Urban Forest Management Quantification Guidance

June 2014

This document provides guidance for quantifying an Urban Forest Management (UFM) Project's Carbon Stocks[1], both for purposes of estimating a project's baseline as well as providing ongoing estimates of project Carbon Stocks throughout the Project Life. This guidance document is based on addressing important monitoring requirements. The specific monitoring objectives are to provide estimates of carbon inventories within the Project Area for purposes of calculating credits generated.

The Project Area must be defined prior to initiating inventory activities. Once defined, the Project Area may only be modified through agreement with the Climate Action Reserve (Reserve). Modification of the Project Area may impact the baseline, analysis of legal requirements affecting the Project Area, and other aspects of UFM Projects.

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[1] Capitalized terms are defined in the Urban Forest Management Project Protocol Version 1.0.

1 Reporting Requirements for Urban Forest Carbon Pools

Only Standing Live and Dead Trees can be included in quantifying UFM Project baselines and project estimates.

For standardized reporting, all estimates of forest Carbon Stocks must be provided in terms of tonnes (metric) of CO_2-equivalent (CO_2e) on a project and a per acre basis. Unless otherwise required in the referenced biomass equations, the following conversion formulae shall be used:

Base Unit	Conversion		Final Unit
Biomass	.5 * biomass	=	Carbon
Carbon	3.67 * carbon		CO_2e
Tons	0.90718474 * tons		Metric Tons (MT) or Tonnes
Hectares	0.404686 * hectares		Acres

2 Methodology(ies) for Estimating Current and Historical CO_2e in Urban Forest Management Projects

UFM Projects require a representation of the project's forest inventory in the past and at the Project Commencement Date. Project inventories must be updated, through the use of modeling as well as through the use of any field measurements that occurred since the previous reporting period on an annual basis for project monitoring. Only trees that are remeasured (DBH and height of all trees) within a maximum timeframe of 10 years are considered 100% inventoried. In cases where 100% inventories have been in place for at least the past 10 years, the historical inventory data can be used with the current inventory data to create the baseline trend (described below). Where trees are not 100% inventoried in UFM Projects, either in the current inventory or in the historic inventory, they must be sampled for the period in need of data. This quantification guidance provides sampling methodologies to develop urban forest inventories. Additional sampling methodologies may be added to this section as they are developed and reviewed by the Reserve.

Sampling can be an efficient way to generate estimates of CO_2e in urban forests. The approach to estimating CO_2e estimates for UFM Projects includes deriving a measurement or estimate of the canopy area within the Project Area and, through the use of ratio estimators developed through on the ground sampling of trees, deriving an estimate of CO_2e for the project.

The general approach to developing estimates of CO_2e in UFM Projects has the following generalized steps, all of which are described in more detail in this section:

1. Stratify the Project Area into urban forest classes.
2. Develop a ratio estimate (transfer function) of CO_2e estimates in standing trees.
3. Develop a measure or estimate of the canopy cover in Standing Trees for each of the urban forest classes within the Project Area.
4. Multiply the transfer function by the total canopy cover measure/estimate for each of the urban forest classes to estimate the CO_2e within each urban forest class.
5. Sum the estimates of CO_2e in standing trees for each urban forest class to develop an estimate for the project.

2.1 Stratify the Project Area into Urban Forest Classes

Stratify the Project Area into the urban forest classes described in Table 2.1. The urban forest classes may be combined to form broader strata for sampling. For instance, the residential high density and residential low density forest classes may be combined to form a 'residential' category. There are no limits to how the Project Operator combines urban forest classes. The guiding requirement is that the confidence in the transfer functions generated through sampling meets or exceeds +/-20% @ 90% Confidence Interval for the combined strata.

The result of the stratification shall be a GIS layer for which the sum of the area of the polygons developed through stratification is equal to the Project Area sum and no areas within the Project Area are without an urban forest class identifier. The minimum mapping unit for stratification is 2 acres, which means no 2 acre contiguous unit shall be within a mapping polygon and labeled with a stratum that is clearly distinct from the stratum to which it is assigned.

Table 2.1. Urban Forest Class Labels and Descriptions

Urban Forest Class	Description
Commercial/Industrial Code = CI	In addition to standard commercial and industrial land uses, this category includes outdoor storage/staging areas as well as parking lots in downtown areas that are not connected with an institutional or residential use. [NOTE: For mixed-use buildings, land use is based on the dominant use, i.e., the use that receives the majority of the foot traffic. It might not always occupy the majority of space in the building. For example, a building with commercial use of the first floor and apartments on upper floors would be classified as Commercial/Industrial.]
Institutional Code = IN	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings, etc. Note: If a parcel contains large unmaintained areas, possibly for expansion or other reasons, treat the area as Vacant. However, small forested islands in a maintained landscape would be considered Institutional.
Open Space Code = OS	This category includes land with no clear immediate use, including natural forest stands that are not identified as parks. Abandoned buildings and vacant structures should be classified based on their original intended use.
Residential High Density (>= 8 dwellings per acre) Code = RH	Freestanding structures serving one to four families each with 8 or more structures per acre.
Residential Low Density (<8 dwellings per acre) Code = RL	Freestanding structures serving one to four families each with less than 8 structures per acre. [Note: A block of attached one- to four-family structures is considered multi-family residential. A residential complex consisting of many separate one- to four-family structures.]
Transportation Code = TR	Road right of ways where vehicle traffic commonly exceeds 45 miles per hour and vegetation management of the right of ways is distinct from the areas around it.
Parks Code = PS	Parks include undeveloped (unmaintained) as well as developed areas (but must be identified as a park).
Cemetery	Includes any small unmaintained areas within cemetery grounds.

