



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 CO₂ 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-through 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 (CO₂) 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 peer-reviewed 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 CO₂ 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 CO₂ 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, some parks, and school plantings, individual trees are tracked and randomly sampled
- Clustered Parks Planting Method - planted trees are relatively contiguous in park-like settings and change in canopy is tracked
- Canopy Method – trees are planted very close together, often but not required to be in riparian areas, significant mortality is expected, and change in canopy is tracked. The two main goals are to create a forest ecosystem and generate canopy
- Area Reforestation Method – large areas are planted to generate a forest ecosystem, for example converting from agriculture and in upland areas. This quantification method is under development

In all cases, the estimated amount of CO₂ stored 25-years after planting is calculated. The forecasted amount of CO₂ 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 Clustered Parks Planting 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 CO₂ stored, minus credits already issued.

In the Single Tree Method, the amount of CO₂ stored in project trees 25-years after planting is calculated as the product of tree numbers and the 25-year CO₂ 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 Clustered Parks Planting Method, the amount of CO₂ 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 CO₂ 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 CO₂ estimated to be stored after 25 years based on the 20% anticipated mortality rate and the 5% buffer pool deduction.

In the Canopy Method, the forecasted amount of CO₂ stored at 25-years is the product of the amount of TC and the CO₂ Index (CI, t CO₂ 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 Canopy Method.

Source Materials for Single Tree Method and Clustered Parks Planting Methods

Estimates of stored (amount accumulated over many years) and sequestered CO₂ (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 CO₂ 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.

