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Appendix B

Quantification Methods for Tree Planting Projects

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This Appendix B on Quantification for Tree Planting Projects consists of a Summary of Quantification Steps, followed by a longer section entitled Quantification Methods and Examples, which provides a more detailed walk-though of quantification methods using a sample project.

We are developing spreadsheet tools that will make using these methods as easy as possible. Users will enter required data in the spreadsheet tool, and the tool will perform the necessary calculations from that data and from tables built into the spreadsheet. We are testing those spreadsheets now and will post them as soon as possible.

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

Summary of Quantification Steps

This section summarizes the steps to quantify carbon storage in tree planting projects. Quantification can occur in three ways. The first is when a Project Operator seeks issuance of forward credits. The second is when a PO seeks issuance of progress credits using the Single Tree Method. The third is when a PO seeks issuance of progress credits using the Canopy Method.

Forward credits can be issued at three tiers – after planting, after year 3, and after Year 5. The quantification method for those forward credits involves projecting the carbon storage of project trees, and adjusting for mortality at each of the three times that forward credits are requested.

Progress credits – credits issued after a project has progressed and trees are more mature – can be issued at any time after year 10 of a project. Progress credits requested at the end of a project that received forward credits also reconcile the forward credits with quantified carbon stored by the end of the project duration.

For quantification leading to progress credits, two different methods are available. Project Operators can select to use the Single Tree Method (where planted trees are scattered among many existing trees, such as street or yard tree plantings) or the Tree Canopy Method (where planted trees are relatively contiguous, such as in park or riparian plantings).

The Single Tree Method requires tracking and sampling of individual trees. The Tree Canopy Method requires tracking of changes in the project's overall tree canopy area using data and the iTree tool. This Appendix B contains an example for each method, with associated spreadsheet tables and calculations.

Steps for Forward Credits

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) Determine sample size using Sample Size Calculator
    a. Using your complete list of site numbers, configure it as a list of random numbers that do not repeat and use Excel functions to select random sample of sites to visit (see below)
3) PO visits each sample site
    a. Confirm accuracy of
        i. Site number

ii. Tree number
iii. Species identification

b. Record status
    i. Live
        1. Original
        2. Replacement #1
        3. Replacement #2
    ii. Standing dead
    iii. Vacant
        1. Removal date #1 if known
        2. Removal date #2 if known

c. Photograph tree site
    i. Include time stamp and GPS coordinates
    ii. Capture tree size and condition in 2 images at approximately 90º
    iii. If site is vacant, place orange reflective rod (4 ft long) where tree was planted to show site location.

4) Calculate percentage of sample trees that are live
    a. Divide number of live trees recorded by total sites sampled (ex: 70/100 = 0.70)
5) Multiple this number by the forecasted CO_2 credits in spreadsheet to adjust forward credits for mortality.

Steps for the Single Tree Method for Progress Credits

1) Describe the project (i.e., dates trees planted, general locations and climate zone used for calculations).

2) Create a list of trees planted that contains data on the numbers of trees planted by species (with tree-type for each species), location and date. We provide tables for each climate zone that match species with tree-types.
3) Use the Sample Size Calculator that we provide and the Stored CO_2 per Tree Look-Up Table to determine the number of tree sites to sample. We define a "tree site" as the location where a project tree was planted, and use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.
4) Randomly sample tree sites collecting data on species, status (alive, dead, removed, replaced), dbh (to nearest inch) and photo of tree site (may be with or without the tree planted) with geocoded location and date.
5) Fill-in the table provided showing the number of live trees sampled in each 1" dbh class by tree-type.
6) Combine data from the step 5 table with the CO_2 Stored by DBH Look-Up Table for your climate zone to calculate CO_2 stored by sampled trees for each tree-type.
7) 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.
8) Combine data from tables in step 7 (Extrapolation Factors) and step 6 to scale-up CO_2 stored from the sample to the population of trees planted.
9) Fill-in the table provided to incorporate error estimates of ±15% to CO_2 stored by the entire tree population.
10) Fill-in the table provided to incorporate estimates of co-benefits.

Steps for the Tree Canopy Method for Progress Credits

1) Describe the project (i.e., dates trees planted, locations and climate zone).
2) Create a planting list that contains data on the numbers of trees planted by species (with tree-type for each species obtained from the table provided).