Code = CE	
Agriculture Code = AG	Cropland, pasture, orchards, vineyards, nurseries, farmsteads and related buildings, feed lots, rangeland, timberland/plantations that show evidence of management activity for a specific crop or tree production are included.
Utility Code = UT	Power-generating facilities, sewage treatment facilities, covered and uncovered reservoirs, and empty stormwater runoff retention areas, flood control channels, and conduits.
Water/Wetland Code = WA	Streams, rivers, lakes, and other water bodies (natural or man-made). Small pools and fountains should be classified based on the adjacent land use.
Other Code = OT	Land uses that do not fall into one of the categories listed above. This designation should be used very sparingly as it provides very little useful information for the model. Clarify with comments in Notes.

2.2 Develop Ratio Estimates (Transfer Functions) of CO_2e Estimates in Standing Trees

Transfer functions provide the ability to estimate the CO_2e in Standing Trees as a function of canopy cover. Transfer functions are developed from ground-based plots in which all trees in the plots are measured for variables that enable calculation of CO_2e estimates and canopy cover within the plot. This enables a ratio of CO_2e per unit area of canopy cover to be derived that can be applied to a measurement or estimate of canopy cover for each of the urban forest classes within the Project Area.

Project Operator's must select between one of two methods for establishing sample points. Method 1 is based on a systematic approach to locating points. Method 2 is based on a random approach to locating points. The following sub-steps from either Method 1 or Method 2 are required to develop the transfer functions:

Method 1 – Systematic Allocation of Points

1. A grid of points spaced equally at 100 foot spacing across the Project Area must be created within the GIS map of the Project Area. Each point shall be attributed with latitude, longitude, and a unique identifier that is established in a sequential order within a database. Individual points will be selected from this set of points to serve as the basis for random sample locations of Standing Trees. A map of the point location and urban forest classes must be included within the Project Design Document.

2. The points shall be grouped into sets within a database based on the urban forest class they are associated with.

3. A subset of points shall be randomly selected from the sets of urban forest class/point combinations for sampling. Project Operators must provide a description of the random methodology used to select a subset of points. Alternatively, the Reserve provides the following suggested methodology:

   A list must be included in the Project Design Document that displays the sets of points with their associated urban forest classes. Randomization shall be conducted by organizing the plots in separate lists in Microsoft Excel based on their associated urban forest classes using the following steps.

A field shall be added and identified as plot/urban class number. A sequential value (1-n) shall be assigned to each plot. The Microsoft Excel function 'randbetween' shall be used with a minimum value of 1 and a maximum value the total number of plots in the plot/urban class association. In a separate added field, the order of random selection shall be identified until all of the plots are assigned a random value or a minimum of 100 plots are assigned a random value (whichever comes first). In the event a plot is selected more than once, the value assigned to the plot shall be the value of the first time it was selected.

Method 2 – Random Allocation of Points

1. The U.S. Forest Service's i-Tree Canopy tool can be used as the basis of selecting random plot locations. The tool has additional utility in its ability to calculate canopy area (described below). The i-Tree Canopy tool will place randomized points within a user-defined area (Project Area). Project Operators must establish a minimum of 100 points, or a point for every 10 acres (whichever is smaller), in each of the strata initially. This step will likely result in more than the needed points being established in some strata. It is important to maintain the order of the location of the points as they must be visited in the field in the sequential order for each urban forest class.

2. The subset of sample points randomly selected in either of the two methods above are to be installed as fixed radius plots. The size of the radius from the plot center (from the point coordinates) is 37.2 feet (1/10th acre). Project Operators may explain and justify an alternative plot radius in the Project Design Document. The radius must be consistently applied throughout the Project Life. Only the random plots selected need to be installed (measured).

   Project Operators must apply reasonable diligence to sample the selected random plots as they are ordered. Reasonable diligence means the Project Operator has made contact, either through written or oral (telephone or onsite) media. Certain randomly selected points may be impossible to sample due to safety or accessibility and therefore must be rejected, as in cases where permission to trespass is not granted, either explicitly or indirectly through inadequate communication. Project Operators must wait 10 days following the posting of letters to make a claim of inadequate communication, in the event the landowner fails to follow up with the Project Operator. Additionally, many points may not have any standing trees associated with them. When a plot is rejected for any reason, the reason for the rejection must be noted in a sampling log and included in the PDD. A communication log with the landowner must also be maintained, detailing the phone calls and/or physical correspondence used to communicate. Any additional plot rejected over the Project Life must be noted in a project log and submitted with the annual monitoring report. The rejected plot log must be available for verification oversight.

