California Environmental Protection Agency

AIR RESOURCES BOARD

Compliance Offset Protocol Urban Forest Projects

Adopted: October 20, 2011

(This page left intentionally blank)

Table of Contents

Abbreviations and Acronyms 1
1 Introduction 2
2 The GHG Reduction Project 3
2.1 Project Definition – Quantification Methodology 3
2.2 Offset Project Operator or Authorized Project Designee 3
3 Eligibility Rules 4
3.1 Location 4
3.2 Offset Project Commencement 4
3.3 Project Crediting Period 4
3.4 Additionality 4
3.5 Regulatory Compliance 6
4 Offset Project Boundary – Quantification Methodology 7
4.1 Leakage 8
5 GHG Calculation Methods – Quantification Methodology 9
5.1 Quantifying Project Tree CO_2 Sequestration 9
5.2 Quantifying GHG Emissions from Motor Vehicles Related to Tree Planting and Care 11
5.3 Quantifying GHG Emissions from Equipment Related to Tree Planting and Care 12
5.4 Quantifying GHG Emissions from Vehicles and Equipment for Municipalities with Insufficient Data 14
6 Permanence 15
7 Offset Project Monitoring – Quantification Methodology 16
7.1 Tree Maintenance Plan 16
7.2 Project Tree Monitoring Plan 18
7.3 GHG Emissions and Sequestration Activity Data 18
8 Reporting Parameters 20
8.1 Annual Reporting Requirements 20
8.2 Document Retention 20
8.3 Verification Cycle 20
9 Regulatory Verification Requirements 21
10 Glossary of Terms 22
11 References 24
Appendix A Urban Forest Inventories and Sampling – Quantification Methodology 25
A.1 Options for Data Collection 25
A.2 Complete Inventory 25
A.3 Sampling from Populations 29
Appendix B Calculating Biomass and Carbon – Quantification Methodology 35
B.1 Estimating Biomass and Carbon Using Volumetric Equations 35
B.2 Error in Estimating Carbon and Biomass 37
B.3 Reporting Uncertainty versus Inherent Uncertainty 37
Appendix C Offset Project Listing Information 40
Appendix D Offset Project Data Report 42

List of Tables

Table 6.1. Sampling Error and Carbon Stock Change Adjustment 11
Table 6.2. Carbon Dioxide Emission Factors for Fuels 11

Table 6.3. Typical Load Factors (LF) and Average CO_2 Emissions (EF) for Maintenance Equipment....13
Table 6.4. Total Hours of Equipment Run-Time for Tree Pruning and Removal....14
Table A.1. Example of Common Data Fields for Tree Inventorying....26
Table A.2. Minimum Required Sampling Criteria....33
Table A.3. Summary Results for Each Plot in a Stratum....34
Table B.1. Volume Equations for 26 Urban Tree Species....38
Table B.2. Dry Weight Biomass Equations....39

List of Figures

Figure A.1. Measuring DRC in Various Situations....28
Figure A.2. Example of Tree with Erratic Leader....29

Abbreviations and Acronyms

ARB	California Air Resources Board
C	Carbon
CAR	Climate Action Reserve
CH_4	Methane
CO_2	Carbon dioxide
dbh	Diameter at breast height
GHG	Greenhouse gas
lb	Pound
N_2O	Nitrous oxide
NTG	Net tree gain
Regulation	Cap-and-Trade Regulation, title 17, California Code of Regulations, sections 95800 et seq.
TMP	Tree maintenance plan
USFS	United States Forest Service

1 Introduction

The Compliance Offset Protocol Urban Forest Projects provides methods to quantify and report greenhouse gas (GHG) removal enhancements associated with a planned set of tree planting and maintenance activities to permanently increase carbon storage in trees. This protocol is based on The Climate Action Reserve's Urban Forest Project Protocol Version 1.1[1] (CAR 2010).

Offset Project Operators or Authorized Project Designees that implement tree-planting programs must use this protocol to quantify and report GHG removal enhancements. The protocol provides eligibility rules, methods to quantify GHG removal enhancements, offset project-monitoring instructions, and procedures for reporting Offset Project Data Reports. Additionally, all offset projects must submit to independent verification by ARB-accredited verification bodies at least once every six years. Requirements for verification bodies to verify offset project emissions data reports are provided in the Cap-and-Trade Regulation (Regulation).

To register urban forest project GHG removal enhancements, Offset Project Operators and Authorized Project Designees are not required to prepare and submit an annual municipal, campus, or utility-level GHG inventory.

This protocol is designed to ensure the complete, consistent, transparent, accurate, and conservative quantification of GHG emission reductions associated with urban forest projects. The protocol is comprised of both quantification methodologies and regulatory program requirements to develop an urban forest project and generate ARB or registry offset credits.

AB 32 exempts quantification methodologies from the Administrative Procedure Act (APA)[2]; however those elements of the protocol are still regulatory. The exemption allows future updates to the quantification methodologies to be made through a public review and Board adoption process but without the need for rulemaking documents. Each protocol identifies sections that are considered quantification and exempt from APA requirements. Any changes to the non-quantification elements of the offset protocols would be considered a regulatory update subject to the full regulatory development process. Those sections that are considered to be a quantification methodology are clearly indicated in the title of the chapter or subchapter if only a portion of that chapter is considered part of the quantification methodology of the protocol.

[1] Climate Action Reserve (2010) Urban Forest Project Protocol Version 1.1 March 10, 2010 http://www.climateactionreserve.org/how/protocols/adopted/urban-forest/current-urban-forest-project-protocol/ (accessed May 20, 2011).
[2] Health and Safety Code section 38571.

2 The GHG Reduction Project

2.1 Project Definition – Quantification Methodology

For the purpose of this protocol, the GHG reduction (“removal enhancement”) project is defined as a planned set of tree planting and maintenance activities that permanently increase carbon storage, taking into account GHG emissions associated with planting and maintenance of project trees.

While project trees are planted for the purposes of the urban forest GHG project, tree sites are the primary unit of analysis. A tree site contains one tree at a time, however, the tree may be replaced over time and the site itself may be moved. This is because project trees are subject to mortality and other types of losses and therefore may need to be replaced and/or relocated during the offset project life (see Section 6 for details).

This protocol is not applicable for forest management and conservation activities that occur on large natural forested tracts within cities (≥ 100 acres contiguously forested and containing dead downed woody material).

An Offset Project Operator or Authorized Project Designee can assemble several smaller offset projects into a single offset project for the purposes of achieving economies of scale and more efficient reporting. However, reporting, monitoring, and verification practices must follow the requirements set forth in this protocol and the Regulation.

This protocol is applicable to three specific project types: urban forest GHG projects undertaken (1) in municipalities[3], (2) on educational campuses[4], and (3) by utilities. An offset project is defined by a specific number of project tree sites, determined a priori, that will be planted and maintained within one of the above types of entities over the offset project life. If the Offset Project Operator or Authorized Project Designee intends to plant more project tree sites than the number defined under the original offset project, this constitutes a second, distinct urban tree project. Offset Project Operators or Authorized Project Designees can undertake as many urban tree projects as desired in the future as long as they each, separately, meet the eligibility criteria and reporting requirements in this protocol and set forth in the Regulation.

2.2 Offset Project Operator or Authorized Project Designee

The Offset Project Operator or Authorized Project Designee is responsible for offset project listing, monitoring, reporting and verification. The Offset Project Operator or Authorized Project Designee must have legal authority to implement the offset project. For the purpose of this protocol, an Offset Project Operator or Authorized Project

[3] Including cities, counties, and other local agencies or special districts.
[4] As noted in Section 4, the physical area owned and/or controlled by the municipality, educational campus, or utility determines municipal, campus, or utility service area boundaries. In the case of educational campuses, the Offset Project Operator or Authorized Project Designee may define the entity as a single campus or a system of campuses, as long as the definition is clearly stated and the entity can demonstrate that it has ownership and/or control over the physical area.

Designee must represent a municipality, educational institution, or utility. The Offset Project Operator or Authorized Project Designee must submit the information in Appendix C along with the listing requirements in the Regulation. Responsibility for tree planting, care, and maintenance activities may reside with either the Offset Project Operator or Authorized Project Designee.

3 Eligibility Rules

General eligibility requirements for offset projects are set forth in the Regulation. The Offset Project Operator or Authorized Project Designee using this protocol must also satisfy the following rules to be eligible to receive ARB or registry offset credit.

3.1 Location

Only offset projects located in the United States and its territories are eligible under this protocol. In addition, offset projects situated on the following categories of land are only eligible under this protocol if they meet the requirements of this protocol and the Regulation, including the waiver of sovereign immunity requirements of section 95975(l) in the Regulation:

1. Land that is owned by, or subject to an ownership or possessory interest of a Tribe;
2. Land that is “Indian lands” of a Tribe, as defined by 25 U.S.C. §81(a)(1); or
3. Land that is owned by any person, entity, or Tribe, within the external borders of such Indian lands.

Project tree sites must be located according to the requirements in Section 4 (average spacing of no less than 5 meters and placement along streets, in parks and parking lots, etc.) Thus, urban forest projects must take place in urban or other types of developed areas.

3.2 Offset Project Commencement

Offset Project Commencement for an urban forest project is defined as the date at which the Offset Project Operator or Authorized Project Designee implements a planned set of tree planting activities and becomes operational. For the purposes of this protocol, the commencement of operation means when trees are planted and regular maintenance begins. Offset projects may always be submitted for listing prior to their commencement date.

3.3 Project Crediting Period

The crediting period for this project type is 25 years. Requirements for renewal of offset project crediting periods are set forth in the Regulation.

3.4 Additionality

Offset projects must meet the additionality requirements in the Regulation, in addition to the requirements below.

3.4.1 Net Tree Gain – Quantification Method

The offset project must demonstrate a priori that it will exceed the business-as-usual threshold, and information confirming this, in accordance with the requirements below, must be provided in the documentation for applying for offset project listing as set forth in Appendix C.

The business-as-usual threshold comparison for municipalities, educational campuses, and utilities is based on information within the area the offset project will take place. If a partner organization/individual working with a municipality, educational campus, or utility plants trees outside the offset project boundary, these activities should not be included in the comparison.

Municipalities and Educational Campuses

The business-as-usual thresholds for municipalities and educational campuses are measured in terms of net tree gain (NTG), i.e., the annual number of trees planted by a municipality or educational campus minus the annual number of trees removed by a municipality or educational campus. Only project activities that exceed this threshold are eligible.

The threshold for municipalities and educational campuses is set at maintaining a stable urban forest population (i.e. a NTG of 0). In other words, municipalities and educational campuses must plant at least as many trees as they remove.

