UFORE-ACE (Version 6.5) model splined equations were 14% higher (1368 kg) with an RMSE that was more than 35% higher than that of the local equation (614 kg or 51%). Mean total carbon (C) storage in the sampled urban oaks was 423 kg, while i-Tree

ECO over-predicted storage by 14% (483 kg C) with a RMSE of 51% (217 kg C). The CTCC under-predicted total C storage by 9% and had a RMSE of 611 kg (39%)

Result: Prediction bias for carbon storage ranged from -9% to 14%

Source: Timilsina, N., Staudhammer, C.L., Escobedo, F.J., Lawrence, A. 2014. Tree biomass, wood waste yield and carbon storage changes in an urban forest. Landscape and Urban Planning. 127: 18-27.

The study found a maximum 29% difference in plot-level $CO_2$ storage among 4 sets of biomass equations applied to the same trees in Sacramento, CA. i-Tree Eco produced the lowest estimate (458 t), Urban General Equations were intermediate (470 t, and i-Tree Streets was highest (590 t).

Source: Aguaron, E., McPherson, E.G. Comparison of methods for estimating carbon dioxide storage by Sacramento's urban forest. pp. 43-71. In Lal, R. and Augustin, B. (Eds.) Carbon Sequestration in Urban Ecosystems. New York. Springer.

## Sampling Error

This error term depends primarily on sample size and variance of $CO_2$ stored per tree. If sample size is on the order of 80-100 sites for plantings of up to 1,000 trees, and most of the trees were planted at the same time, so the standard deviation in $CO_2$ stored is on the order of 30% or less of the mean, then the error is small, about 2-4%.

Source: US Forest Service, PSW Station Statistician Jim Baldwin's personal communication and sample size calculator (Sept. 6, 2016)

## Measurement Error

In this study the mean sampling errors in dbh measurements with a tape were 2.3 mm (volunteers) and 1.4 mm (experts). This error had small effect on biomass estimates: 1.7% change (from 2.3 mm dbh) in biomass calculated from allometric equations.

Source: Butt, N., Slade, E., Thompson, J., Malhl, Y., Routta, T. 2013. Quantifying the sampling error in tree census measurements by volunteers and its effect on carbon stock estimates. Ecological Applications. 23(4): 936-943.

Attachment A

## Approach for Establishing Carbon Dioxide Stored by Tree Canopy in Riparian Tree Planting Projects in Austin, TX

This Attachment A provides an example of the Riparian Tree Planting Quantification Method.

There are two different methods for quantifying carbon dioxide ($CO_2$) storage in urban forest carbon projects – the Single Tree Method (where planted trees are few or are scattered among many existing trees) and the Tree Canopy For Park-like Projects Method (where planted trees are relatively contiguous). Instead of using the traditional Tree Canopy Approach for riparian tree planting projects in Austin, we use a forest ecosystem approach. The traditional approach, which is based on the biometrics of open-growing urban trees, cannot adequately describe biomass distribution among closely-spaced trees and the dynamic changes in $CO_2$ stored in dead wood and understory vegetation as a riparian forest stand matures.

In our modified approach the amount of $CO_2$ stored after 25-years by planted project trees is based on the anticipated amount of tree canopy area (TC). The forecasted amount of $CO_2$ stored at 25-years is the product of the amount of tree canopy (TC) and the $CO_2$ Index (CI, t $CO_2$ per acre). This amount is the value from which the Registry issues credits in the amounts of 10%, 40% and 30% at Years 1, 4 and 6 after planting, respectively. A 5% buffer pool deduction is applied, with these funds going into a program-wide pool to insure against catastrophic loss of trees. At the end of the project, in year 25, the Operator will receive credits for all $CO_2$ stored, minus credits already issued.

To provide an accurate and complete accounting of carbon pools in these riparian projects we used the US Forest Service General Technical Report (GTR) NE-343, with its allometrics for the elm/ash/cottonwood forest ecosystem in the South Central region (Smith et al., 2006). The table we used (B50) provides carbon stored per hectare for each of six pools as a function of stand age. We used values for 25-year old stands for afforestation projects, because the sites contain little carbon in down dead wood and forest floor material at the time of planting. Data used to derive the 51 forest ecosystem tables came from U.S. Forest Inventory and Assessment plots. More information on methods used to prepare the tables can be found in Smith et al. (2006).

Following guidance in GTR NE-343 we adjusted the GTR NE-343 values for live wood, dead standing and dead down wood using local plot data provided by the team. According to the plot data the mean amount of C stored in all tree biomass was 24 t/ha. This value does not include biomass of invasive woody species. Lacking a measured breakdown of this total for trees among the live, standing dead, and down dead biomass components, the 24 t/ha was proportionately distributed as per the GTR (i.e., live: 87%, 20.9 t/ha; standing dead: 7%, 1.7 t/ha; down dead: 6%, 1.4 t/ha). The remaining three carbon pools (understory, forest floor and soil) remained the same as in GTR Table B50 because their values are independent of tree biomass. The customized values are shown below in Table 1. Carbon in the tree pool totals 24 t/ha and accounts for 33% of the total 71.9 t/ha after 25 years for this forest ecosystem. Soil organic carbon is the single largest pool (56%).

After conversions, **the $CO_2$ Index (CI) is 106.7 t $CO_2$ per acre of tree canopy (TC) and the forecasted amount of $CO_2$ stored after 25-years is the CI x TC.** This is the value from which the Registry will issue credits (Table 1).

Table 1. Estimated amounts of carbon stored in each pool at 25-years after planting for riparian forest projects in Austin, TX. These values are based on local plot data for these types of forests and values from GTR NE-343 for the elm/ash/cottonwood forest ecosystem in the South Central region.

| elm/ash/cottonwood | t/C/ha | t/CO2/ha | t/CO2/ac | % total |
|---|---|---|---|---|
| live tree | 20.9 | 76.8 | 31.08 | 29% |
| std dead tree | 1.7 | 6.1 | 2.48 | 2% |
| understory | 3.3 | 12.1 | 4.90 | 5% |
| down dead wood | 1.4 | 5.1 | 2.07 | 2% |
| forest floor | 4.4 | 16.1 | 6.53 | 6% |
| soil | 40.2 | 147.4 | 59.68 | 56% |
| total | 71.9 | 263.6 | 106.73 | 100% |

## Quantification at end of Year 25

- Project provides images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).
    - Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. I-Tree Canopy will supply you with the standard errors.
    - If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.
- Project calculates total $CO_2$ storage at end of Year 25 as follows:
    - Multiply the CI (106.73 t $CO_2$/ac TC) times the acres of TC (tree canopy) in the Project Area.

**References**

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.