   Since the purpose of the sample plots is to develop a relationship between CO_2e and urban forest canopy, points with no trees within the radius described above can be rejected. Project Operators must document the rationale for rejecting plots prior to selecting the next random plot in their list. In the event of plot rejection, the Project Operator shall select the next numerical point (1,2,3,…) in the plot list as a potential plot for measuring. In the event a successive plot is a plot that was selected randomly, the Project Operator shall continue to the next plot (1,2,3,…) in the plot list. Plot rejections and selections of subsequent plots shall be documented in the Project Design Document.

Plot centers must be monumented so they can be relocated for future measurement or for verification. Monumenting plot locations so that they are available for re-measurement and/or verification can be challenging. GPS coordinates must be recorded for each plot at, or offset from, the plot center. Since GPS coordinates will only partially assist in relocating the plot center due to accuracy of GPS, additional navigational devices are necessary. It is recommended that, where possible, an object or marking be placed at plot center that is highly resistant to environmental features, including weather, animals, and fire.

However, the placement of a monument at plot center is not feasible in urban areas under most circumstances. Therefore, monumenting plot locations may require identifying features that can be used to triangulate to the plot center using distance and compass bearing measurements. Care should be used to ensure features are selected that are likely to endure up to 10 years. This might include building corners, fire hydrants, street signs, etc. Notes should clearly describe the feature being used as well as distance and bearing data. A minimum of two navigational features are required. It is recommended that the features be separated by at least 20 degrees to plot center.

Measurement standards and data requirements on each plot are outlined in Table 2.2.

Table 2.2. Measurement Standards for Urban Forest Sample Plots

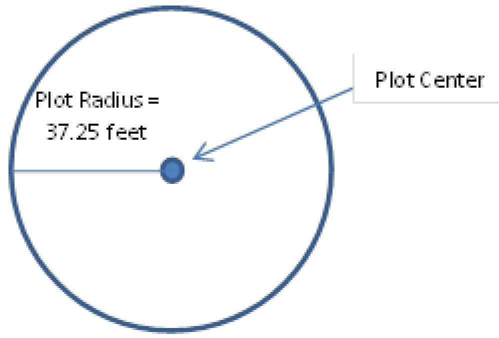
<table>
<tr><th colspan="3">For Each Plot</th></tr>
<tr><th>Attribute</th><th colspan="2">Description</th></tr>
<tr><td>Date of Plot Visit</td><td colspan="2">Day/Month/Year</td></tr>
<tr><td>Latitude of Plot Center</td><td colspan="2">From GPS</td></tr>
<tr><td>Longitude of Plot Center</td><td colspan="2">From GPS</td></tr>
<tr><td rowspan="3">Navigational Feature 1</td><td>Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.</td><td>(Fire hydrant, street sign, building corner, etc.)</td></tr>
<tr><td>Distance from feature to plot center</td><td>Feet</td></tr>
<tr><td>Azimuth from feature to plot center</td><td>Degrees</td></tr>
<tr><td rowspan="3">Navigation Feature 2</td><td>Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.</td><td>(Fire hydrant, street sign, building corner, etc.)</td></tr>
<tr><td>Distance from feature to plot center</td><td>Feet</td></tr>
<tr><td>Azimuth from feature to plot center</td><td>Degrees</td></tr>
<tr><td>Stratum</td><td colspan="2">Enter the Urban Class Code or user-defined stratum associated with the plot.</td></tr>
</table>

Plot Number	Enter the plot number for the plot, as described in the section (Plots) above.
Inventory Personnel	Enter the initials of the inventory technicians responsible for measuring and recording data on the plot.

Measure all canopy area and all trees within a fixed 1/10th acre radius (radius = 37.25 feet) according to guidance below.

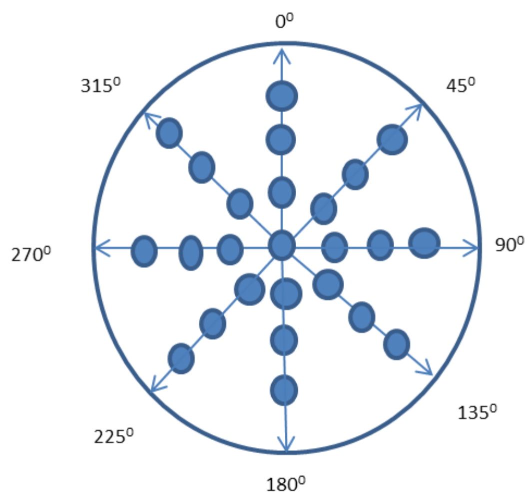
Radial measurements need to be corrected for horizontal distances.