In addition to the requirements for offset project listing, the Offset Project Operator or Authorized Project Designee must demonstrate a priori that an offset project will exceed the threshold, by calculating the anticipated NTG of the municipality, or educational campus, based on recent activities and anticipated project activities. Specifically, the calculation must be based on:

1. The annual average number of urban trees planted and removed in the municipality or educational campus over no more than the most recent five year period preceding the offset project commencement date, or using data from a single year occurring at some point during the past most recent five year period.
2. The expected average annual number of GHG project tree sites to be planted by the offset project.
3. Where urban trees include trees under municipality or educational campus ownership or control and are open-grown in managed landscapes.

In addition to the general requirements for monitoring, reporting, and record retention set forth in the Regulation, for each year of the offset project the Offset Project Operator or Authorized Project Designee is required to report an annual average NTG (number of urban trees planted minus removed) for the municipality, or educational campus, including regular activities (planting of “non-project” trees) and project activities (planting of “project” trees). The annual average NTG must be based on a five-year rolling average (i.e. the most recent previous five years including the reporting year), except in the first five years of the offset project when the average may be based on less than five years of data (i.e. one-year average in the first year of the offset project, two-year average in the second year). When the average annual NTG for the municipality or educational campus is positive (more trees are planted than removed), the number of trees planted in excess of the number removed determines how many eligible project trees can be designated that year. Specific eligible project trees are identified each year by the Offset Project Operator or Authorized Project Designee and tracked individually for the duration of the offset project. Carbon sequestration and GHG emissions from tree care, monitoring, and maintenance of the eligible project trees are the basis for calculating offset project GHG reductions.

If the municipality or educational campus reports a negative NTG in any given year, no new trees planted that year can be considered eligible project trees and no ARB or registry offset credits can be issued. When the municipality or educational campus returns to an average annual NTG of zero or greater, ARB or registry offset credits for GHG reductions from project trees during the intervening years (up to a maximum of five years) can be issued ex-post upon verification, as long as the criteria in this protocol for project trees were met during those years.

Utilities

Most utilities do not have tree planting programs that go beyond replacing trees removed during line clearance operations. While some have programs specifically aimed at storing carbon and conserving energy in residential households, on average utilities are planting fewer than 400 trees annually in these types of programs. All trees planted under these types of programs are considered additional because these types of projects are not common practice and not required by regulation, therefore they are designated as eligible project trees. Trees planted that replace those removed during line clearance operations or are planted for energy conservation are eligible for offset credits. These trees may be used to generate GHG reductions, provided all criteria in this protocol and the regulation are met.

3.5 Regulatory Compliance

Offset Project Operators or Authorized Project Designees must fulfill all applicable local, regional and national requirements for environmental impact assessments that apply based on the offset project location. Offset projects must also meet all other local, regional, and national requirements that might apply. Offset projects are not eligible to receive ARB or registry offset credits for GHG emission reductions or GHG removal enhancements that occur as the result of activities that are not in compliance with regulatory requirements.

4 Offset Project Boundary – Quantification Methodology[5]

The Offset Project Boundary delineates the GHG sources, GHG sinks, and GHG reservoirs that are considered significantly affected by the project activity and must be included in the calculation of GHG reductions.

In this protocol, the Offset Project Boundary is defined as the carbon stored in standing trees and GHG emissions from motor vehicles and equipment used in tree care activities.

Required GHG source and GHG sink categories for reporting are as follows:

- Carbon stored in standing trees
- CO_2 emissions from motor vehicles related to tree planting, care, and monitoring
- CO_2 emissions from equipment related to tree planting and care

CO_2 is the primary GHG to report for urban forest projects.

The Offset Project Boundary includes the components of the project operations that are impacted by the project activity, including the physical area covered by the offset project as well as the specific equipment used by the offset project. This includes:

- The number of eligible project tree sites (determined in Section 3)
- Equipment used to plant and maintain the trees

Tree sites must be located within the boundary of a municipality, educational institution, or utility. Boundaries are determined by the physical area owned and/or controlled by a municipality or educational campus, or the service area covered by a utility.

For each offset project, eligible project trees must be planted:

- Along streets, in parks, city golf courses, cemeteries, near city buildings, greenbelts, city parking lots, and other public open space, or on private property in municipalities
- Along streets, near classrooms, dorms, office buildings, near recreational fields and other facilities, in parking lots, arboretums, and other open space on educational campuses
- In parks, streets, parking lots, private property, and open spaces by utilities

Tree plantings must have an average spacing of no less than 5 meters. Biomass equations for estimating carbon stock changes are for open-growing urban trees and assume relatively intensive management. The spatial location of all project tree sites must be known and recorded using GPS or GIS.

[5] The entirety of Chapter 4 is considered a quantification method.

4.1 Leakage

Leakage is an increase in GHG emissions or decrease in sequestration caused by the offset project but not accounted for within the offset project boundary. In the case of urban forest projects, the most likely form of leakage is the shifting of funds and maintenance from non-project tree resources (i.e. trees within the municipality, educational campus, or utility service area that are not part of the project) to project trees within a municipality, educational campus, or utility service area. For example, if funding is reduced for pruning existing trees to fund a GHG tree planting project, there may be an overall decline in the health of the urban forest within a municipality, educational campus, or utility service area and a long-term increase in mortality. A tree maintenance plan (TMP) is used to assess whether this type of activity-shifting leakage is occurring. Details on the TMP requirements are provided in Section 8.1. If annual expenditures of the municipality, educational campus, or utility (separate from offset project expenditures) in one or more program areas decrease by more than 10% from amounts in the initial TMP or from amounts in the previous year TMP, and these changes cannot be explained by the Offset Project Operator or Authorized Project Designee to the verifier, leakage will be assumed and if confirmed, no ARB or registry offset credits can be issued in that year.

5 GHG Calculation Methods – Quantification Methodology[6]

This section provides the detailed methods for calculating GHG emissions and GHG removal~~s~~ enhancements from the required GHG sources and GHG sinks:

- Carbon storage in standing trees: *Project Tree CO_2 Sequestration*
- GHG emissions from motor vehicles related to tree planting, care, and monitoring: *Vehicle CO_2 Emissions*
- GHG emissions from equipment related to tree planting and care: *Equipment CO_2 Emissions*

Project GHG reductions (removal enhancements) are based on the amount of carbon sequestered in eligible project trees minus GHG emissions from the planting, care and maintenance of those trees over the reporting period. Below is the general formula for determining project GHG reductions.

$$\textit{Project GHG Reductions} = \textit{Project Tree } CO_2 \textit{ Sequestration} - \textit{Vehicle } CO_2 \textit{ Emissions} - \textit{Equipment } CO_2 \textit{ Emissions}$$

5.1 Quantifying Project Tree CO_2 Sequestration

For each crediting period, the Offset Project Operator or Authorized Project Designee estimates the amount of carbon contained in eligible project trees (carbon stocks) and then uses these data to calculate an incremental carbon stock change (carbon sequestration). Carbon stock changes are reported in final units of carbon dioxide equivalent (metric tons CO_2e). The change in carbon stocks (in kilograms) is the basis for estimating project tree carbon sequestration, and is calculated using the equation below. The factor 3.67 is the molecular weight ratio of CO_2 to carbon and is used to convert carbon stock change to CO_2. The factor 0.001 is used to convert the result from kilograms to metric tons.

$$\textit{Project Tree } CO_2 \textit{ Sequestration} = (Cstock_{year\ x} - Cstock_{year\ x-n}) \times (3.67) \times 0.001$$

5.1.1 Quantifying Tree Carbon Stocks

Quantifying the carbon stocks in eligible project trees is based on direct measurements of trees and approved urban tree carbon models ("allometric equations"). Consult Appendix A and Appendix B for detailed requirements.

Appendix A covers how to design tree measurement programs (inventories), including required tree measurement data and sampling techniques, design, and error. Appendix B describes how to estimate tree carbon from tree measurement data using allometric equations.

[6] The entirety of Chapter 5 is considered a quantification method.

Approved approaches for quantifying carbon stocks:

1. Measure all trees in project tree sites during a single year (census). Use the measurement data with approved allometric equations (Appendix B) to estimate tree volume, biomass, and carbon stocks. Data from direct tree measurements (i.e. tree dbh, diameter at breast height, and height if applicable) can be input directly into approved allometric equations.

2. Measure a sample of trees in the project tree population each year (Appendix A), use the measurement data with approved allometric equations to estimate carbon stocks in the samples (Appendix B), and extrapolate the carbon stock estimates to the entire tree population (Appendix A). As described above in Approach 1, direct measurement must be used to estimate tree carbon stock.

5.1.2 Requirements for Tree Monitoring and Acceptable Levels of Uncertainty

In addition to the general requirements for monitoring, reporting, and record retention set forth in the Regulation, a tree monitoring plan must be included as part of the offset project documents (see Section 7.2 for details). The tree monitoring plan must describe in detail the approach the offset project plans to use to quantify carbon stocks. The document will serve as evidence for the Offset Project Operator or Authorized Project Designee and will communicate the methodology to the verification body.

Approach 2 involves statistical extrapolation from sample data. The sampling method must be stratified by like-species and age classes (not to exceed groupings of five-year age classes). The combinations of species and age classes create independent sampling populations, or strata. Appendix A provides further details on stratified sampling design.

The resulting estimates must meet a minimum confidence level of 90% to report all of the estimated carbon stocks. If the project sampling design results in lower levels of confidence, the carbon stock estimates will be discounted according to the method below. See Appendix A for details on sampling programs.

Descriptive statistics must be produced at the time of verification if a sampling methodology is incorporated. The estimate of carbon stock change in project trees is adjusted based on the level of confidence in the carbon stock estimate according to the table below. The table provides sampling error ranges (where sampling error is on either side of the mean estimate at the 90% confidence level), calculated with the following equation:

Sampling Error (90% confidence interval) =	*[(1 Standard Error *1.645)/(Sample mean)] x 100*

Table 5.1. Sampling Error and Carbon Stock Change Adjustment

Sampling Error*	Carbon Stock Change Adjustment (deduction by)
0 to 5%	0%
5.1 to 10%	10%
10.1 to 15%	20%
15.1 to 20%	30%
> 20%	100%

* Minimum confidence interval at 90% confidence limits.

5.2 Quantifying GHG Emissions from Motor Vehicles Related to Tree Planting and Care

Vehicle emissions are those associated with transport of personnel, supplies, and trees to and from eligible project tree sites.

Calculations of CO_2 emissions from vehicles are based on actual fuel use (gallons per year) and an emission factor (kg CO_2 per gallon) for fuel.

$$C_{vehicle\ emis} = TC \times EF$$

Where,

TC = Total annual fuel consumption (gallons)
EF = Emission factor by fuel type. Divide by 1,000 to convert kilograms into metric tons (t).