3) Fill-in the table provided using data from the Stored CO_2 per Unit Canopy Look-Up Table for 25 years after planting and numbers of trees planted by tree-type to calculate the Project Index.
4) Use i-Tree Canopy to calculate total project area and area in tree canopy.
5) In the table provided, multiply the area in tree canopy by the Project Index to calculate total CO_2 stored by trees planted in the project area.
6) Fill-in the table provided to incorporate error estimates of ±15% to CO_2 stored by the entire tree population.
7) Fill-in the table provided to incorporate estimates of co-benefits.

Quantification Methods and Examples

Forward Credit Quantification

The process summarized above sets out the process for a PO to request issuance of forward credits after planting, after Year 3, and after Year 5. We will be posting a spreadsheet tool that contains look-up tables and calculations built in to the spreadsheet so that projects can enter their project data and then walk though the sheets to quantify CO2 and co-benefits.

Overview

Forward Crediting Method

The analyst can use this method to calculate the amount of CO_2 (in metric tonnes, t) stored by live project trees after 25 years for forward crediting. Forward Credits can be issued at three points in time – within one year after planting, after year 3, and after year 5. Basic data on all trees need to be collected at the time of planting. Then, when a user wishes to seek Forward Credits at one of the three points in time above, they will use this tool to select a random sample of sites for collection and entry of a few additional pieces of data. Sampling reduces costs of monitoring and verification. This tool then calculates CO_2 stored, co-benefits, and the number of Forward Credits that may be issued. Users will submit this spreadsheet to the Registry with current images of sample tree sites so the Registry can verify the process and sampled data.

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, at year 3, and at 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) Forward 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.

Data Collection

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 conincides 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 that gets replaced, that new tree will then be tree# 5.
  - 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.
- To request Forward Credits, draw a random sample and record these additional data on each tree site sampled.
  - 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: 04/24/2017 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

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 melanoxylon	black acacia	BEL	
Acacia species	acacia	BEM	
Acer buergerianum	trident maple	BDS	
Acer negundo	boxelder	BDL	
Acer palmatum	Japanese maple	BDS	16
Acer platanoides	Norway maple	BDL	
Acer rubrum	red maple	BDL	33
Acer saccharinum	silver maple	BDL	
Acer species	maple	BDL	
Acer tataricum subsp ginnala	Amur maple	BDS	
Acer x freemanii	Freeman maple	BDL	
Aesculus californica	California buckeye	BDS	
Aesculus carnea	red horsechestunt	BDM	
Aesculus pavia	red buckeye	BDS	
Ailanthus altissima	tree of heaven	BDM	
Albizia julibrissin	mimosa	BDS	
Alnus cordata	Italian alder	BDM	
Alnus rhombifolia	white alder	BDL	
Araucaria species	araucaria	BEL	
Arbutus unedo	strawberry tree	BES	
Betula pendula	European white birch	BDM	
Betula species	birch	BDM	
Brachychiton populneus	kurrajong	BEM	
Callistemon citrinus	lemon bottlebrush	BES	
Callistemon viminalis	weeping bottlebrush	BES	
Calocedrus decurrens	incense cedar	CEL	
Carpinus betulus 'Fastigiata'	hornbeam 'fastigiata'	BDM	
Carpinus caroliniana	American hornbeam	BDM	
Carya illinoinensis	pecan	BDL	
Casuarina equisetifolia	Australian pine	BEL	
Catalpa speciosa	northern catalpa	BDL	
Cedrus atlantica	Atlas cedar	CEL	
Cedrus deodara	deodar cedar	CEL	
Celtis australis	European hackberry	BDL	
Celtis occidentalis	northern hackberry	BDL	
Celtis reticulata	western hackberry	BDS	
Celtis sinensis	Chinese hackberry	BDL	41
Ceratonia siliqua	algarrobo Europeo	BEM	

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

Sample Size Calculator

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)	Expected proportion of tree survival (75% required)	75%
	Calculated sample size	87

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

Directions

1) Margin of error, the default value of 15% is used.

2) Confidence level, the default value of 95% is used.

3) The total number of original sites is automatically filled in from the Planting List tab.

4) Mean stored CO_2 for all tree types 25 years after planting is automatically filled in from Table 4 below.

5) Standard deviation of the average CO_2 stored for all tree types 25 years after planting is automatically filled in from the Table 4.

6) Expected proportion of tree survival – for sampling purposes we conservatively estimate that 75% of the planted trees are expected to survive. This value is used as the default in the Sample Size Calculator.