Slope %	5	10	15	20	25
Adj. Radius	37.30	37.44	37.67	37.99	38.40
Slope %	30	35	40	45	50
Adj. Radius	38.89	39.47	40.12	40.85	41.65
Slope %	55	60	65	70	75
Adj. Radius	42.51	43.44	44.43	45.47	46.56
Slope %	80	85	90	95	100
Adj. Radius	47.70	48.89	50.11	51.38	52.68

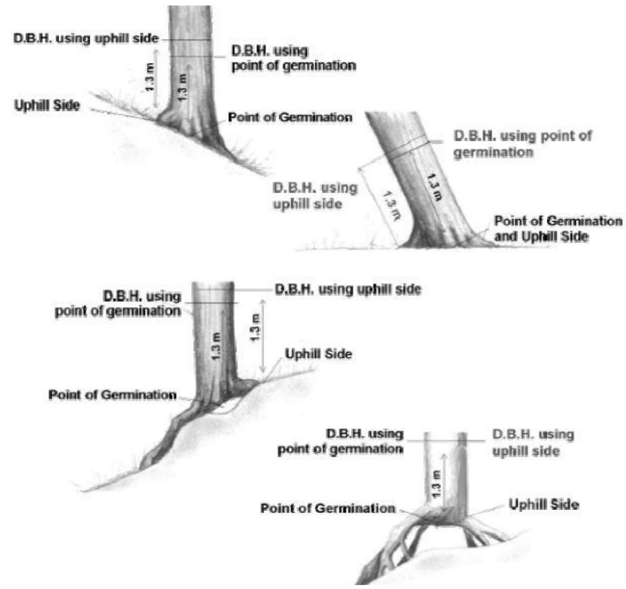


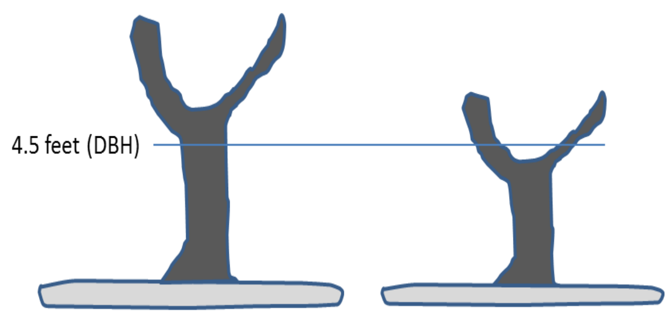
To determine canopy area, use a sighting tube at plot center and at 10 feet, 20 feet, and 30 feet from plot center on the compass bearings shown to determine a canopy 'hit' or canopy 'miss'.

Multiply the sum of the hits by 4 to estimate the canopy cover percentage within the 1/10th acre fixed plot.



For Each Tree	
Attribute	**Description**
Tree Number	Trees are assigned a number 1 to X starting from 0 degrees (North) and generally proceeding clockwise. The numbering convention facilitates the relocation and the verification of the trees.
Species	Enter the species code for each species on the plot. The species code can be found for each species in the corresponding reference document. The species code is based on the first two letters of the genus and the first two letters of the species for any given species.
DBH	Measure and record Diameter at Breast Height (DBH) of all trees 3"DBH and greater to the nearest inch on every tree using a diameter tape and wrapping the tree at a height of 4.5 feet from the base of the tree on the uphill side.

<table>
<tr><td></td><td>

Forked trees above DBH are counted as one tree. Forked trees below DBH are counted as two trees (or however many forked stems exist). Add minimum DBH to be included.

</td></tr>
<tr><td>Total Height</td><td>Measure of total height (height from base of tree to top) of each tree to the nearest foot.</td></tr>
<tr><td>Growth Condition</td><td>An attribute of ‘Open’ or ‘Closed’ must be assigned to each tree according to the description below:
<table>
<tr><th>Class</th><th>Description</th></tr>
<tr><td>O</td><td>An open attribute is assigned to trees growing in non-natural settings. Tree species may be a variety of native and non-native species. Most often, trees exist in areas where disturbance of natural areas and conversion to another land use has occurred.</td></tr>
<tr><td>C</td><td>A closed attribute is assigned to trees growing in natural settings. Trees present are characteristic of the species diversity and structure in forested areas outside the urban area.</td></tr>
</table></td></tr>
<tr><td>Vigor</td><td>For each tree, provide a rating of the tree’s apparent vigor. Determination of vigor based on consideration of color of foliage, crown proportion and appearance, retention of leaves/needles, appearance of apical growth, length between growth whorls, and</td></tr>
</table>

<table>
<tr><td rowspan="9"></td><td colspan="2">presence of cavities and fungal growth. The code is assigned based on the following classes:</td></tr>
<tr><th>Code</th><th>Description*