See the CO_2 emission factors for fuel combustion in the table below.

Table 5.2. Carbon Dioxide Emission Factors for Fuels

Fuel	CO_2 Emission Factor (kg CO_2/gallon)
Aviation Gasoline	8.31
Biodiesel (B100)	9.45
Crude Oil	10.28
Diesel 1 Diesel 2 Diesel 4	10.18 10.21 10.96
Ethane	6.01
Ethanol (E100)	5.75
Isobutane	6.29
Jet Fuel (Jet A or A-1)	9.75
Kerosene	10.15
Liquefied Petroleum Gas (LPG)	5.79
Methanol	4.15

Motor Gasoline	8.78
n-Butane	6.58
Propane	5.59
Residual Fuel Oil (#5,6)	10.21, 11.27
	(kg CO_2/therm)
Natural Gas	5.30

Source: Federal Register, Vol. 74, No. 209 (October 30, 2009)

The volume of fuel consumed during the crediting period can be derived from fuel records data (including bulk fuel purchase records, collected fuel receipts, official logs of vehicle fuel gauges or storage tanks). Where actual fuel use (TC) is not available, it can be estimated using vehicle information (make, model, model year, and fuel type) and annual mileage estimates by vehicle type. For each vehicle, convert annual mileage to fuel consumption using EPA's fuel economy formula below. In this equation, DP_c and DP_h are the proportion of miles traveled spent in city and highway driving conditions, respectively. A DP_c value of 0.55 and a DP_h value of 0.45 may be used as a default value, or a fleet specific number may be substituted if known.

Total Fuel Use (gallons)	=	Total Mileage (miles)	/	(	Fuel Economy City (mpg)	x	DP_c	+	Fuel Economy Highway (mpg)	x	DP_h	)

Alternatively, the amount of fuel used for the eligible project trees can be estimated by prorating total fuel usage for all tree maintenance and monitoring activities of the municipality, educational campus, or utility by the number of eligible project tree sites relative to total trees managed by the municipality, educational campus, or utility.

5.3 Quantifying GHG Emissions from Equipment Related to Tree Planting and Care

Equipment emissions are associated with back hoes used in planting, and chain saws, aerial lifts, and chippers used during tree removal and pruning activities.

If the total amount of fuel consumed by equipment on GHG project-related activities is known, CO_2 emissions can be calculated using fuel-specific emission factors in Table 5.2:

$$C_{equip\ emis} = TC \times EF$$

In many cases, equipment use is tracked in hours. If the hours are known, the emissions can be calculated for each piece of equipment based on the following formula and then summed:

$$C_{equip\ emis} = HRS \times LF \times HP \times EF$$

Where,

HRS	=	Hours used
LF	=	Typical load factor
HP	=	Maximum horsepower
EF	=	Average CO_2 emissions per unit of use (kg/hr)

Typical load factors, horsepower, average emissions, and EFs for equipment are given in Table 5.3. Typical hours required for pruning and removal activities are given for maintenance equipment in Table 5.4.

Table 5.3. Typical Load Factors (LF) and Average CO_2 Emissions (EF) for Maintenance Equipment

Equipment	HP range[b]	LF[a]	EF (kg/hp/hr)[b]
Aerial lift (45 hp)	25<HP≤50	0.505	0.783
Backhoe	HP≤120	0.465	0.775
Chain saw (2 hp)	HP≤2	0.500	0.429
Chain saw (7 hp)	2<HP≤7	0.500	0.429
Chipper (50 hp)	HP≤50	0.370	0.783

[a] Climate Action Reserve 2010, Section 6.3 pg 16.
[b] California Air Resources Board 2008

Table 5.4. Total Hours of Equipment Run-Time for Tree Pruning and Removal

	Pruning				Removal				
dbh	2.3-hp saw	3.7-hp saw	Bucket truck[a]	Chipper[b]	2.3-hp saw	3.7-hp saw	7.5-hp saw	Bucket truck	Chipper
1-6	0.05	NA	NA	0.05	0.3	NA	NA	0.2	0.1
7-12	0.1	NA	0.2	0.1	0.3	0.2	NA	0.4	0.25
13-18	0.2	NA	0.5	0.2	0.5	0.5	0.1	0.75	0.4
19-24	0.5	NA	1.0	0.3	1.5	1.0	0.5	2.2	0.75
25-30	1.0	NA	2.0	0.35	1.8	1.5	0.8	3.0	1.0
31-36	1.5	0.2	3.0	0.4	2.2	1.8	1.0	5.5	2.0
36+	1.5	0.2	4.0	0.4	2.2	2.3	1.5	7.5	2.5

[a] Mean HP = 43
[b] Mean HP = 99

Note: Values by dbh classes (inches) and assume crews work efficiently and equipment is not run idle.

Source: see references in CAR 2010.

5.4 Quantifying GHG Emissions from Vehicles and Equipment for Municipalities with Insufficient Data

In some instances, municipalities may not have the data necessary to calculate GHG emissions for tree planting and maintenance activities as required in Sections 5.2 and 5.3 (if, for instance, tree maintenance activities are contracted out to private entities). If data required to calculate CO_2 emissions from tree planting and maintenance activities is not obtainable, municipal projects may use a default emission factor equal to 4.17 kg CO_2 per project tree per year to calculate the annual CO_2 emissions from all, or a portion of, the tree planting and maintenance activities associated with a municipal urban forest project.[7] However, all offset projects must use the methods described in Sections 5.2 and 5.3 to assess CO_2 emissions from vehicles and equipment if there is sufficient data to do so. The metric listed above is based on survey results from municipal tree planting programs, and is thus only applicable to municipal urban forest projects.

[7] The default emission factor was derived from survey responses detailing annual fuel usage for the tree planting and maintenance activities of 30 municipal urban forest programs nation-wide. The default value is equal to one standard deviation above the mean of the data set.

6 Permanence

The Regulation requires that credited GHG reductions and GHG removal enhancements be "permanent." GHG offset projects involving biological carbon sequestration must address the potential reversibility of sequestered carbon, which is the loss of stored carbon after ARB or registry offset credits have been issued. Consistent with guidance from the Intergovernmental Panel on Climate Change, permanence is defined as 100 years - the biological carbon should remain stored for 100 years (e.g. a reduction of carbon created in 2010 will remain stored until 2110 and if it is reversed, e.g. through mortality, it must be replaced).

Project Life is defined as the period of time between offset project commencement and a period of 100 years following the issuance of any ARB or registry offset credit for GHG reductions or GHG removal enhancements achieved by the offset project. Urban forest offset projects must continue to monitor, verify and report project data for a period of 100 years following any ARB or registry offset credit issuance. For example, if ARB or registry offset credits are issued to an urban forest project in year 25 following offset project commencement, monitoring and verification activities must be maintained until year 125. Offset Project Operators and Authorized Project Designees must take steps to maximize the likelihood that the carbon gains of urban forest projects are preserved for the project life. To this end, the following are requirements of this protocol:

1. All offset projects must monitor onsite carbon stocks, submit annual Offset Project Data Reports, and undergo third-party verification of those reports with site visits at least once every six years for the duration of the Project Life.
2. Continuous replacement of dead project trees at all tree sites during the Project Life (i.e. projects must have an average net tree gain of no less than zero). Prior to removal, dead trees must be measured for dbh (and height, if applicable) and their carbon content calculated and recorded using procedures in Appendix B. Dead trees must be replaced within one year from when they were removed. This timeframe allows for planting to occur at the appropriate time of year (e.g. loss and removal may occur in the fall and replanting occurs in the spring). Each tree site may have one or more replacement trees over time. Also, the location of some GHG project tree sites may change due to disturbances that unexpectedly eliminate tree sites. It is the Offset Project Operator's or Authorized Project Designee's responsibility to promptly locate and plant replacement sites so that there is no reduction in the total number of treed project sites.
3. If reversals are not compensated for with replacement trees, ARB requires that GHG offset credits be retired in proportion to any reversals (i.e. the carbon lost, in CO_2 equivalents, from removed trees), such that the total number of issued ARB offset credits does not exceed the total quantity of carbon stored (in CO_2 equivalents) by a project since its commencement date.

7 Offset Project Monitoring – Quantification Methodology[8]

General requirements for monitoring, reporting, and record retention are provided in the Regulation. Offset Project Operators and Authorized Project Designees are responsible for monitoring the performance of the offset project and maintaining records of monitoring data in accordance with the Regulation as well as the requirements stipulated in Section 8 and Appendix D. Monitoring is required for the Project Life (a period of 100 years following the issuance of ARB or registry offset credits for quantified GHG reductions or GHG removal enhancements).

Monitoring requirements are divided into these categories:

- Tree maintenance plan
- Project tree monitoring plan
- GHG emissions and sequestration activity data

The tree maintenance plan (TMP) is used to assess the potential of leakage and other aspects of offset project performance. The tree monitoring plan and GHG emissions and sequestration activity data are used to verify GHG emissions and sequestration estimates.

7.1 Tree Maintenance Plan

Reporting planting and maintenance activities and expenditures is critical to assessing leakage and GHG tree project compliance. At the level of the municipality, campus, or utility, by comparing reported annual tree care expenditures for different years a verifier can assess if a boost in project activity coincides with a drop in the level of care non-project trees are receiving. At the project level, information about tree maintenance and expenditures helps assess the strength of the project and its likelihood of success. In addition, all tree planting and removal practices by the municipality, campus, or utility must be reported each year to determine the number of eligible project trees.

To standardize annual reporting of tree planting and maintenance operations, activities are grouped into five program areas: tree planting, young tree care (< 5 years), mature tree care (> 5 years), tree removal, and administration/other (e.g. clerical, training, outreach). Annual expenditures and the level of service provided are indicators for each program area. Level of service is a quantifiable measure of tree care activities performed during a year. Higher levels of service indicate greater amounts of work performed. Reporting municipalities, educational campuses, or utilities must provide a TMP that describes municipal, educational campus, or utility-level expenditures for a 10- to 20-year period and project level activities for the reporting period.

Below are the specific TMP requirements. All information is for GHG project activities and expenditures (i.e. those related to project trees), except where noted. In some cases, information about the municipality, educational campus, or utility is also required to assess leakage potential (i.e. activities and expenditures related to non-project trees).

[8] The entirety of Section 7 is considered a quantification method.

Where both project and municipal, educational campus, or utility-level information is required, this is denoted in parentheses. Otherwise the information pertains to the project only.

Note that the Offset Project Operator or Authorized Project Designees must report on the most recent annual levels and expenditures and estimate the anticipated annual levels and expenditures for each of the criteria below in the project listing form and maintain records on actual levels and expenditures each year for the Project Life.