Table 4. Stored CO_2 (kg) by tree type for years after planting in Inland Valley climate zone.

Age	BDL	BDM	BDS	BEL	BEM	BES	CEL	CEM	CES	Avg.	Std. Dev.
5	104	251	78	59	24	13	39	13	47		
10	434	725	230	239	133	60	259	203	167		
15	1,011	1,232	395	570	315	150	761	964	315		
20	1,836	1,735	560	1,062	550	288	1,623	2,021	475		
25	**2,894**	**2,223**	**721**	**1,718**	**824**	**478**	**2,912**	**2,162**	**640**	**1,128**	**642**
30	4,167	2,695	877	2,536	1,128	725	4,688	2,162	807		
35	5,631	3,150	1,028	3,505	1,454	1,031	7,006	2,162	974		
40	7,259	3,589	1,174	4,614	1,799	1,400	9,918	2,162	974		

Random Sampling

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

Random List of Sites
124
129
16
165
194
5
30
182
207

Directions

1) Replace the XXXX in the following formula with the total number of sites, =RANDBETWEEN(1,XXXX). Copy and paste that formula into cell B5.

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

3) Copy and paste that formula into cell B6. You will get a #NUM! error in that cell. Double click that cell and then press CTRL+SHIFT+ENTER to enter this as an array formula.

4) Copy cell B6 down for as many rows as you are required to sample, the resulting values should all be unique.

5) Starting in cell B5 you have a list of random site numbers where you will collect data.

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

Sample Data

Dirtections

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

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

Table 5. Sample Data on Tree Numbers

Sample Data	Number of Sites Originially Planted	Sampled - No. Live Original Planting	Sampled - No. Live 1st Replacements	Sampled - No. Live 2nd Replacements	Total Sites Sampled - Live Trees	Sampled Dead - Original Planting Not Replaced	Sampled - Dead - 1st Replacements, Not Replaced	Sampled - Dead - 2nd Replacements, Not Replaced	Total Sites Sampled - Vacant / Dead Trees	Total Sites Sampled	Original Planting Survival (%)	Current Survival w/ Replacements (%)	Extrapolation Factor	Total Number Live Trees Inferred from Sample
Brdlf Decid Large (>50 ft)	140	34	4	1	39	12	1	0	13	52	65	75	2.69	105
Brdlf Decid Med (30-50 ft)	94	23	1	1	25	12	3	0	15	40	58	63	2.35	59
Brdlf Decid Small (<30 ft)	16	4	1	0	5	3	0	0	3	8	50	63	2.00	10
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	61	6	2	69	27	4	0	31	100	61	69		174

Forward Credits

Directions

Using the information you provide and background data, the tool calculates the amount of credits that could be issued at years 1 (10%), 3 (40%) and 5 (30%) after planting. A mortality deduction (% loss) is applied to account for tree losses based on sampling results.

Table 6. Forward credits are based on 10%, 40% and 30% at Years 1, 3 and 5 after planting, respectively, of the projected CO2 stored by live trees 25-years after planting. This value accounts for tree losses based on sampling results.

						10%	40%	30%
	No. Sites Planted	**No. Live Trees**	**Mortality Deduction (%)**	**25-yr CO_2 stored (kg/tree)**	**Tot. 25-yr CO_2 stored (t)**	**10% CO_2 (t)**	**40% CO_2 (t)**	**30% CO_2 (t)**
BDL	140	105	0.25	2894.27	303.9	30.39	121.56	91.17
BDM	94	59	0.38	2223.15	130.6	13.06	52.24	39.18
BDS	16	10	0.38	720.75	7.2	0.72	2.88	2.16
BEL	0	0	0	0.00	0.0	0.00	0.00	0.00
BEM	0	0	0	0.00	0.0	0.00	0.00	0.00
BES	0	0	0	0.00	0.0	0.00	0.00	0.00
CEL	0	0	0	0.00	0.0	0.00	0.00	0.00
CEM	0	0	0	0.00	0.0	0.00	0.00	0.00
CES	0	0	0	0.00	0.0	0.00	0.00	0.00
	250	174	0.31		441.7	44.17	176.69	132.51

Total CO_2

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

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

Tree-Type	**No. Sites Planted**	**Extrap. Factor**	**Total Live (Original + Replaced Trees) Sampled**	**Total Number Live Trees Inferred from Sample**	**Sample CO_2 Tot. (kg)**	**Grand Total CO_2 (t)**
Brdlf Decid Large (>50 ft)	140	2.69	39	105	112,876.5	303.90
Brdlf Decid Med (30-50 ft)	94	2.35	25	59	55,578.7	130.61
Brdlf Decid Small (<30 ft)	16	2.00	5	10	3,603.7	7.21
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	172,058.9	441.72

CO_2 Summary

Directions
In Table 8, enter the low and high price of CO_2 in $ per tonne (t).