*based on conditions present during growing periods. Professional judgment need be applied if sampling conducted outside of growing periods.</th></tr>
<tr><td>1</td><td>Excellent – Tree exhibits high level of vigor and no barriers (soil, light, etc.) to continued vigor. No decay or broken branches are observed.</td></tr>
<tr><td>2</td><td>Good – Tree exhibits high level of vigor and some minor barriers (soil, light, etc.) to continued vigor. No decay or broken branches are observed.</td></tr>
<tr><td>3</td><td>Fair – Tree appears generally healthy. Barriers (soil, light, etc.) affect the trees vigor. Tree's crown may be smaller proportionally than in healthier trees. Decay and/ or broken branches, if observed, are not likely to have negative impacts in the short term.</td></tr>
<tr><td>4</td><td>Poor – Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have high likelihood of being rectified through management of said tree and trees surrounding it.</td></tr>
<tr><td>5</td><td>Critical – Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have low likelihood of being rectified through management of said tree and trees surrounding it.</td></tr>
<tr><td>6</td><td>Dying – Tree is unhealthy. Minimal live crown is present; portions of bark may be missing and/or substantial levels of broken stems and branches. Tree may exhibit advanced decay. No further investment in restoring the tree to a higher vigor is deemed worthwhile.</td></tr>
<tr><td>7</td><td>Dead – No live material is observed in the tree.</td></tr>
<tr><td>Defect – Bottom 33%</td><td colspan="2" rowspan="3">For each portion of the tree, provide an ocular estimate of the portion of tree that is missing (as a percentage of the section) as the result of breakage or cavities.</td></tr>
<tr><td>Defect – Mid 33%</td></tr>
<tr><td>Defect – Top 33%</td></tr>
</table>

3. 1/10th acre plots shall be measured in each urban forest class. The tree canopy shall be measured as shown in Table 2.2 above. The percent estimate derived from the plot shall be multiplied by 43,560 to provide an estimate of the square feet per acre represented by the plot. CO_2e shall be calculated for each tree using the appropriate biomass equations provided by the Reserve on the Urban Forest Project Protocol website. The biomass equations enable calculation of CO_2e for the above-ground portion of trees, using the units of conversion provided at the top of this section. The below-ground portion of trees shall be calculated by multiplying the above-ground portion of trees by 26%. This value shall be added to the above-ground portion to produce a value that represents the above and below-ground tree. These values shall be summed for each plot and multiplied by 10 to establish a per-acre estimate from each plot. All values shall be presented as metric tonnes CO_2e per acre.

   The average canopy cover (per acre basis) and the average CO_2e value (per acre basis) from all measured plots shall be calculated and documented in the Project Design Document. A ratio of CO_2e per square foot of canopy cover shall be calculated, as shown in Table 2.3.

Table 2.3. Urban Forest Class and Transfer Functions

Urban Forest Class	Average Canopy Cover Area from Ground-Based Plots	Average CO_2e from Ground-Based Plots	Transfer Functions
	(ft^2/acre)	(per acre)	(CO_2e/ft^2 of canopy cover)
Commercial/Industrial	3,485	15	0.0043044
Utility	5,227	20	0.0038261
Residential – High Density	15,246	60	0.0039355
Transportation	3,485	12	0.0034435

2.3 Measure or Estimate the Current Canopy Cover in Standing Trees for Each of the Urban Forest Classes within the Project Area

The canopy of Trees must be measured or estimated for each of the urban forest classes using remotely-sensed data. If measured, the entire canopy cover for the Project Area will be mapped as a layer in a GIS. The data and tools used to measure the canopy area are not limited and may include a variety of remotely sensed data and automated digitizing, as well as manual digitizing. Any tools and methodologies used to develop the GIS layer of canopy will be reviewed by the verifier for statistical accuracy and appropriateness.

If the canopy layer is sampled rather than measured, the sampled portion must be displayed as a layer in a GIS. The following methods are allowed for sampling canopy area:

1. Randomized points developed using the i-Tree Canopy tool derive a 'hit' or 'miss' (of tree canopy), and must be determined by the technician. The proportional points superimposed on canopy allow a percentage and confidence statistics to be calculated. The percent estimate is applied to the area of each stratum within the Project Area to determine a canopy area estimate for each stratum. i-Tree Canopy does not currently allow the user to calculate canopy percentages independently for each stratum. Therefore, the Project Operator must attribute each point to the stratum it is in and calculate the percentages and confidence statistics independently from the i-Tree Canopy tool.

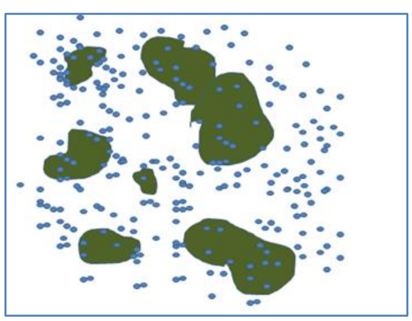


Figure 2.1. Example of Overlaying Random Points in the Project Area to Determine Canopy Percentage

2. A systematic sample can be conducted with a grid of points established in a GIS and placed over the Project Area for the purposes of estimating canopy area. The Project

Operator must determine the 'hit' and 'miss' of each point (in terms of being coincident with a tree crown(s)), which will enable a percentage to be determined and canopy area to be determined (as described above).