Tree planting:

- Number of trees planted in new tree sites each year, not including replacement trees (total for the municipality, educational campus, or utility, including project and non-project trees).
- Number of trees planted to replace removed trees each year ("replacement trees"), including replacement trees planted in relocated tree sites (separately for non-project and project trees).
- Species, size, and location[9] of project trees planted in new tree sites each year.
- Species, size, and location9 of project replacement trees planted in existing or relocated tree sites each year.
- Number and location[9] of relocated project tree sites each year.
- Reasons for relocations and, if applicable, modifications made to the project to reduce the chance of future relocations.
- Project tree resource: percentage of total project tree sites now planted.
- Annual tree planting expenditure (separately for the project and for the municipality, educational campus, or utility).

Young tree care:

- Number of young project trees inspected/pruned each year.
- Inspection/pruning cycle (total number of project trees / number treated per year).
- Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

Mature tree care:

- Number of mature project trees inspected/pruned each year.
- Inspection/pruning cycle (total number of project trees / number treated per year).
- Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

Tree removal:

- Number of trees removed from existing tree sites each year (separately for non-project and project trees).
- Species, size, and location[9] of project trees removed each year.
- Reasons for removals and, if applicable, modifications made to the project to reduce the chance of future removals.

[9] Tree site location must be designated on a map of the project physical boundaries.

- Removal cycle (total number of project trees to remove / number removed per year).
- Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

Administration/other:
- Average $/tree site expenditure (total $ on admin and other / total tree numbers) (separately for the project and municipality, educational campus, or utility).
- Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

If the potential for leakage is determined, the Offset Project Operator or Authorized Project Designee must explain to the verifier the changes in expenditures. Additional information on municipal, educational campus, or utility-level tree planting activities may be requested by the verification body.

7.2 Project Tree Monitoring Plan

A Project Tree Monitoring Plan is important for several reasons. The plan provides sufficient and transparent information on tree measurement and monitoring. This information is used to ensure the quantification methods meet the standards of this protocol. In addition, the plan informs the offset project about the status of tree sites, helping to ensure that lost trees are replaced and risks of reversals are minimized. The items below must be included in a project tree monitoring plan. For further technical information on urban forest inventory and monitoring, consult Appendix A.

- Choice of method from the options in Section 5.1.
- Detailed description of procedures to census (or sample, if applicable), measure, and report information on the project trees, including the survey method, sample sizes, and method for choosing samples.
- Methods used to measure and record tree size.
- Methods used and information collected on tree survival and health.
- Statistical methods used to extrapolate sample data to the total project tree population, if applicable.
- Estimated sampling error, if applicable.

7.3 GHG Emissions and Sequestration Activity Data

The data below are required inputs for estimating project GHG reductions. Transparent reporting of this information assists with verification of the project.

- Data on the species, dimensions (including dbh), date of measurement, and location of measured trees.
- Specific equations used to calculate tree volume, biomass and carbon content.
- Make and model year, annual amount and type of fuel used by tree planting and care vehicles (or the vehicle miles traveled and average fuel economy).

- Equipment type, horsepower rating, annual amount and type of fuel consumed in tree maintenance equipment (or the number of hours equipment is used).

8 Reporting Parameters

General requirements for monitoring, reporting, and record retention are included in the Regulation. This section provides requirements on additional reporting and procedures specific to this protocol.

8.1 Annual Reporting Requirements

The Offset Project Operator or Authorized Project Designees must submit an Offset Project Data Report according to the requirements in the Regulation. The Offset Project Data Report must include the information listed in the Regulation and this protocol and cover a single reporting period. See the Regulation and Appendix D for specific requirements.

All reports must be submitted after a review by a Professional Urban Forester. If the offset project is located in a jurisdiction without a Professional Urban Forester law or regulation, then a Professional Urban Forester must either have a Certified Forester credential managed by the Society of American Foresters, or any one of the following: California Certified Urban Forester credential managed by the California Urban Forests Council, Certified Arborist credential managed by the International Society of Arboriculture, Registered Consulting Arborist credential managed by the American Society of Consulting Arborists, or any other valid professional Forester, Arborist, Landscape Contractor, Landscape Architect, or Planner license or credential, approved by a government agency in the jurisdiction where the project is located.

8.2 Document Retention

The Offset Project Operator or Authorized Project Designee is required to retain all documentation and information outlined in the Regulation and in this protocol. Record retention requirements can be found in the Regulation.

Specific types of information the Offset Project Operator or Authorized Project Designee must retain includes but is not limited to:

- All data inputs for the calculation of vehicle and equipment fuel consumption and CO_2 emissions, tree carbon stocks, and project GHG reductions
- CO_2e tonnage calculations
- Initial and subsequent verification records and results
- Tree monitoring plan, and all tree maintenance plans and records relevant to the urban forest project

8.3 Verification Cycle

Offset project verification schedules are set forth in the Regulation.

9 Regulatory Verification Requirements

Regulatory verification requirements are set forth in the Regulation. In addition, each urban forest offset project verification team must include the following:

1. At least one Professional Urban Forester that takes an active role in reviewing the urban forest offset project tree biomass and carbon inventory, tree maintenance plan, tree monitoring plan, and conducting the site visit.
2. An ARB-accredited Forest or Urban Forest Offset Project Specialist.

An explanation demonstrating that the verification team includes individuals with the required experience and expertise must be included in the Notice of Verification Services submittal. The required experience and expertise may be demonstrated by a single individual, or by a combination of individuals.

During initial verification, the verification body must determine if the methodology in the Project Tree Monitoring Plan is acceptable and if it has sufficient detail for analysis during verification of the project.

10 Glossary of Terms[10]

GHG reservoir	GHG reservoir is defined in the Regulation. For urban forest projects, GHG reservoirs include above-ground or below-ground biomass or roots, litter, soil, bole, branches and leaves, among others.
Carbon sequestration	The removal and storage of carbon from the atmosphere in greenhouse gas sinks or greenhouse gas reservoirs through physical or biological processes The process by which trees remove carbon dioxide from the atmosphere and transform it into biomass.
Carbon stock	The quantity of carbon contained in a GHG reservoir. For this protocol, urban trees are carbon stocks.
Dry weight (DW) biomass	The weight of aboveground tree biomass when dried to 0% moisture content. Also known as oven-dry and bone-dry biomass. Convert from green biomass to dry weight biomass by multiplying by 0.56 for hardwoods or 0.48 for softwoods.
Freshweight or green biomass	The weight of aboveground tree biomass when fresh (or green), which includes the moisture present at the time the tree was cut. The moisture content of green timber varies greatly among different species. This protocol assumes that the moisture content of freshweight biomass is 30%.
Inherent uncertainty	For this protocol, the scientific uncertainty associated with calculating carbon stocks and greenhouse gas emissions.
Leakage	Increased GHG emissions or decreased GHG removals that result from the displacement of activities or resources from inside the offset project's boundary to locations outside the offset project's boundary as a result of the offset project activity. For this protocol, shifting of activities or resources *from* other parts of the

[10] For terms not defined in this section, the definitions in the Regulation apply.

	municipality, educational campus, or utility *to* the project, causing unanticipated increases in GHG emissions outside the project boundary.
Net tree gain (NTG)	Number of trees planted minus the number removed annually. NTG can be measured at the entity or project level.
Professional Urban Forester	A professional engaged in the science and profession of urban forestry. A Professional Urban Forester is defined as having any one of the following: Certified Forester credential managed by the Society of American Foresters; California Certified Urban Forester credential managed by the California Urban Forests Council; Certified Arborist credential managed by the International Society of Arboriculture; Registered Consulting Arborist credential managed by the American Society of Consulting Arborists; any other valid Forester, Arborist, Landscape Contractor, Landscape Architect, or Planner professional license or credential approved by a government agency in the jurisdiction where the project is located.
Project activity	The atmospheric CO_2 removal, carbon storage, GHG emission reductions and GHG emissions due to an urban forest tree project.
Project Life	Refers to the duration of an urban forest project and its associated monitoring and verification activities, as defined in Section 6.
Reporting uncertainty	The level of uncertainty associated with an entity's chosen method of sampling and/or inventorying carbon stock and calculation methodologies. Contrast with inherent uncertainty.
Tree Biomass	The amount of organic material comprising the above-ground (bole, stems and leaves) and below-ground (roots) components of a tree.
Tree maintenance plan (TMP)	Describes annual tree maintenance levels of service and associated expenditures.
Tree residue	Above-ground biomass from urban trees (as distinguished from construction debris) that can be salvaged for reuse, such as mulch, wood products, or fuel.
Tree resource	All trees planted and maintained by an entity.

11 References

Health and Safety Code, section 38571.

California Air Resources Board. 2008. *Off-road mobile sources emission reduction program*. http://www.arb.ca.gov/msprog/offroad/offroad.htm. (May 25, 2008).

Climate Action Reserve. 2010, Urban Forest Project Protocol, version 1.1. Climate Action Reserve, March 10, 2010. www.climateactionreserve.org (accessed March 16, 2010).

Federal Register, Vol. 74, No. 209. (October 30, 2009).

Appendix A Urban Forest Inventories and Sampling – Quantification Methodology[11]

The Compliance Offset Protocol Urban Forest Projects requires collecting information about trees over time. This can be accomplished through field surveys, where it may not be practical to perform a complete inventory of every tree in the overall population. However, it is still possible to obtain reliable information about the overall population by collecting data from a representative subset or sample. Sampling is the technique used to choose representative units for study from a larger population. This appendix provides basic information about field survey and remote-sensing approaches, inventories and sampling, and lists additional resources.

A.1 Options for Data Collection

A.1.1 Field Surveys

Field or ground surveys can provide high quality data on individual trees if inspectors are well-trained and motivated. For example, tree dbh can be directly measured for use in biomass equations. Urban tree inventory includes locating the tree using a Global Positioning System (GPS), collecting relevant data, delivery of a database, and reporting findings. During a field survey information on the condition and management needs of each tree can be collected. These data may trigger actions that will improve tree growth and survival.

A.2 Complete Inventory

A complete inventory will always provide the most accurate assessment of the tree population. Typically the only bias introduced is from measurement inaccuracies. Establishing measurement protocols, training data collectors, and performing regular quality control assessments should limit this error.

The primary questions to answer when conducting both complete inventories and sampling are 1) what data are necessary to collect, 2) how should these data be recorded – on paper or electronically, and 3) what margin of error is acceptable for samples? The first two questions are data collection issues and are addressed in this section. The third question is a data analysis issue and will be addressed in the sampling section of this appendix.

A.2.1 Inventory Systems

There are numerous urban tree inventory systems available to consumers ranging from freeware to software packages requiring fee-for-service support. See the Climate Action Reserve Urban Forest Project Protocol, version 1.1, 2010 for guidance on inventory systems.