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

Table 8. CO_2 value

	CO_2 $ per tonne
Low	$20.00
High	$40.00

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

Tree-Type	Total CO_2 (t) at 25 years	Low $ value	High $ value
Brdlf Decid	441.72	$8,834.31	$17,668.63
Brdlf Evgrn	0.00	$0.00	$0.00
Conif Evgrn	0.00	$0.00	$0.00
Total	441.72	$8,834.31	$17,668.63
	CO_2 (t)	**Total $**	**Total $**
Grand Total CO_2 (t) at 25 years:	441.72	$8,834.31	$17,668.63
High Est. with Error:	507.97	$10,159.46	$20,318.92
Low Est. with Error:	375.46	$7,509.17	$7,509.17
± 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

Progress Credit Quantification

There are two different methods for quantifying carbon storage for progress credits in urban forest carbon projects – the Single Tree Method (where planted trees are few or are scattered among many existing trees) and the Tree Canopy Method (where planted trees are relatively contiguous). The Project Operator (PO) can decide which approach to use.

Single Tree Method

The PO calculates the amount of CO_2 currently stored by planted project trees in metric tonnes (t) on a tree-by-tree basis and calculates the total for all live trees, based on sampling of the resource. The following steps are required and illustrated

for a hypothetical planting of 500 street/front yard sites in Sacramento, with 71 trees sampled 25-years after planting.

Step 1. Acquire the following information: numbers of trees planted, date planted, species name and tree-type for each species, gps location and climate zone (Table 1).

Tree types: BDL = broadleaf deciduous large, BDM = broadleaf deciduous medium, BDS = broadleaf deciduous small, BEL = broadleaf evergreen large, BEM = broadleaf evergreen medium, BES = broadleaf evergreen small, CEL = conifer evergreen large, CEM = conifer evergreen medium, CES = conifer evergreen small.

Table 1. Planting list for street tree sites in Sacramento, CA (Inland Valley climate zone).

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

Step 2. Measure and record species, status (i.e., alive, standing dead, removed (date), replaced (date/species) and current dbh of live trees (to nearest 1-inch or 2.54-cm) from a sample or census of planted tree sites.

The number of tree sites to sample is derived using the Sample Size Calculator (Fig. 1).

Figure 1. The PO enters project information described below to calculate the sample size necessary to adequately quantify carbon storage.

	Sample Size Calculator*	
Description		**Value**
1) Choose:	**Margin of Error (15% recommended)**	**15%**
2) Choose:	**Confidence level (95% recommended)**	**95%**
3) Enter:	**Total number of project sites**	**500**
4) Enter:	**Mean stored CO2 per tree (kg)**	**1,534**
5) Enter:	**Standard deviation of stored CO2 (kg)**	**832**
6) Enter:	**Expected proportion of tree survival**	**85%**
	Calculated sample size	**76**

* Normally assumes 15% margin of error at a 95% confidence interval.

The PO enters the following information:

1) Choose the margin of error from the drop down menu, 15% is recommended.
2) Choose the confidence level value (%) from the drop down menu, 95% is recommended.
3) The total number of sites - Enter the total number of original sites, in this example 500.
4) Mean stored CO_2 per tree – using Table 2, look-up the mean CO_2 stored by all tree types for the closest age after planting date, in this case 25-years after planting. Enter this number (1,534 kg) into the Sample Size Calculator.
5) Standard deviation of stored CO_2 – using Table 2, look-up the standard deviation of CO_2 stored by all tree types for the closest age after planting date, in this case 25-years after planting. Enter this number (832 kg) into the Sample Size Calculator.

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, in this case 85% (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 and then multiplying by 100). Note: if you do not have an estimate for tree survival, 50% should be entered.

Table 2. The Stored CO_2 By Age Look-Up Table shows kg stored per tree by tree-type for years after planting in Sacramento, CA (Inland Valley climate zone). There is an equivalent table for each of the 16 U.S. climate zones. Values in the highlighted column for 25-year old trees are used in the Sample Size Calculator and Forward Crediting.