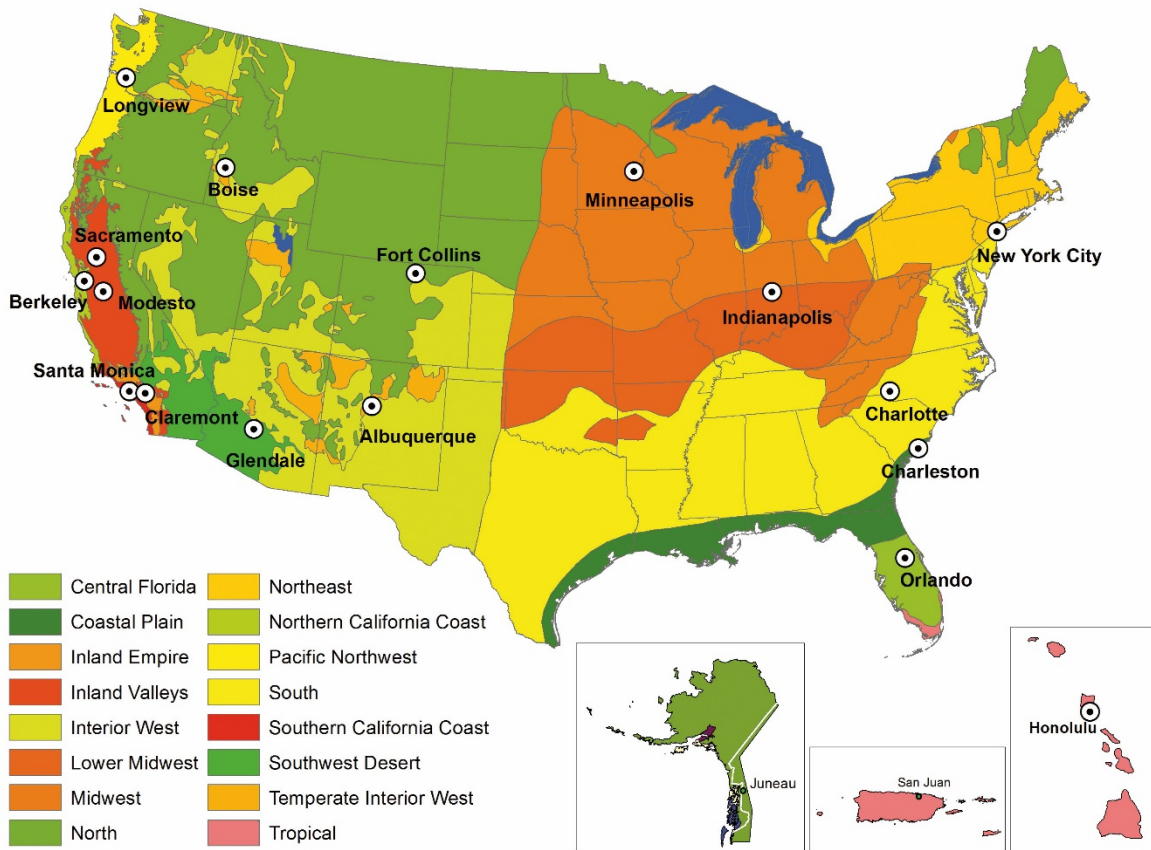


Fig. 1. Climate zones of the United States and Puerto Rico were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree data were collected. Sacramento, California was added as a second reference city (with Modesto) to the Inland Valleys zone. Zones for Alaska, 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/m³) 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	<i>Quercus phellos</i>	600	<i>Quercus macrocarpa</i> ¹ .
Brdlf Decid Med (30-50 ft)	BDM	<i>Pyrus calleryana</i>	600	UGB ² .
Brdlf Decid Small (<30 ft)	BDS	<i>Cornus florida</i>	545	UGB ² .
Brdlf Evgrn Large (>50 ft)	BEL	<i>Quercus nigra</i>	797	UGB ² .
Brdlf Evgrn Med (30-50 ft)	BEM	<i>Magnolia grandiflora</i>	523	UGB ² .
Brdlf Evgrn Small (<30 ft)	BES	<i>Ilex opaca</i>	580	UGB ² .
Conif Evgrn Large (>50 ft)	CEL	<i>Pinus taeda</i>	389	UGC ² .
Conif Evgrn Med (30-50 ft)	CEM	<i>Juniperus virginiana</i>	393	UGC ² .
Conif Evgrn Small (<30 ft)	CES	<i>Pinus contorta</i>	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 CO₂ 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 (Za). 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ stored as an indicator of precision.

It should be noted that estimates of CO₂ 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 CO₂ 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 ft² (929 m²), 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: CO₂ Avoided

Energy savings result in reduced emissions of CO₂ and criteria air pollutants (volatile organic hydrocarbons [VOCs], NO₂, SO₂, PM₁₀) 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 CO₂ avoided to a dollar amount in the spreadsheet tools, City Forest Credits uses the price of \$20 per metric ton of CO₂.

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 foliage 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 four different methods for quantifying CO₂ 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
- Clustered Parks Planting Method (where planted trees are relatively contiguous, such as in park plantings)
- Canopy Method (where trees are planted in riparian or similar areas, with the goal of generating canopy via closely-spaced planting and high expected mortality)
- Area Reforestation Method (where large areas are planted to generate a forest ecosystem, such as conversion from agriculture or in upland areas) – this method is under development

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

The Canopy 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 Canopy 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 Clustered Parks Planting 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

Clustered Parks Planting Method:

- Clustered Parks Planting Initial Credit Quantification
- Clustered Parks Planting Credit Quantification
- Clustered Parks Planting 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 CO₂e 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 CO₂e 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 CO₂e 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 CO₂e stored) and credits earned based on final quantification and verification of CO₂e 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 CO₂e 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 a Clustered Parks Planting 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 CO₂ 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 CO₂ 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 CO₂ Stored by DBH Look-Up Table for your climate zone to calculate CO₂ 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 CO₂ stored from the sample to the population of trees planted.
- 8) Fill in the table provided to incorporate error estimates of ±15% to CO₂ stored by the entire tree population.
- 9) Fill in the table provided to incorporate estimates of co-benefits.

Steps for the Clustered Parks Planting 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 CO₂ 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 CO₂ stored by trees planted in the project area.

- 6) Fill-in the table provided to incorporate error estimates of ±15% to CO₂ 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							

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 into the spreadsheet so that projects can enter their project data and then walk through the sheets to quantify CO₂ and co-benefits.

Overview

Single Tree Projects Initial Credit Quantification Tool for the Southern California Coast Climate Zone											
<p>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.</p> <p>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.</p>											
Steps											
<p>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.</p>											
<p>2) If the anticipated 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.</p>											
<p>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.</p>											
<p>5) For planning purposes only, users can enter a low and high price of CO₂ (\$ per t) in Table 5. Table 6 incorporates error estimates of ±15% to calculate low and high amounts of CO₂ stored.</p>											
<p>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.</p>											

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 cunninghamiana	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% anticipated 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 CO₂ stored (kg/tree)	Tot. 25-yr CO₂ stored w/ losses and 5% deduction (t)	Initial CO₂ (t)	4 Years CO₂ (t)	6 Years CO₂ (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 CO₂

In Table 4 the tool infers the amount of CO₂ 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 CO₂ 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 CO ₂ stored (kg/tree)	CO ₂ Tot. - No Deductions (t)	Grand Total CO ₂ 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