A.2.2 What to Record

For assessing and monitoring carbon stocks, any database associated with an inventory system must be capable of producing the reports required for project reporting. Table A.1 shows an example list of key data fields, drawn from the i-Tree software suite developed by the USDA

[11] The entirety of Appendix A is considered a quantification method.

Forest Service as an inventory and reporting tool. More detailed components are listed in the users guide available at http://www.itreetools.org.

Table A.1. Example of Common Data Fields for Tree Inventorying

Data Field	Description	Purpose
Tree Id	unique tree identifier	tree location
Zone	alphanumeric code/name showing management area or zone where tree is located	area/zone comparisons or sampling areas
Street Segment	numeric code used with STRATUM sampling program	used in sampling to predict population by dbh classes
City Managed	numeric code showing city or private tree ownership	asset value, structure
Species Code	alphanumeric code denoting genus and species	species and tree count,
Land Use	numeric code for landuse types (e.g., single family residential, commercial, park)	may assist in stratified sampling
Loc Site	numeric code for tree site (e.g., front lawn, planting strip, median, cutout)	tree location info, stratified sampling, energy benefits
DBH	numeric code for diameter-at-breast-height	growth, structure, age, carbon storage, annualization, costs
Mtce Recommendation	numeric code for recommended mtce (e.g., young tree, mature tree)	tree health,mortality, pruning needs assessments
Priority Task	numeric code for highest priority task to perform on tree	tree health,mortality, pruning needs assessments
Sidewalk Damage	numeric code describing extent of damage	costs, size and species associated with damage
Wire Conflict	numeric code describing utility line conflicts	costs, size and species associated with conflicts
Condition Wood	numeric code describing wood (structural) health of tree	asset value, structure
Condition Leaves	numeric code describing foliar (functional) health of tree	asset value, structure
OtherOne, Two, Three	numeric data field with up to 10 variables to be described by user	3 fields in STRATUM to be defined by user
Setback	distance between tree and nearest air-conditioned/heated space	energy analysis use/energy conservation projects
Tree Orient	numeric data listing 1 of 8 azimuth orientations of tree in reference to building	energy analysis use/energy conservation projects

Source: i-Tree program.

Essentially, the data to be collected will depend upon the project needs. To estimate carbon stocks, information on tree species and 'diameter at breast height' (dbh) are the minimum requirements.

A.2.3 Measuring Method and Allowable Error for Primary Measurements

This section describes the minimum data collection fields and allowable measurement error necessary to report under this protocol.

Species

The most common method for identifying species in an inventory is the use of species code – usually a four-letter code taken from first two letters of genus and species names, or four letters plus one number when genus and species letters are duplicated in study. Use species coding lists in i-Tree Manual 2.2 as guide. (Example: *Acer saccharum* = ACSA and *Acer saccharinum* (in same study) would be ACSA1).

Diameter at Breast Height (dbh in cm)

Measure the diameter at breast height (1.37m) to nearest 0.1 cm using a dbh tape (available from most forestry suppliers). Where possible for multi-stemmed trees forking below 1.37 m measure above the butt flare and below the point where the stem begins forking. When this is not possible, measure diameter at root collar (DRC) as described below. Saplings (dbh/DRC 2.54 - 12.5 cm) will be measured at 1.37 m unless falling under multi-stemmed/unusual stem categories requiring DRC measurements (per FHM Field Methods Guide [see reference in CAR 2010]).

Diameter at Root Collar (DRC in cm)

The method for measuring diameter at the root collar is adapted from the FHM Field Methods Guide. For species requiring diameter at the root collar, measure the diameter at the ground line or at the stem root collar, whichever is higher. For these trees, treat clumps of stems having a unified crown and common root stock as a single tree; examples include mesquite, juniper, and mountain mahogany. For multi-stemmed trees, compute and record a cumulative DRC (see below); record individual stem diameters and a stem status (live or dead) on a separate form or menu as required.

Measuring DRC: Before measuring DRC, remove the loose material on the ground (e.g. litter) but not mineral soil. Measure just above any swells present, and in a location so that the diameter measurements are reflective of the volume above the stems (especially when trees are extremely deformed at the base).

Stems must be at least 1.0 ft in length and 1.0 inch in diameter to qualify for measurement; stems that are missing due to cutting or damage must have previously been at least 1.0 ft in length (estimate by checking diameter of wound and compare with diameter and length of other stems – checking taper).

Whenever DRC is impossible or extremely difficult to measure with a diameter tape (e.g. due to thorns, extreme number of limbs), stems may be estimated and recorded to the nearest 1.0 inch class.

Additional instructions for DRC measurements are illustrated in Figure A.1. Do not measure cut stems as shown in Diagram 5 of Figure A.1; measure only complete stems.

Computing and Recording DRC: For all trees requiring DRC, with at least one stem 1.0 inch in diameter or larger at the root collar, DRC is computed as the square root of the sum of the squared stem diameters. For a single-stemmed DRC tree, the computed DRC is equal to the single diameter measured and rounded to the nearest 0.1 inch.

Use the following formula to compute DRC:

$$\text{DRC} = \text{SQRT [SUM (stem diameter}^2\text{)]}$$

For example, a multi-stemmed woodland tree with stems of 12.2, 13.2, 3.8, and 22.1 would be calculated as:

$$\begin{aligned} \text{DRC} &= \text{SQRT } [12.2^2 + 13.2^2 + 3.8^2 + 22.1^2] \\ &= \text{SQRT } [825.93] \\ &= 28.74 \\ &= 28.7 \end{aligned}$$

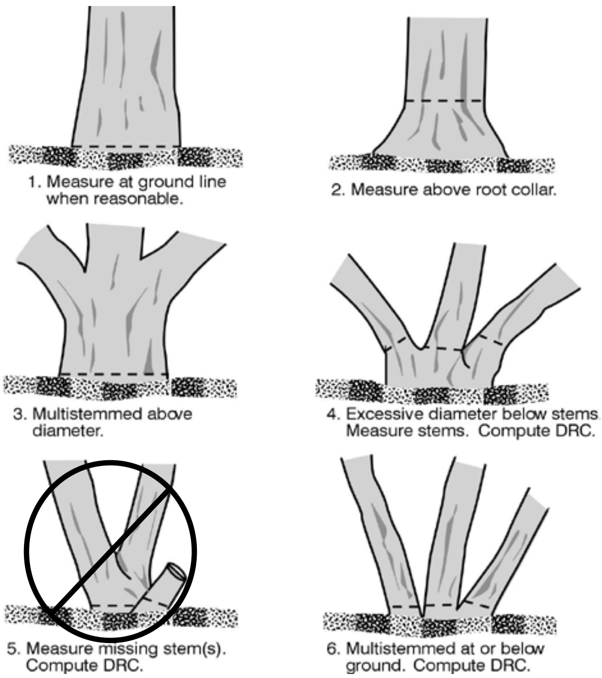

Figure A.1. Measuring DRC in Various Situations

Tree Height

From ground level to tree top to nearest 0.5 m (omit erratic leader as shown in Figure A.2) with range pole, altimeter or clinometer.

Tree height measurement. Measure to white line.

Figure A.2. Example of Tree with Erratic Leader

A.3 Sampling from Populations

As previously mentioned, sampling involves measuring only a portion of the trees on the offset project and using the data to estimate parameters of interest for the overall population.

A.3.1 Statistical Bias

The reason for using statistically sound sampling methods is to avoid bias in the estimates of the parameter(s) measured. Although the value of any single estimate (biased or not) is unlikely to equal the true population value, the mean of a large number of unbiased estimates will approximate the true value. In contrast, the mean of a large number of biased estimates will either be higher or lower than the true population value, depending on the direction of the bias. If the project developer is interested in knowing the actual value of a parameter from the population (e.g. actual tree dbh), they generally want to use an unbiased estimator of that parameter. In some situations, a small bias (e.g. a tendency to slightly over- or underestimate cover) can be tolerated if the bias is small relative to the standard deviation of the estimation errors (perhaps 10% to 15% or less).

Bias in estimates can come from various sources. For instance, if tree shadows are counted as canopy in aerial photo interpretation (misclassification bias), the canopy cover estimate will be biased upward. Many types of bias can be avoided through good sampling design and the careful implementation of appropriate evaluation techniques.

A.3.2 Random Sampling and Random Numbers

Most statistical methods used in environmental areas are based on the assumption of random sampling. This means that every unit in the population has an equal chance (or known probability) of being chosen for the sample. Furthermore, the selection of random units should be independent of other units that have been sampled. If a sample unit is rejected because it is too close to one already chosen, the sample will not be random and independent. A relatively simple and reliable method for randomization is to use random numbers. Most spreadsheet, database, and statistical programs have functions that generate random numbers, or random numbers can be found on-line or chosen from printed tables.

Several techniques can be used to draw a random sample from a population that consists of individual objects or records (e.g. street addresses or tree numbers). Many spreadsheet programs include tools that can produce a random sample of a specified size from a range of cells. Alternatively, a unique random number can be assigned to each unit or record, sorting the list based on the random number, and picking the required number of units from the top of the sorted database.

In some cases, it is necessary to take random samples across a geographic area, such as part or all of a city or forested area. In such a situation, random sample points can be assigned by randomly sampling from a coordinate grid that has been established for the area in question. This may either be an existing set of map-based coordinates, such as UTM or State Plane grids, or an arbitrary grid based on units measured on a map or aerial photograph (e.g. distances measured from the bottom and left edge of the map or photo). After the range of X and Y coordinates have been determined within the area to be sampled, X and Y coordinates can be selected randomly to generate random sample points. This is simple random sampling, one of five common random sampling techniques. The other four include systematic sampling, stratified sampling, cluster sampling, and multi-stage sampling.

A.3.3 Systematic Sampling

Systematic sampling means that the sample units are selected at equally spaced intervals over a population. Examples include selecting every tenth tree from a list of trees or selecting sample plots at equally spaced distances over a project area. In carefully planned forest surveys, systematic sampling can yield more precise results than simple random sampling. Systematic sampling is unbiased if the first unit is randomly selected. One advantage to systematic sampling is that it is simpler to select one random number and then collect data on every 5th, 10th or 15th (project developer chooses the interval) tree on the list, than to select as many random numbers as the sample size (although these numbers can be generated by any spreadsheet program). It also provides a good spread across a tree population. A disadvantage is that a list is needed to start with to be able to know total sample size and to calculate a sampling interval. The only advantage of systematic sampling over simple random sampling is the simplicity of needing to choose only one random number.