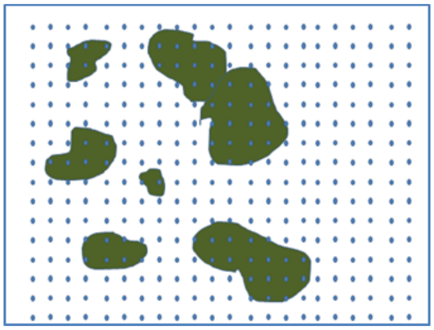


Figure 2.2. Example of Overlaying a Systematic Grid in the Project Area to Determine Canopy Percentage

3. Sampling can be conducted using remotely sensed data as a subset of the Project Area. Again, the sampling must be designed to develop estimates for each stratum independently. The sampling must incorporate randomized strips (two parallel lines with a known distance between them to calculate area) or randomized or systematic area plots. The Project Operator must be able to calculate accurately the area within the strip or plot that is tree canopy and the area that is not tree canopy.

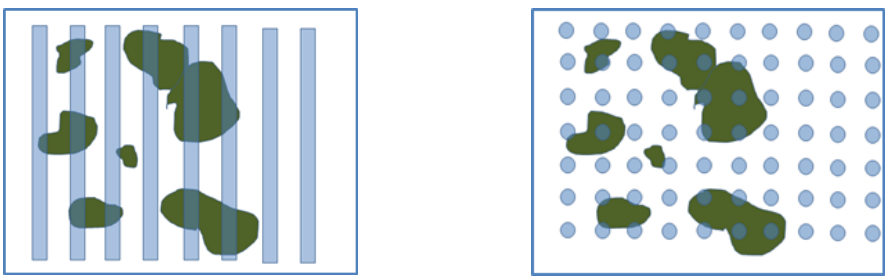


Figure 2.3. Example of Overlaying Known Area Sampling Units (Strips and Fixed Radius)

Regardless of the method utilized:

1. The points, strips, or plots must be maintained for the Project Life and be available for verification.

2. The sample effort must result in an estimate of canopy cover that exceeds +/- 10% @ 90% Confidence Interval.

3. Sampling for canopy cover must continue until a confidence estimate for average canopy cover for each urban forest class is achieved at +/-10% @ 90% confidence interval. A list of plots sampled and each plot's estimated percentage and canopy area estimate must be included in the Project Design Document.

4. A table must be presented in the Project Design Document that provides the data shown in Table 2.4. Data shall be carried out to two decimal points. If canopy was 100%

measured, the canopy area can be entered directly into the table below. If sampled, the mean percent canopy estimate from sampling is multiplied by the area within each urban forest class to estimate the canopy area.

Table 2.4. Example of Canopy Cover Data Required in Project Area

Urban Forest Class/Stratum	Total Area within Project Area (acres)	Total Area of Tree Canopy within Project Area (acres)	Total Area of Tree Canopy within Project Area (ft^2)	Mean Estimate at 90% CI (if sampled. If not sampled, enter measured)
Commercial/Industrial	50.45	5.35	233,046.00	4.50%
Utility	10.56	1.87	81,457.20	7.90%
Residential – High Density	155.67	54.32	2,366,179.20	3.70%
Transportation	67.23	4.57	199,069.20	9.30%
Total	283.91	60	2,613,600.00	5.20%

2.4 Determine the Current Project Area Estimate of CO_2e

With the total tree canopy area estimated or measured and transfer functions developed for each of the urban forest classes, an estimate of CO_2e for the Project Area can be estimated. The transfer functions are multiplied by the total square feet of canopy cover in each urban forest class and summed to determine the estimated CO_2e in the Project Area, as shown in Table 2.5.

Table 2.5. Example of Expanding Transfer Functions Based on Canopy Cover Area to Estimate Total Current CO_2e within the Project Area

Urban Forest Class	Transfer Functions (from above) (CO_2e/ft^2 of canopy cover)	Current Estimated/Measured Canopy Cover Area (ft^2)	Total CO_2e (metric tons)
Commercial/Industrial	0.0043044	233,046.00	1,003.12
Utility	0.0038261	81,457.20	311.66
Residential – High Density	0.0039355	2,366,179.20	9,312.10
Transportation	0.0034435	199,069.20	685.49
		Total	11,312.38

2.5 Calculate the Historic Project Area Estimate of CO_2e

A historic inventory is required to develop a trend used in the development of the project baseline. The historic Project Area estimate of CO_2e is calculated by expanding the transfer functions developed for the current inventory data using canopy cover estimates from remotely-sensed data that was produced at least 10 years prior to the image used to produce the current canopy cover estimate. The trend line must pass through two points of inventory estimates that are at least 10 years apart and with the earliest point no earlier than 1990.

It is acceptable to either measure the entire canopy area from an earlier image or to sample the canopy area as described above for current images. The analysis of plot area shall terminate upon completion of the same plots sampled for the current inventory estimate. The image used must be available to a verifier and identified in the PDD. An example of using a historic estimate of canopy cover to expand transfer functions in order to calculate a historic CO_2e estimate is shown in Table 2.6.