CO2 (kg)	BDL	BDM	BDS	BEL	BEM	BES	CEL	CEM	CES		Std.
Age	ZESE	PYCA	PRCE	CICA	MAGR	ILOP	SESE	PIBR2	PICO5	Avg.	Dev.
5	45	251	78	59	24	13	39	13	47		
10	236	725	230	239	133	60	259	203	167		
15	630	1,232	395	570	315	150	761	964	315		
20	1,256	1,735	560	1,062	550	288	1,623	2,021	475		
25	2,127	2,223	721	1,718	824	478	2,912	2,162	640	1,534	832
30	3,243	2,695	877	2,536	1,128	725	4,688	2,265	807		
35	4,595	3,150	1,028	3,505	1,454	1,031	7,006	2,371	974		
40	6,166	3,589	1,174	4,614	1,799	1,400	9,918	2,479	974		

In this example, 76 sites are needed for sampling to achieve a 15% margin of error with a 95% confidence level for the 500 original project sites, 25 years after planting. Because the gps location of each site was taken when the trees were planted, relocating the tree sites is straightforward. The PO randomly samples 76 of the original sites without bias, visiting each site whether a tree is known to be alive, dead or removed. Because each site is numbered she creates a random number list (i.e., RANDBETWEEN function) without duplicates in Excel to identify the sites to sample.

Table 3. Results from Step 2 combined with information from Step 1 indicate that 76 sites were sampled, 19 of the originally planted trees were removed and 57 remained alive (57+19=76). Of the 19 trees that were removed, 17 were replaced

with the same tree-type. Hence, the total number of live trees is 74 (57 originals +17 replacements). This example assumes that all replacements survived.

Sample Data	Tree-Type	No. Sites Planted	No. Sites Sampled	No. Removed Trees	No. Live Trees	No. Replaced Trees	Total Live + Replaced Trees
Brdlf Decid Large (>50 ft)	BDL	120	20	4	15	4	19
Brdlf Decid Med (30-50 ft)	BDM	70	10	3	7	3	10
Brdlf Decid Small (<30 ft)	BDS	50	9	3	7	2	9
Brdlf Evgrn Large (>50 ft)	BEL	80	12	2	9	2	11
Brdlf Evgrn Med (30-50 ft)	BEM	55	7	3	4	3	7
Brdlf Evgrn Small (<30 ft)	BES	30	4	1	3	1	4
Conif Evgrn Large (>50 ft)	CEL	50	8	1	7	1	8
Conif Evgrn Med (30-50 ft)	CEM	45	6	2	5	1	6
Conif Evgrn Small (<30 ft)	CES	0	0	0	0	0	0
		500	76	19	57	17	74

Step 3. Record the number of live + replaced trees sampled by tree-type and dbh class (Table 4).

Table 4. This table shows the distribution of the 74 live sampled trees by dbh class. Replacement trees are smaller than the originally planted trees. The initial version of this table is in 1-inch dbh increments, because tree dbh is measured to the nearest 1-inch. The spreadsheet will bin these into 3- and 6-inch dbh classes used to calculate co-benefits.

	Tree-Type	0-3"	3-6"	6-9"	9-12"	12-15"	15-18"	18-21"	21-24"	24-27"	27-30"	Total Number
Brdlf Decid Large (>50 ft)	BDL	2	2	1	4	5	5	0	0	0	0	19
Brdlf Decid Med (30-50 ft)	BDM	3	0	0	0	2	5	0	0	0	0	10
Brdlf Decid Small (<30 ft)	BDS	0	2	2	5	0	0	0	0	0	0	9
Brdlf Evgrn Large (>50 ft)	BEL	1	1	1	0	0	4	4	0	0	0	11
Brdlf Evgrn Med (30-50 ft)	BEM	2	1	0	0	2	2	0	0	0	0	7
Brdlf Evgrn Small (<30 ft)	BES	1	0	1	2	0	0	0	0	0	0	4
Conif Evgrn Large (>50 ft)	CEL	0	1	0	0	0	0	0	0	6	1	8
Conif Evgrn Med (30-50 ft)	CEM	1	0	0	0	0	0	3	2	0	0	6
Conif Evgrn Small (<30 ft)	CES	0	0	0	0	0	0	0	0	0	0	0
		10	7	5	11	9	16	7	2	6	1	74

Step 4. Multiply the number of live trees for each tree-type in Table 4 by the CO_2 Stored by DBH Look-Up Table values in Table 5 below. The amount of CO_2 stored is calculated and shown for sampled live trees in Table 6 below.