A.3.4 Stratified Sampling

In many urban forest applications, it is desirable to have samples distributed throughout the population. For instance, the project developer may want to ensure that trees from each of several different land use zones are included in the sample because it has been determined that trees are growing differently in different land use areas due to differences in care and maintenance. In such situations, stratified random sampling will be the most efficient and meaningful method for selecting samples. In this method, the population to be sampled is first divided into meaningful subunits or strata. These may be large subdivisions, planning sectors, maintenance districts, or any other convenient management or planning unit.

If strata are assigned so that each is more or less homogeneous with respect to the characters being measured, fewer samples will be needed to adequately characterize each stratum. For instance, if tree cover is to be assessed in different portions of a city, visual estimates of the tree canopy cover could be used to help demarcate zones where canopy cover is relatively uniform. A sample of street trees might be stratified by tree species, size, and/or age, depending on the purpose of the evaluation. If these trees were classified in a municipal street tree database, stratification might be accomplished relatively simply from existing tree data. However, if such data are lacking, it may be necessary to conduct a preliminary sample to delineate the population before sampling occurs.

Once strata are assigned and delineated, samples are drawn at random from within each stratum. If the number of samples selected from each stratum is not proportional to the size of the stratum, the averages from each will have to be weighted to obtain an overall population average. Given prior knowledge about the population, stratified sampling is a commonly used probability method that is superior to random sampling because it reduces error.

A.3.5 Sampling Size

Optimal sample size will vary somewhat with the characteristics being rated or tallied.

In general:

- Up to a point, the reliability of estimates will increase as sample size increases

- The more variable the population is with respect to the characteristic(s) being rated, the larger the sample should be
- A large sample is required to accurately estimate the frequencies of relatively rare events or characteristics
- Larger sample sizes are needed to detect relatively small differences between means or proportions; smaller sample sizes may suffice if the differences are relatively large

The optimum sample size represents a compromise between cost and accuracy, since both generally increase with increasing sample size. An optimum sample size can be determined by identifying the point of diminishing returns beyond which further increases in accuracy are not worth the additional costs of data collection. Optimum sample size will vary with the type of data being collected, so it is not possible to set a single number for all applications.

However, certain statistical formulas can be used to estimate the minimum sample size needed for a specific purpose. A number of statistics web sites include on-line interactive calculators that allow required sample sizes to be estimated. Before these sample size calculators can be used, several things must be known about the data that will be collected and how it will be analyzed.

Type of Data

Main types include:

1. Continuous – variables can take any value, e.g. tree diameters
2. Discrete – variables can only have certain discrete values
    a. Types of discrete data include:
        i. Ranks – ordered ratings, e.g. low, moderate, high
        ii. Counts – e.g. number of trees by species or dbh class
        iii. Binary – variable has only two outcomes, e.g. present/absent. Binary data is typically expressed as proportions or percents, such as the percent canopy cover determined from dot grid counts (canopy is rated as present or absent for each dot)

Type of Analysis

Continuous data are typically analyzed using linear models, including linear regression and analysis of variance techniques. Discrete data may be analyzed in various ways, including contingency table analysis, logistic regression, and survival analysis. Different formulas are used to estimate sample sizes for various analysis methods.

Expected Values

To estimate sample sizes for analyses of continuous data, estimates of expected population means (the Greek letter mu may be used for this term) and standard deviations or variances (the Greek letter sigma symbolizes the population standard deviation; variance is the square of the standard deviation) will have to be specified. For proportions, estimates of the expected proportions are needed; margins of error (as percents) may also be needed.

Data Structure

If data are paired or arranged in blocks or other more complex designs, the structure of the statistical model should be specified.

Confidence Level

Also abbreviated as the Greek letter alpha, this is the probability of Type I error, the chance that a difference is significant when it really is not (i.e. the probability of rejecting the null hypothesis when it is true). This is typically set at a low level, often 5% (alpha=0.05), meaning that there would only be a 5% (1 in 20) chance of deciding that a spurious difference is real (i.e. a 95% chance of avoiding Type I error).

Power

This parameter is expressed as (1-beta) where beta is the probability of Type II error. Power is the probability of detecting a real difference (i.e. the probability of rejecting the null hypothesis when it is false). When detecting real differences, the power of a test should be high, generally at least 80% (0.8) or greater.

A.3.6 Sampling Design and Monitoring Frequency

The frequency of monitoring is related to the rate and magnitude of change in tree growth, removal rates, planting rates and so forth – the smaller the expected change, the greater the potential that frequent monitoring will not detect a significant change. Frequency of monitoring should be determined by the magnitude of expected change – less frequent monitoring is applicable if only small changes are expected (see reference in CAR 2010).

All sampling designs should incorporate some form of random sampling to quantify the carbon stocks within established project boundaries using statistically accepted methods for inferring the urban forest biomass based on sample plots. There are multiple ways one can design a sampling plan. Although a few examples are provided here, it is important to remember that the specific sampling method used should be determined after evaluating project size, monitoring frequency and acceptable level of sampling error. Four basic designs are addressed here.

1. ***Rolling Sample***
   A percentage of the complete inventory is sampled annually, with results used to infer biomass or volume for the complete inventory.

   Example: during year 1 a non-profit tree group plants 3,000 new tree sites along a greenway, with a variety of species mixed throughout the area. Each year, 10% of the tree sites are sampled, until, at the end of 10 years, 100% of the inventory has been sampled. The annual 10% samples are fixed samples proportional to representation. Thus, the complete inventory is divided into 10 samples at the outset of the project. These 10% samples may be based on stratified random sampling with species type and frequency (number of trees planted per species) as the strata, or to reduce data collection costs, trees could be clustered into 10 cohorts based on geographic proximity. Other forms of random sampling, including cluster sampling for obtaining the 10% sample may also be suitable.

2. ***Periodic Sampling***
   All trees are re-inventoried but not annually. A sampling period is determined at the outset. For example, all trees are re-inventoried every 6 years.

3. ***Fixed Plot Sampling***
   All trees in a geographical area are never completely inventoried. A set of plots of fixed size and number are established and used to extrapolate volume or biomass on an area basis. Example: the city of San Francisco establishes a new 30-mile long multi-use

greenway along a former railroad corridor. They employ the UFORE plot sampling method (see references in CAR 2010) and establish thirty 10-m radius permanent plots based on land use stratification. The plots are sampled annually. Biomass or volume for the greenway is extrapolated based on sample plots to area relationship.

4. ***Variable Plot***
   Variable plot is similar to fixed plot sampling except the area sampled varies to coincide w/ logistical requirements, such as property boundaries where permission to access private property is required. Area of the plot is measured and used to infer to the total area based on plot area to total area ratio.

Note that items 1 and 2 can be applied to items 3 and 4; they are potentially at different levels or scales within a sampling design.

A.3.7 Minimum Required Sampling Criteria

All sampling methodologies and measurement standards must be statistically sound and reviewed by verification bodies. All sample plots should be permanently benchmarked for auditing and monitoring purposes. Plot centers, street segments, or individual trees (in the case of some forms of rolling samples) should be referenced on maps, preferably using GPS coordinates or using GIS. The methods utilized shall be documented and made available for verification and public review. The design of the sampling methodology and measurement standards must include the requirements stated in Table A.2.

Table A.2. Minimum Required Sampling Criteria

GHG Reservoir	Required?	Name of Requirement	Description of Requirement
Tree Biomass	Yes	Diameter (breast height) Measurements	Stated minimum diameter in methodology not to be greater than 7.6 cm (3 in.)
		Measurement Tools	Description of tools used for height, diameter, and plot measurement.
		Measurement Standards	The methodology shall include a set of standards for height and diameter measurements and describe compliance with allowable measurement error.
		Stratification Design	A description of the rules used to stratify the trees.
		Plot Layout	A description of the plot layout.
		Allometric Equations used for Estimating Biomass	The methodology shall include a description of the allometric equations used to estimate the whole tree biomass (bole, branches, and roots) from bole diameter measurements. This includes a description of how equations were assigned and implemented. Use only the equations provided in this protocol.

A.3.8 Sampling Error

All estimates of reported GHG reservoirs must have a high level of statistical confidence. Measurement standards are established by ARB for the estimate of metric tons of carbon in the required pools derived from sampling. Confidence in the estimate of metric tons of carbon from sampling can be measured statistically in terms of the size of the standard error relative to the estimate of the mean. This establishes confidence limits and can be expressed as a percentage of the mean. Larger confidence intervals indicate that there is less confidence in the mean estimate than smaller confidence intervals. For all GHG reservoirs reported, the standard error must be within 20% of the estimate of the mean for the estimate to be accepted. However, estimates are adjusted based on the statistical level of confidence, such that only estimates with a standard error within 5% or less receive no deduction. Most spreadsheet software packages provide users the ability to run descriptive statistics on a set of data, and results include the mean, standard error, standard deviation and confidence level. Table A.3 provides an example of summary results for each plot in a measured stratum. Note that standard deviation quantifies the scatter, how much the measured values differ from one another, whereas, standard error quantifies how accurately the true mean of the population is known. Standard error gets smaller as the sample gets larger, but standard deviation does not change predictably since it only quantifies scatter.

Table A.3. Summary Results for Each Plot in a Stratum

Plot #	Carbon Tons per Hectare	Plot #	Carbon Tons per Hectare	Plot #	Carbon Tons per Hectare
1	337	8	367	15	342
2	296	9	260	16	366
3	308	10	260	17	355
4	271	11	322	18	423
5	289	12	323	19	437
6	228	13	439	20	156
7	144	14	309		
Average Carbon Tons per Hectare					312
Standard error (must be <20% of mean)					17.85

Note: Confidence level is less than 10% of the mean as required by ARB.

Appendix B Calculating Biomass and Carbon – Quantification Methodology[12]

This appendix describes how measured tree size data are used with biomass equations to calculate tree volume and carbon content. Equations are presented for 26 open-grown urban tree species. To be consistent with biomass equations used in the Compliance Offset Protocol U.S. Forest Projects, foliar biomass is not included in the formulations. Additional biomass equations have been adapted from the literature on natural and native forest biomass for use in urban settings. The urban species equations have also been used to develop two general equations for broadleaf trees and conifers. Complete listings of equations are available in Table B.1 and Table B.2 at the end of this appendix. Table B.1 lists equations based on measurements of dbh and height or dbh only, derived from data collected on open-grown trees. Additional information can be found in CAR 2010 section B.5 pg 67-68.

B.1 Estimating Biomass and Carbon Using Volumetric Equations

Estimating biomass and carbon using volumetric equations is a two-step process that entails 1) calculating green volume, and 2) converting green volume to dry weight biomass and then carbon content (C). Table B.1 and Table B.2 provide examples of volumetric equations and biomass conversion factors for common urban species. Table B.1 equations estimate volume (m^3/tree) from diameter at breast height (dbh in centimeters) and height (in meters) measurements.