Table 2.6. Example of Expanding Transfer Functions Based on Historic Canopy Cover Area to Estimate Historic CO_2e within the Project Area

Urban Forest Class	**Transfer Functions (from above)** **(CO_2e/ft^2 of canopy cover)**	**Historic Estimated/Measured Canopy Cover Area** **(ft^2)**	**Total CO_2e** **(metric tons)**
Commercial/Industrial	0.0043044	201,222.00	866.14
Utility	0.0038261	79,566.00	304.43
Residential – High Density	0.0039355	2,375,898.20	9,350.35
Transportation	0.0034435	168,951.20	581.78
		Total	11,102.70

2.6 Baseline Development for Urban Forest Management Projects

The baseline for UFM Projects is calculated by developing a trend based on a comparison of two sets of historic estimates of Standing Live and Dead Trees and /or a comparison of historic estimates of Standing Live and Dead Trees to current estimates. The slope developed by plotting the two points of inventory on their respective year of reporting is continued into the future for the next 20 years and then held steady for the subsequent 80 years where legal requirements have not been modified substantially, as described below.

An analysis of legal requirements must accompany the baseline development. The PDD must include a full disclosure of legal requirements affecting tree management within the Project Area. Any substantial change in legal requirements, including ordinances, regulations, or other legal obligations, not including legal obligations associated with the use of this protocol, that would modify the trend described above over the next 20 years must be modeled for the next 20 years or as long as stated in the requirements (whichever is longer). Modeling is conducted by projecting any carbon stored by trees obligated by the regulation forward into time. Modeling must be conducted by a Certified Arborist, a Certified Forester, or a Professional Forester. Where modeling must be conducted, the baseline shall be defined by a straight line from the UFM Project's initial stocks to the highest point determined from baseline modeling. Examples of sources of legal obligations may include, but are not limited to, tree ordinances, urban forest ordinances or management plans, landscaping ordinances, or other environmental regulations associated with urban development and land use change.

Examples of the baseline approach are displayed in Figures 2.4 and 2.5.

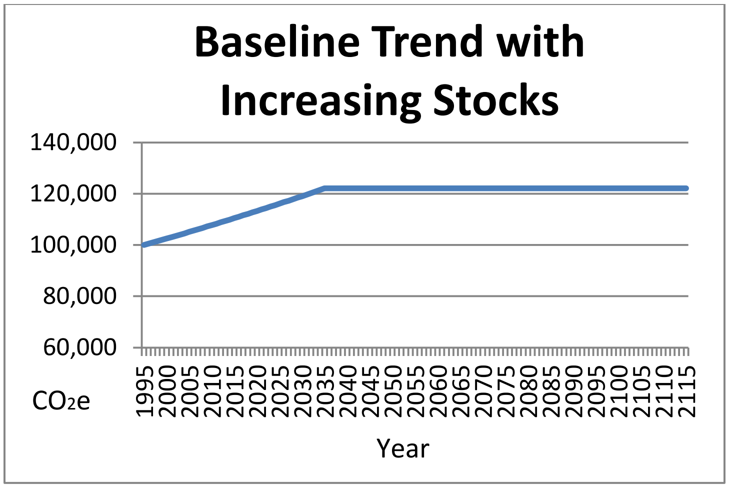


Figure 2.4. Example of Increasing Baseline Trend Extending 20 Years Beyond Current Inventory and then Static for Balance of 100 Years

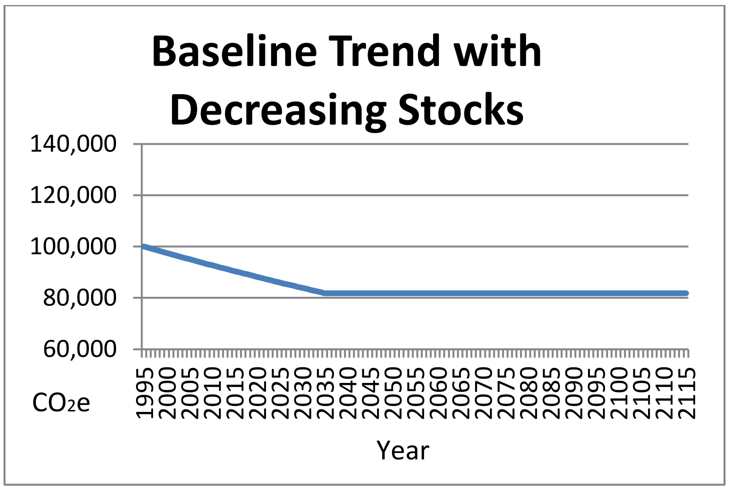


Figure 2.5. Example of Increasing Baseline Trend Extending 20 years Beyond Current Inventory and then Static for Balance of 100 Years

3 Updating Forest Inventories

Urban forest inventories must be reported to the Reserve on an annual basis. Urban forest inventories are in constant flux due to forest growth and mortality or removal and therefore must be updated on an annual basis for reporting. The inventory must be updated annually through a combination of projecting existing inventory data and/or re-measuring inventory data with an objective of reporting inventory data that reflects actual conditions in the field.