Table 5. CO_2 Stored by DBH Look-Up Table. The version of the table shows values in 1-inch dbh increments. There is a separate table for each of the 16 US climate zones.

dbh (cm)	2.5	5.1	7.6	10.2	12.7	15.2	17.8	20.3	22.9	25.4	27.9	30.5	33.0	35.6	38.1	40.6	43.2	45.7	48.3	50.8	53.3	55.9	58.4	61.0	63.5	66.0	68.6	71.1	73.7	76.2
dbh (inches)	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"	11"	12"	13"	14"	15"	16"	17"	18"	19"	20"	21"	22"	23"	24"	25"	26"	27"	28"	29"	30"
Brdlf Decid Large (>50 ft)	1	5	14	30	55	89	135	193	265	351	453	571	708	863	1,038	1,233	1,451	1,690	1,953	2,240	2,553	2,891	3,256	3,649	4,069	4,520	5,000	5,510	6,053	6,627
Brdlf Decid Med (30-50 ft)	3	17	44	85	142	216	309	420	552	704	878	1,073	1,291	1,532	1,797	2,086	2,399	2,738	3,103	3,493	3,910	4,354	4,824	5,323	5,850	6,404	6,988	7,601	8,243	8,914
Brdlf Decid Small (<30 ft)	3	13	34	66	111	169	242	329	432	552	687	840	1,011	1,200	1,408	1,634	1,880	2,145	2,430	2,736	3,063	3,410	3,779	4,170	4,582	5,017	5,474	5,954	6,457	6,983
Brdlf Evgrn Large (>50 ft)	1	6	18	37	64	102	151	212	285	373	475	592	725	875	1,042	1,227	1,431	1,654	1,896	2,160	2,444	2,750	3,078	3,428	3,802	4,200	4,621	5,067	5,539	6,036
Brdlf Evgrn Med (30-50 ft)	1	4	12	26	47	76	114	162	221	291	374	470	580	704	844	999	1,172	1,361	1,568	1,794	2,039	2,303	2,588	2,894	3,220	3,569	3,941	4,335	4,753	5,194
Brdlf Evgrn Small (<30 ft)	3	14	37	71	119	182	260	355	466	594	741	906	1,091	1,295	1,519	1,764	2,030	2,317	2,626	2,956	3,310	3,686	4,086	4,509	4,955	5,426	5,922	6,442	6,987	7,557
Conif Evgrn Large (>50 ft)	1	4	11	23	41	66	98	139	188	247	316	395	486	588	703	830	970	1,124	1,292	1,475	1,673	1,886	2,115	2,360	2,622	2,901	3,197	3,511	3,844	4,195
Conif Evgrn Med (30-50 ft)	1	5	13	28	49	79	118	166	225	295	377	472	580	702	839	991	1,159	1,343	1,543	1,762	1,998	2,252	2,526	2,819	3,132	3,465	3,819	4,194	4,591	5,011
Conif Evgrn Small (<30 ft)	1	4	12	25	44	70	104	147	199	261	333	417	513	621	742	876	1,024	1,187	1,364	1,557	1,766	1,990	2,232	2,491	2,767	3,062	3,375	3,707	4,058	4,428

Table 6. CO_2 stored for the 74 sampled live trees (kg) (rounded to the nearest whole number)