1. Use equations for dbh and height (or equations for dbh only if necessary) to calculate volume.

   Example:
   Volume in cubic meters (V) for a 15.6 m tall hackberry (*Celtis occidentalis*) with a 40.4 cm dbh is calculated as:

$$V = 0.002245 \times (40.4)^{2.118} \times (15.6)^{-0447}$$
$$= 1.66 \text{ m}^3$$

[Eq. 1]

2. Determine freshweight (FW) biomass, dry weight (DW) biomass and carbon content by applying biomass conversion factors in Table B.1, incorporating belowground biomass, and calculating carbon.

   a. Convert from volume to FW biomass by multiplying V by the species-specific density factor.

      For hackberry, FW would be calculated as:

$$FW = 1.66 \times 801$$
$$= 1329.66 \text{ kg}$$

[Eq. 2]

[12]The entirety of Appendix B is considered a quantification method.

b. The equations given here only calculate volume (and hence biomass) for the *aboveground* portion of the tree. Add the biomass stored belowground by multiplying the FW biomass by 1.28. For total FW biomass, including belowground roots calculate:

$$\text{Total FW} = 1329.66 \times 1.28 = 1704.62 \text{ kg} \quad \text{[Eq. 3]}$$

c. Convert FW biomass into DW biomass by multiplying by the constant 0.56 for hardwoods and 0.48 for conifers (see reference in CAR 2010). For our hackberry example:

$$\text{DW} = 1704.62 \times 0.56 = 954.59 \text{ kg} \quad \text{[Eq. 4]}$$

d. Convert DW biomass into kilograms of carbon (C) by multiplying by the constant 0.50:

$$\text{C} = 954.59 \times 0.5 = 477.30 \text{ kg} \quad \text{[Eq. 5]}$$

e. Tree carbon stock is to be reported in metric tons. Therefore, results calculated in kilograms must be multiplied by 0.001 to convert to metric tons.

B.1.1 Estimating Biomass and Carbon Using Forest-Derived Equations

Biomass calculated using equations derived from native or natural forest trees (Table B.2) must be adjusted by a factor of 0.80 when applied to open-grown, urban trees because of differences in biomass allocation between the tree populations.

Unlike the equations used above, the forest equations listed produce DW biomass rather than FW biomass. Therefore the step involving the species-specific density factor (step 2a above) does not need to be incorporated. The calculation for carbon content (kg) is:

$$\text{C} = \text{DW} \times 1.28 \times 0.5 \quad \text{[Eq. 7]}$$

B.1.2 Estimating Tree Biomass for Standing Dead or Dying Trees

Unlike trees in forest settings, dead or dying trees in urban areas are usually removed immediately due to safety concerns in public and private areas. Typically, the only difference between biomass in a live tree and that in a dead tree is the absence of foliage for the latter.

Because foliar biomass is not included in these formulations, dead and dying tree biomass should be calculated just as for live tree biomass.

B.1.3 Estimating Carbon in Lying (Dead/Downed) Tree Biomass

As discussed in Section B.1.2 above, it is assumed in nearly all urban applications that dead/dying trees are removed almost immediately and that lying tree biomass will rarely, if ever exist. It is most likely to exist in natural settings within cities like riparian or nature areas. In that case, sampling, measurement and carbon estimation procedures should follow the Compliance Offset Protocol U.S. Forest Projects rather than this protocol.

B.2 Error in Estimating Carbon and Biomass

The volume equations used in this protocol were developed from trees that may differ in size from the trees in a specific sample or inventory. The dbh ranges for trees sampled to develop the volume and biomass equations are listed where known at the end of the appendix (Table B.1 and Table B.2). Applying the equations to trees with dbh outside of this range may increase the error in estimates.

B.3 Reporting Uncertainty versus Inherent Uncertainty

Reporting uncertainty is the level of uncertainty associated with an entity's chosen carbon stock sampling and calculation methodologies. Inherent uncertainty refers to the scientific uncertainty associated with calculating carbon stocks and GHG emissions.

There is an inherent scientific uncertainty in quantifying carbon stocks of entities. However, determining scientific accuracy is not the focus of this protocol. Instead, the verification process is designed to identify and assess reporting uncertainty. Therefore, when assessing if the estimate of the carbon content in project trees meets ARB's minimum quality standard, only quantification differences that result from reporting uncertainty should be considered, not inherent uncertainty. Therefore, it is not necessary to attempt to quantify error for biomass equations accepted by ARB. Any statistical error associated with these equations falls under the category of inherent uncertainty.

Table B.1. Volume Equations for 26 Urban Tree Species

	Species	DBH Range (cm)	Volume (m^3)	Vol to FW Conversion kg/m3
	Acacia longifolia	15.0 - 57.2	$=0.0283168466 (0.048490 * (dbh/2.54)^{2.347250})$	1121
	Acer platanoides	9.7 - 102.1	$=0.0019421 * dbh^{1.785}$	737
	Acer saccharinum	13.2 - 134.9	$=0.000363 * dbh^{2.292}$	721
	Celtis occidentalis	10.9 - 119.4	$=0.0014159 * dbh^{1.928}$	801
	Ceratonia siliqua	15.5 - 71.4	$=0.0283168466(0.066256 * (dbh/2.54)^{2.128861})$	961
D	Cinnamomum camphora	12.7 - 68.8	$=0.0283168466(0.031449 * (dbh/2.54)^{2.534660})$	817
B	Cupressus macrocarpa	15.7 - 146.6	$=0.0283168466(0.035598 * (dbh/2.54)^{2.495263})$	577
H	Eucalyptus globulus	15.5 - 130.0	$=0.0283168466(0.055113 * (dbh/2.54)^{2.436970})$	1121
	Fraxinus pennsylvanica	14.7 - 122.7	$=0.0005885 * dbh^{2.206}$	785
O	Fraxinus velutina 'Modesto'	14.5 - 84.8	$=0.0283168466(0.022227 * (dbh/2.54)^{2.633462})$	769
N	Gleditsia triancanthos	9.1 - 98.3	$=0.0005055 * dbh^{2.220}$	977
L	Gymnocladus dioicus	10.2 - 36.8	$=0.0004159 * dbh^{2.059}$	929
Y	Jacaranda mimosifolia	17.3 - 59.7	$=0.0283168466(0.036147 * (dbh/2.54)^{2.486248})$	609
	Liquidambar styraciflua	14.0 - 54.4	$=0.0283168466(0.030684 * (dbh/2.54)^{2.560469})$	801
	Magnolia grandiflora	14.5 - 74.2	$=0.0283168466(0.022744 * (dbh/2.54)^{2.622015})$	945
	Pinus radiata	16.8 - 105.4	$=0.0283168466(0.019874 * (dbh/2.54)^{2.666079})$	705
	Pistacia chinensis	12.7 - 51.3	$=0.0283168466(0.019003 * (dbh/2.54)^{2.808625})$	657
	Platanus acerifolia	15.5 - 73.9	$=0.0283168466(0.025170 * (dbh/2.54)^{2.673578})$	833
	Populus sargentii	6.4 - 136.7	$=0.0020891 * dbh^{1.873}$	753
	Quercus ilex	12.7 - 52.1	$=0.0283168466(0.025169 * (dbh/2.54)^{2.607285})$	1186
	Quercus macrocarpa	10.9 - 100.1	$=0.0002431 * dbh^{2.415}$	993
	Tilia cordata	11.2 - 64.5	$=0.0009359 * dbh^{2.042}$	673
	Ulmus americana	17.5 - 114.3	$=0.0018 * dbh^{1.869}$	865
	Ulmus parvifolia chinensis	17.3 - 55.9	$=0.0283168466(0.028530 * (dbh/2.54)^{2.639347})$	865
	Ulmus pumila	15.5 - 131.6	$=0.0048879 * dbh^{1.613}$	865
	Zelkova serrata	14.5 - 86.4	$=0.0283168466(0.021472 * (dbh/2.54)^{2.674757})$	865
	General Broadleaf	6.4 - 136.7	=0.280285*(dbhcm)^2.310647	Eqtn produces FW
	General Conifer	6.4 - 136.7	=0.05654*(dbhcm)^2.580671	Eqtn produces FW
	Acacia longifolia	15.0 - 57.2	$=0.0283168466(0.01406 * (dbh/2.54)^{2.18649} * (3.28*ht)^{0.46736})$	1121
	Acer platanoides	9.7 - 102.1	$=0.001011 * dbh^{1.533} * ht^{0.657}$	737
	Acer saccharinum	13.2 - 134.9	$=0.000238 * dbh^{1.998} * ht^{0.596}$	721
D	Celtis occidentalis	10.9 - 119.4	$=0.002245 * dbh^{2.118} * ht^{-0.447}$	801
B	Ceratonia siliqua	15.5 - 71.4	$=0.0283168466(0.00857 * (dbh/2.54)^{1.79584} * (3.28*ht)^{0.92667})$	961
H	Cinnamomum camphora	12.7 - 68.8	$=0.0283168466(0.00982 * (dbh/2.54)^{2.13480} * (3.28*ht)^{0.63404})$	817
	Cupressus macrocarpa	15.7 - 146.6	$=0.0283168466(0.00576 * (dbh/2.54)^{2.26035} * (3.28*ht)^{0.63013})$	577
a	Eucalyptus globulus	15.5 - 130.0	$=0.0283168466(0.00309 * (dbh/2.54)^{2.15182} * (3.28*ht)^{0.83573})$	1121
n	Fraxinus pennsylvanica	14.7 - 122.7	$=0.000414 * dbh^{1.847} * ht^{0.646}$	785
d	Fraxinus velutina 'Modesto'	14.5 - 84.8	$=0.0283168466(0.00129 * (dbh/2.54)^{1.76296} * (3.28*ht)^{1.42782})$	769
	Gleditsia triancanthos	9.1 - 98.3	$=0.000489 * dbh^{2.132} * ht^{0.142}$	977
H	Gymnocladus dioicus	10.2 - 36.8	$=0.000463 * dbh^{1.545} * ht^{0.792}$	929
E	Jacaranda mimosifolia	17.3 - 59.7	$=0.0283168466(0.01131 * (dbh/2.54)^{2.18578} * (3.28*ht)^{0.54805})$	609
I	Liquidambar styraciflua	14.0 - 54.4	$=0.0283168466(0.01177 * (dbh/2.54)^{2.31582} * (3.28*ht)^{0.41571})$	801
G	Magnolia grandiflora	14.5 - 74.2	$=0.0283168466(0.00449 * (dbh/2.54)^{2.07041} * (3.28*ht)^{0.84563})$	945
H	Pinus radiata	16.8 - 105.4	$=0.0283168466(0.00533 * (dbh/2.54)^{2.22681} * (3.28*ht)^{0.66899})$	705
T	Pistacia chinensis	12.7 - 51.3	$=0.0283168466(0.00292 * (dbh/2.54)^{2.19157} * (3.28*ht)^{0.94367})$	657
	Platanus acerifolia	15.5 - 73.9	$=0.0283168466(0.01043 * (dbh/2.54)^{2.43642} * (3.28*ht)^{0.39168})$	833
	Populus sargentii	6.4 - 136.7	$=0.001906 * dbh^{1.806} * ht^{0.134}$	753
	Quercus ilex	12.7 - 52.1	$=0.0283168466(0.00431 * (dbh/2.54)^{1.82158} * (3.28*ht)^{1.06269})$	1186
	Quercus macrocarpa	10.9 - 100.1	$=0.000169 * dbh^{1.956} * ht^{0.842}$	993
	Tilia cordata	11.2 - 64.5	$=0.000945 * dbh^{1.617} * ht^{0.59}$	673
	Ulmus americana	17.5 - 114.3	$=0.0012 * dbh^{1.696} * ht^{0.405}$	865
	Ulmus parvifolia chinensis	17.3 - 55.9	$=0.0283168466(0.01046 * (dbh/2.54)^{2.32481} * (3.28*ht)^{0.49317})$	865
	Ulmus pumila	15.5 - 131.6	$=0.000338 * dbh^{0.855} * ht^{2.041}$	865
	Zelkova serrata	14.5 - 86.4	$=0.0283168466(0.00666 * (dbh/2.54)^{2.36318} * (3.28*ht)^{0.55190})$	865