CO₂ 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 CO ₂ (t) stored by the live tree population after 25 years. For planning purposes only, it calculates dollar values.					
Table 5. CO₂ value		Table 6. Summary of CO₂ stored after 25 years (all live trees, includes tree losses)			
	CO₂ \$ per tonne	Tree-Type	Total CO₂ (t) at 25 years	Low \$ value	High \$ value
Low	\$20.00	Brdlf Decid	241.00	\$4,820.04	\$9,640.09
High	\$40.00	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
			CO₂ (t)	Total \$	Total \$
		Grand Total CO₂ (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									
<p>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.</p> <p>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.</p>									
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 anticipated 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 CO₂ (\$ per t) in Table 5. Table 6 incorporates error estimates of ±15% to calculate low and high amounts of CO₂ 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 cunninghamiana	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

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 CO₂ for all tree types 25 years after planting is automatically filled in from Table 4 below.
 - 5) Standard deviation of the average CO₂ 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 CO₂ (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

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

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

- 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)-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 Originally 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	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 CO₂

In Table 7 the tool infers the amount of CO₂ stored after 25 years from the sample to the population of live trees.

Table 7. Grand Total CO₂ 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)	CO ₂ (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

CO₂ Summary

Table 8. CO₂ value		Table 9. Summary of CO₂ stored after 25 years (all live trees, includes tree losses)			
	CO₂ \$ per tonne	Tree-Type	Total CO₂ (t) at 25 years	Low \$ value	High \$ value
Low	\$20.00	Brdlf Decid	579.21	\$11,584.20	\$23,168.39
High	\$40.00	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
			CO₂ (t)	Total \$	Total \$
		Grand Total CO₂ (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 CO₂ 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 CO₂ 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 CO ₂ Summary sheet, Table 16, enter the low and high price of CO ₂ 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				Table 2. Summary of Planting Sites		
ScientificName	CommonName	Tree-Type Abbreviation	No. Sites Planted	Tree-Type	Tree-Type Abbreviation	No. Sites Planted
Acacia baileyana	Bailey acacia	BES		Brdlf Decid Large (>50 ft)	BDL	140
Acacia decurrens	green acacia	BEM		Brdlf Decid Med (30-50 ft)	BDM	94
Acacia longifolia	Sydney golden wattle	BES		Brdlf Decid Small (<30 ft)	BDS	16
Acacia melanoxylon	black acacia	BEL		Brdlf Evgrn Large (>50 ft)	BEL	0
Acer palmatum	Japanese maple	BDS		Brdlf Evgrn Med (30-50 ft)	BEM	0
Acer rubrum	red maple	BDL		Brdlf Evgrn Small (<30 ft)	BES	0
Acer saccharinum	silver maple	BDL		Conif Evgrn Large (>50 ft)	CEL	0
Acer species	maple	BDL		Conif Evgrn Med (30-50 ft)	CEM	0
Agonis flexuosa	peppermint tree; Australian willow myrtle	BES		Conif Evgrn Small (<30 ft)	CES	0
Albizia julibrissin	mimosa	BDS	16	Total Sites Planted		250
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 cunninghamiana	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				

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

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 – 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 multiply 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	Random Sampling Steps
1	129	1) Replace the XXXX in the following formula with the total number of sites, =RANDBETWEEN(1,XXXX). Enter this formula in cell B5.
2	48	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	64	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	148	4) Copy cell B6 down for the amount of rows that is equivalent to the amount of sites you are required to sample, the resulting values should all be unique.
5	188	5) Starting in cell B5 you have a list of random site numbers where you will collect data.
6	201	6) Note that DIFFERENT random samples must be drawn each time crediting is sought to avoid any sampling bias.
7	97	
8	26	
9	65	
10	233	
11	205	
12	167	
13	95	

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 coincides 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: $\text{sqrt}(10^2 + 18^2 + 14^2) = 24.9$
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 Originally 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 CO₂- Final Credits at 26 Years After Planting

In Table 15 the tool infers the amount of CO₂ stored from the sample to the population of live trees.

Table 15. Grand Total CO₂ 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 CO₂ Tot. (kg)	Grand Total CO₂ (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

CO₂ Summary

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

Table 16. CO ₂ value		Table 17. Summary of CO ₂ stored			
	CO ₂ \$ per tonne	Tree-Type	Total CO ₂ (t) at 25 years	Low \$ value	High \$ value
Low	\$20.00	Brdlf Decid	203.49	\$4,069.76	\$8,139.52
High	\$40.00	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 CO₂ (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