dbh (cm)	2.5	5.1	7.6	10.2	12.7	15.2	17.8	20.3	22.9	25.4	27.9	30.5	33.0	35.6	38.1	40.6	43.2	45.7	48.3	50.8	53.3	55.9	58.4	61.0	63.5	66.0	68.6	71.1	73.7	76.2	Sample
dbh (inches)	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"	11"	12"	13"	14"	15"	16"	17"	18"	19"	20"	21"	22"	23"	24"	25"	26"	27"	28"	29"	30"	Total
Brdlf Decid Large (>50 ft)	0	5	14	0	110	0	0	0	265	351	905	571	1,416	1,726	1,038	1,233	2,901	3,380	0	0	0	0	0	0	0	0	0	0	0	0	13,915
Brdlf Decid Med (30-50 ft)	3	17	44	0	0	0	0	0	0	0	0	1,291	0	1,797	4,172	2,399	5,476	0	0	0	0	0	0	0	0	0	0	0	0	0	15,199
Brdlf Decid Small (<30 ft)	0	0	0	66	111	0	0	0	865	1,655	1,375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,072
Brdlf Evgrn Large (>50 ft)	0	6	0	0	64	0	0	212	0	0	0	0	0	0	0	1,227	2,861	1,654	3,793	4,319	0	0	0	0	0	0	0	0	0	0	14,136
Brdlf Evgrn Med (30-50 ft)	0	0	25	26	0	0	0	0	0	0	0	0	0	704	844	999	1,172	0	0	0	0	0	0	0	0	0	0	0	0	0	3,770
Brdlf Evgrn Small (<30 ft)	0	14	0	0	0	0	0	355	0	594	741	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,704
Conif Evgrn Large (>50 ft)	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,622	8,702	6,394	3,511	0	0	0	21,253
Conif Evgrn Med (30-50 ft)	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,543	1,762	1,998	2,252	2,526	0	0	0	0	0	0	0	10,095
Conif Evgrn Small (<30 ft)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	42	96	116	285	0	0	566	1,129	2,600	3,021	571	2,707	2,430	3,678	7,631	9,333	10,510	5,336	6,081	1,998	2,252	2,526	0	2,622	8,702	6,394	3,511	0	0	84,145

Step 5. In this step Extrapolation Factors are calculated that are used to scale-up tree numbers from the sample to the population. Calculate the Extrapolation Factor (# sites planted / # sites sampled) for each tree-type (Table 7). Although not required for the carbon calculations, the sample's gross and net survival rates show the significance of replacement plantings. Gross survival is calculated without replacement as:

Gross survival = (# live that were originally planted/#sample sites) * 100

Net survival is with replacements = (total live + replaced / #sample sites) * 100

Table 7. Of the original planting, sample results indicate that 75% survived (i.e., gross survival rate). With replacements, 97.4% of the sites contained live trees (i.e., net survival rate). The Extrapolation Factor for each tree-type is shown (i.e., for the CEM tree-type it is 7.5 (45/6).

Sample Data	Tree-Type	Number Sites Planted	No. Sites Sampled	No. Live (Original Planting)	Gross Survival (%)	No. Replace-ment Plt.	Total Live + Replaced Trees	Net Survival (%)	Extrap. Factor
Brdlf Decid Large (>50 ft)	BDL	120	20	15	75.0	4	19	95.0	6.00
Brdlf Decid Med (30-50 ft)	BDM	70	10	7	70.0	3	10	100.0	7.00
Brdlf Decid Small (<30 ft)	BDS	50	9	7	77.8	2	9	100.0	5.56
Brdlf Evgrn Large (>50 ft)	BEL	80	12	9	75.0	2	11	91.7	6.67
Brdlf Evgrn Med (30-50 ft)	BEM	55	7	4	57.1	3	7	100.0	7.86
Brdlf Evgrn Small (<30 ft)	BES	30	4	3	75.0	1	4	100.0	7.50
Conif Evgrn Large (>50 ft)	CEL	50	8	7	87.5	1	8	100.0	6.25
Conif Evgrn Med (30-50 ft)	CEM	45	6	5	83.3	1	6	100.0	7.50
Conif Evgrn Small (<30 ft)	CES	0	0	0	0.0	0	0	0.0	0.00
		500	76	57	75.0	17	74	97.4	

Step 6. Apply the Extrapolation Factors from Table 7 to scale-up from the sample to the population for each tree-type (Extrap. Factor * Live Sample Trees = Total Number of Live Trees). Cut and paste the Sample CO_2 Total (kg) from Table 6, and multiply by the Total Number of Live Trees to calculate Grand Total CO_2. Convert from kg to metric tonnes (divide by 1000) (Table 8).

Table 8. This table shows that there are an estimated 487 live trees (Ext. Factors x Live Sample Trees). The amount of CO_2 stored by the 76 sample trees is 84,145 kg, and when converted to tonnes and extrapolated to the population of 487 trees, totals 557.7 t CO_2.