Note: Equations require dbh (cm) only or dbh (cm) and height (m) measurements to calculate volume. Factors are listed for converting volume to freshweight (FW), and two FW general biomass equations derived from these species are also listed.

Source: Climate Action Reserve (2010) Urban Forest Project Protocol Version 1.1 March 10, 2010.

Table B.2. Dry Weight Biomass Equations

Spcode	Botanic	Common	Model	Source and DBH Range
ACRU	Acer rubrum	Red maple	$=(0.1970*(dbh^{2.1933}))*0.80$	Ter-Mikaelian, Nova Scotia 0-35 cm red maple
ACSA2	Acer saccharum	Sugar maple	$=(0.1791*(dbh^{2.3329}))*0.80$	Ter-Mikaelian, Maine 3-66 cm sugar maple
PRSE2	Prunus serotina	Black cherry	$=((0.0716*dbh^{2.6174}))*0.80$	Ter-Mikaelian, West VA 5-50 cm black cherry
QURU	Quercus rubra	Northern red oak	$=(0.1130*(dbh^{2.4572}))*0.80$	TerMikaelian, West VA 5-50 cm red oak
FRAM	Fraxinus americana	White ash	$=(0.1063*(dbh^{2.4798}))*0.80$	Ter-Mikaelian, West VA 5-50 cm white ash
TIAM	Tilia americana	American basswood	$=((0.0617*dbh^{2.5328}))*0.80$	Ter-Mikaelian, West VA 5-50 cm basswood
BENI	Betula nigra	River birch	$=(0.0692*(dbh^{2.6606}))*0.80$	Ter-Mikaelian, West VA 5-50 cm black birch
Palms	General palms	General palms	=(6.0*ht(m)+0.8)+(0.8*ht(m)+0.9)	Frangi and Lugo, 1985
Hardwoods	General hardwoods	General hardwoods	=((EXP(-2.437+2.418*(LN(dbh)))+EXP(-3.188 + 2.226*(LN(dbh)))))*0.8	Tritton and Hornbeck, Northeast, 10-50 cm

Note: Use constants to add roots, convert to carbon. Biomass is reduced to 80% of original predicted value to account for less biomass in urban trees.

Appendix C Offset Project Listing Information

Section 1: General Information

1. Date of form completion:
2. Form completed by (name):
3. Project listing as a:
   - Municipal Project
   - Educational Campus Project
   - Utility Project
4. Name and contact information of the Offset Project Operator:
5. Name and contact information of Authorized Project Designee (if applicable):
6. Offset project commencement date:
7. Date of initial reporting period:
8. Location of offset project (including approximate latitude/longitude):

Section 2: Offset Project Summary

1. Describe the goals of the offset project.
2. Name of the person or entity that is responsible for planning, implementation, and reporting of project activity. List and explain the involvement of Authorized Project Designees, if applicable.
3. Briefly describe implementation of the offset project. Include general information on the number of project tree sites and trees that will be planted (including replacements), types of species, where they will be planted, tree maintenance and monitoring plans (Note: Some of this information is also required in the Tree Maintenance Plan [separate document]):
4. Confirm that the trees will be planted in maintained landscapes and spaced at least 5 m (16 ft) apart so as to be open-growing (Y/N):

Section 3: Offset Project Boundaries

1. Physical Boundary: Describe and include a map of the physical boundary of the offset project, including planned tree sites, an outline of the geographical boundary of the municipality, educational campus, or utility service area, and tree care facilities (location where vehicles and equipment are housed):
2. GHG Offset Project Boundary: List the GHG sources and GHG sinks that will be included in the Offset Project Boundary.

Section 4: Offset Project Eligibility

1. State the expected average annual net number of project tree sites created over the Project Life (this is the project NTG):
2. State the average annual NTG prior to offset project commencement (for municipalities and educational campuses only):

3. State the total number of trees prior to the start of the offset project (for municipalities and educational campuses only):
4. Is any portion of the project activity required by any local, state, regional, or federal regulation? (Y/N)
5. Describe tree planting requirements outside of the project activity that are mandated by law and are planned to be undertaken by the entity:

Section 5: Tree Maintenance Plan

This initial Tree Maintenance Plan constitutes a description of planned maintenance activities. Per Section 8 of the protocol, approved offset projects must annually submit a Tree Maintenance Plan for each year of project duration, reporting activities ex post. This initial Tree Maintenance Plan must address the following requirements:

1. Document the most recent and anticipated future levels of service and expenditures for all criteria in the Tree Maintenance Plan (for details, see protocol Section 9: Project Monitoring).
2. Describe how project tree planting sites will be identified and prioritized.
3. Provide estimates for tree mortality rates for newly planted and established project trees, and explain how these estimates were derived.
4. Describe how project trees that need replacing will be identified, the timing of replacement, and the species and size of replacement trees.
5. Identify the personnel who will implement and manage the project, their roles and responsibilities, and funds required for salary, operations, training, and overhead over the duration of the project. Other activities that may be included here are public relations, accounting, fund raising, and outreach.

Section 6: Project Tree Monitoring Plan

Per Section 8.2 of the protocol, the Project Tree Monitoring Plan must address the following requirements:

Provide a detailed description of:

1. Method chosen from the options in Section 5.1.
2. Procedures that will be used to census, measure, and report information on the project trees, including survey method, sample sizes, and method for choosing samples.
3. Methods that will be used to measure and record tree dimensions.
4. Methods that will be used and information collected on tree survival and health.
5. Statistical methods that will be used to extrapolate sample data to the total project tree population, if applicable.
6. Estimating sampling error, if applicable.

Appendix D Offset Project Data Report

Each Offset Project Data Report must contain the following:

1. Offset Project Operator or Authorized Project Designee
2. Offset Project Name
3. Name of Individual Completing the Report
4. Date
5. Verification Period
6. Project personnel
7. Personnel names(s)
8. Organization and title(s)
9. Responsibilities

10. Equations and calculations

    a. Project tree volume, biomass, and carbon stocks (for measured trees and for the project tree population, if sampling and extrapolation are used) at project commencement (or renewal) and annually thereafter.

    b. For (a) above, standard error and sampling error at the 90% confidence interval must be met, if applicable.

    c. Amount and type of fuel consumed by project vehicles and equipment.

    d. Project tree carbon stock change and adjusted carbon stock change, if applicable.

    e. Tree planting
        i. Number of trees planted in new tree sites each year, not including replacement trees (total for the municipality, educational campus, or utility service area, including project and non-project trees).
        ii. Number of trees planted to replace removed trees each year ("replacement trees"), including replacement trees planted in relocated tree sites (separately for non-project and project trees).
        iii. Species, size, and location of project trees planted in new tree sites each year.
        iv. Species, size, and location of project replacement trees planted in existing or relocated tree sites each year.
        v. Number and location of relocated project tree sites each year.
        vi. Reasons for relocations and, if applicable, modifications made to the project to reduce the chance of future relocations.
        vii. Project tree resource: Percentage of total project trees planted.

viii. Annual tree planting expenditure (separately for the project and the municipality, educational campus, or utility).

f. Young tree care
   i. Number of young project trees inspected/pruned each year.
   ii. Inspection/pruning cycle (total number of project trees / number treated per year).
   iii. Annual expenditure (separately for the project and the municipality, educational campus, or utility).

g. Mature tree care
   i. Number of mature project trees inspected/pruned each year.
   ii. Inspection/pruning cycle (total number of project trees / number treated per year).
   iii. Annual expenditure (Reported annually, separately for the project and for the municipality, educational campus, or utility).

g. Tree removal
   i. Number of trees removed from existing tree sites each year (separately for non-project and project trees).
      xiii. Species, size, and location[13] of project trees removed each year.
   ii. Reasons for removals and, if applicable, modifications made to the project to reduce the chance of future removals.
   iii. Removal cycle (total number of project trees to remove / number removed per year).
   iv. Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

h. Administration/other
   i. Average $/tree site expenditure (total $ on administration and other / total tree numbers) (separately for the project and municipality, educational campus, or utility).
   ii. Annual expenditure (separately for the project and for the municipality, educational campus, or utility).

j. Net Tree Gain for each year and annual averages (Section 3.4.2) at the level of the municipality or educational campus.

k. Net Tree Gain for each year at the project level.

11. Project Tree Monitoring Plan
    a. Choice of method from the options in Section 5.1.

[13] Tree site location must be designated on a map of the project physical boundaries.

b. Detailed description of procedures to census (or sample, if applicable), measure, and report information on the project trees, including the survey method, sample sizes, and method for choosing samples.
c. Methods used to measure and record tree size.
d. Methods used and information collected on tree survival and health.
e. Statistical methods used to extrapolate sample data to the total project tree population, if applicable.
f. Estimated sampling error, if applicable.

12. Calculated project GHG reductions (removal enhancements, by year):
    a. Project tree CO_2 sequestration (adjusted for sampling error, if applicable)
    b. Project vehicle CO_2 emissions
    c. Project equipment CO_2 emissions
    d. Project GHG reductions (removal enhancements)