Clustered Parks Planting Initial Credit Quantification Method and Tool

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

Clustered Parks Planting Management Credit Quantification Method and Tool

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

Clustered Parks Planting Final Quantification Method

The PO calculates the amount of CO₂ 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 (CO₂ 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
<i>Celtis australis</i>	European hackberry	BDL	45	
<i>Quercus lobata</i>	valley oak	BDL	40	
<i>Ulmus species</i>	elm	BDL	35	120
<i>Jacaranda mimosifolia</i>	jacaranda	BDM	40	
<i>Melia azedarach</i>	Chinaberry	BDM	30	70
<i>Chitalpa tashkentensis</i>	chitalpa	BDS	30	
<i>Diospyros kaki</i>	Japanese persimmon	BDS	20	50
<i>Grevillea robusta</i>	silk oak	BEL	45	
<i>Quercus suber</i>	cork oak	BEL	35	80
<i>Acacia species</i>	acacia	BEM	30	
<i>Eucalyptus cinerea</i>	silver dollar eucalyptus	BEM	25	55
<i>Laurus nobilis</i>	laurel de olor	BES	30	30
<i>Cedrus atlantica</i>	Atlas cedar	CEL	25	
<i>Pinus halepensis</i>	aleppo pine	CEL	25	50
<i>Pinus pinea</i>	Italian stone pine	CEM	20	
<i>Juniperus species</i>	juniper	CEM	25	45
Total Sites Planted			500	500

Step 2. For each tree-type, locate the Stored CO₂ 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 CO₂ 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 CO₂ per unit tree canopy (TC, kg/m²) 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/m ²)	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 CO₂ 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 CO₂ Project Index (21.53 kg/m²). This value is the average amount of CO₂ 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 CO₂ 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 CO₂ (col. 3) from Table 2.

Tree-Type	Number Planted	25-Yr Stored CO ₂ Indices (kg/m ² TC)	Project Indices (kg/m ² 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 CO₂ in the project tree canopy (TC), multiply the Project Index (from Table 3) by the TC area (m²). Divide by 1,000 to convert from kg to t.

The product of the Project Index (21.53 kg/m² TC) and TC (22,713 m²) is 489,050 kg or 489.1 t CO₂ (Table 5).

Table 5. This table shows that an estimated 22,713 m² of tree canopy (TC) stores 489.1 t of CO₂.

	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 CO₂ stored added and subtracted to 489.1 t (see Appendix 1) the actual amount of CO₂ 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 m² 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 CO₂ emissions associated with energy savings is valued at \$380 assuming a CO₂ 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 m² 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 CO₂, 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
CO ₂ Avoided (t, \$20/t)	19	\$380	\$0.76
Air Quality (t)			
O ₃	0.11	\$244	\$0.49
NO _x	0.03	\$168	\$0.34
PM ₁₀	0.07	\$292	\$0.58
Net VOCs	-0.08	-\$171	-\$0.34
Air Quality Total	0.12	\$532	\$1.06
Rain Interception (m ³)	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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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., Malhi, 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 Canopy Tree Planting Projects in Austin, TX

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

There are two different methods for quantifying carbon dioxide (CO₂) storage in urban forest carbon projects – the Single Tree Method (where planted trees are few or are scattered among many existing trees) and the Clustered Parks Planting Method (where planted trees are relatively contiguous). Instead of using the traditional Clustered Parks Planting 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 CO₂ stored in dead wood and understory vegetation as a riparian forest stand matures.

In our modified approach the amount of CO₂ stored after 25-years by planted project trees is based on the anticipated amount of tree canopy area (TC). The forecasted amount of CO₂ stored at 25-years is the product of the amount of tree canopy (TC) and the CO₂ Index (CI, t CO₂ 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 CO₂ 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 CO₂ Index (CI) is 106.7 t CO₂ per acre of tree canopy (TC) and the forecasted amount of CO₂ 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 CO₂ storage at end of Year 25 as follows:
 - Multiply the CI (106.73 t CO₂/ac TC) times the acres of TC (tree canopy) in the Project Area.

Data required after Years 3 and 5

- Project provides images of the Project Area from any telemetry, imaging, remote sensing, or UAV service, such as Google Earth.
- Project uses i-Tree Canopy and point sampling to calculate canopy cover:

o 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.

Progress Requirements for canopy projects after Years 3 and 5:

- After Year 3, projects must show canopy coverage of at least 4% of the Project Area (average 2.4 foot diameter of canopy per tree of 400 trees per acre)
- After Year 5, projects must show canopy coverage of at least 11% of the Project Area (average 4 foot diameter of canopy per tree of 400 trees per acre)

Note: if projects exceed these Progress Requirements, they will not receive credits early or out of schedule. If projects fail to meet the Progress Requirements, they will not be eligible to request credits until they meet the Progress Requirements.

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.