Sample Data	Tree-Type	No. Sites Planted	Extrap. Factor	Live Sample Trees	Total Number Live Trees	Sample CO2 Tot. (kg)	Grand Total CO2 (t)
Brdlf Decid Large (>50 ft)	BDL	120	6.00	19	114	13,915	83.5
Brdlf Decid Med (30-50 ft)	BDM	70	7.00	10	70	15,199	106.4
Brdlf Decid Small (<30 ft)	BDS	50	5.56	9	50	4,072	22.6
Brdlf Evgrn Large (>50 ft)	BEL	80	6.67	11	73	14,136	94.2
Brdlf Evgrn Med (30-50 ft)	BEM	55	7.86	7	55	3,770	29.6
Brdlf Evgrn Small (<30 ft)	BES	30	7.50	4	30	1,704	12.8
Conif Evgrn Large (>50 ft)	CEL	50	6.25	8	50	21,253	132.8
Conif Evgrn Med (30-50 ft)	CEM	45	7.50	6	45	10,095	75.7
Conif Evgrn Small (<30 ft)	CES	0	0.00	0	0	0	0.0
		500		74	487	84,145	557.7

Step 7. Incorporate error estimates and prices to illustrate the range of amount stored and value (Table 9). Sum the tonnes of CO_2 for the three tree-types (Brdlf Decid, Brdlf Evgrn, and Conif Evgrn) and put the totals into Table 9.

Table 9. This summary table shows that with the ±15% error added to the 557.7 t grand total CO_2 stored (see Appendix 1), the actual amount of CO_2 stored is likely to range between 474 t and 641 t. The estimated value, assuming prices of $20 and $40 per tonne, ranges from $9,481 to $25,654.

	t CO2	$ 20.00	$ 40.00
Tree-Type	at 25 yrs	$ value	$ value
Brdlf Decid	212.5	$ 4,250	$ 8,500
Brdlf Evgrn	136.6	$ 2,733	$ 5,466
Conif Evgrn	208.5	$ 4,171	$ 8,342
Total	557.7	$ 11,154	$ 22,308
	CO2 (t)	Total $	Total $
Total CO2 (t):	557.7	$ 11,154	$ 22,308
High Est.:	641.3	$ 12,827	$ 25,654
Low Est.:	474.0	$ 9,481	$ 18,962
± 15% error = ± 10% formulaic ± 3% sampling			
± 2% measurement (see Appendix 1)			

Step 8. Calculate co-benefits (Table 10).

Co-benefits are shown in Table 10 for 487 live trees 25-years after planting. The total annual value of ecosystem services is $13,861, or $27.72 per site (500 tree sites planted). Estimated energy savings ($6,807) 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 $3,291. Benefits associated with the uptake of air pollutants by trees (net $3,278) is somewhat offset by BVOC emissions. Avoided CO_2 emissions associated with energy savings is valued at $486 assuming a CO_2 price of $20 per t. These co-benefits are first-order approximations and dollar values may not reflect the most current prices for local environmental and utility services.

Table 10. Co-benefits estimated for the 487 live trees 25 years after planting calculated using the Inland Valley data found in the i-Tree Streets and Design software. i-Tree prices were used, except for CO_2, which was $20 per tonne.

Resource Units in ( )		Res Units	RU/site	Total $	$/site
Interception (m3)		1,597.0	3.19	$3,291	$6.58
CO2 Avoided (kg, $20/t)		24,289	48.58	$486	$0.97
Air Quality (kg)					
O3		135.35	0.27	$1,493	$2.99
NOx		36.39	0.07	$1,026	$2.05
PM10		86.04	0.17	$1,785	$3.57
Net VOCs		-99.27	-0.20	-$1,026	-$2.05
Air Quality Total		158.52	0.32	$3,278	$6.56
Energy (kWh & kBtu)					
Cooling - Elec.		56,987	113.97	$6,645	$13.29
Heating - Nat. Gas		13,009	26.02	$162	$0.32
Energy Total				$6,807	$13.61
Grand Total				$13,861	$27.72

Tree Canopy Method

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Area" the user can prompt i-Tree Canopy to provide an estimate of the area in Tree or Non-Tree cover. In this example, the PA is 12.5 acres.

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

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

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

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

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

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

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

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

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

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

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

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

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

References and Resources

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

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

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

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

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

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

Error Estimates in Carbon Accounting

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

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

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

Formulaic Error

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

Mean total carbon (C) storage in the sampled urban oaks was 423 kg, while i-Tree ECO over-predicted storage by 14% (483 kg C) with a RMSE of 51% (217 kg C). The CTCC under-predicted total C storage by 9% and had a RMSE of 611 kg (39%)

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

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

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

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

Sampling Error

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

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

Measurement Error

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

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