Plot data can be ‘grown’, or projected for a maximum of 10 years, after which additional field work is required to either update the plot data or establish new plots.

It is important to note that the basis of a successful verification depends on alignment (within tolerance bands defined in the verification guidance) between verifier data and Project Operator data for each randomly selected plot (selected by verifier), therefore these guidelines do not ensure successful project verification. The actual timeframe between plot re-measurement may need to be reduced to less than 10 years if the updates of inventory data proof to be inaccurate on a plot by plot basis.

Since the biomass of sampled trees is determined through the use of equations that are based on diameter (breast height) and total height variables, updating plot data for forest growth can be accomplished through the use of projections of inventory data in the database that mimic the diameter and height increment of trees in the field. An additional resource document posted on the urban forest webpage (pending) provides a list of publications that reference urban forest growth rates. The references in the resource document may be useful for Project Operators in designing an appropriate mechanism to ‘grow’ their plot data.

Most references address the annual increment of diameter (DBH). Height growth also needs to be addressed to ensure the most accurate comparison of tree records in the database to actual conditions in the field. Heights can be estimated through regression analysis by comparison of measured diameters to measured heights for a given species. It is recommended that, rather than simply relying on the height estimate from the regression analysis, that Project Operators apply the height increment derived from the regression analysis to the height that was measured in the field.

In any case, plot data that is updated to reflect current conditions with the use of predicted increments of height and diameter data, as well as updates for removals, will be used during onsite verifications to compare against verifiers field measurements using the sequential sampling techniques described in the verification section. This provision ensures that plot measurements and update processes are within accuracy thresholds.

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Project Protocol

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Abbreviations and Acronyms

C	Carbon
CAL FIRE	California Department of Forestry and Fire Protection
CH_4	Methane
CO_2	Carbon dioxide
CRT	Climate Reserve Tonne
DBH	Diameter at Breast Height
FIA	Forest Inventory and Analysis Program of the U.S. Forest Service
GHG	Greenhouse gas
GIS	Geographical Information System
ISO	International Organization for Standardization
KML	Keyhole Markup Language (see glossary)
N_2O	Nitrous oxide
PDD	Project Design Document
PIA	Project Implementation Agreement
Reserve	Climate Action Reserve
RPF	Registered Professional Forester (California only)
SSR	Source, sink, or reservoir
UFM	Urban forest management
UFMPP	Urban Forest Management Project Protocol
USFS	United States Forest Service
VOC	Volatile Organic Compound

1 Introduction

The Urban Forest Management Project Protocol (UFMPP) provides requirements and guidance for quantifying the net climate benefits of activities that sequester carbon in woody biomass within an urban environment. The protocol provides project eligibility rules, methods to calculate a project's net effects on greenhouse gas (GHG) emissions and removals of carbon dioxide (CO_2) from the atmosphere ("removals"), procedures for assessing the risk that carbon sequestered by a project may be reversed (i.e., released back to the atmosphere), and approaches for long term project monitoring and reporting.

The goal of this protocol is to ensure that the net GHG reductions and removals caused by a project are accounted for in a complete, consistent, transparent, accurate, and conservative manner[1] and may therefore be reported to the Climate Action Reserve (Reserve) as the basis for issuing carbon offset credits (called Climate Reserve Tonnes, or CRTs). Additionally, it is the goal of the Reserve to ensure the protocol is as efficient and practical as possible for Project Operators.

As the premier carbon offset registry for the North American carbon market, the Reserve encourages action to reduce GHG emissions by ensuring the environmental integrity and financial benefit of emission reduction projects. The Reserve establishes high quality standards for carbon offset projects, oversees independent third-party verification bodies, issues carbon credits generated from such projects, and tracks the transaction of credits over time in a transparent, publicly-accessible system. The Reserve is a private 501(c)(3) nonprofit organization based in Los Angeles, California.[2]

Only projects that are eligible under and comply with this UFMPP may be registered with the Reserve. Section 8 of this protocol provides requirements and guidance for verifying the performance of project activities and their associated GHG reductions and removals reported to the Reserve.

1.1 About Urban Forests, Carbon Dioxide and Climate Change

Urban forests have the capacity to both emit and absorb CO_2, a leading greenhouse gas that contributes to climate change. Trees, through the process of photosynthesis, naturally absorb CO_2 from the atmosphere and store the gas as carbon in their biomass, i.e., trunk (bole), leaves, branches, and roots. Carbon may also be stored in the soils that support the urban forest, as well as the understory plants and litter on the urban forest floor. After trees are removed, their wood residue may be converted into mulch, with CO_2 gradually released to the atmosphere through decomposition. Carbon may continue to be sequestered for a substantial amount of time in wood products and in landfills. Carbon from urban forests may also be used to provide fuel for biomass energy. Urban trees can reduce summertime air temperatures and building energy use for air conditioning, thus reducing GHG emissions from electricity generation (Akbari 2002). In winter, trees can increase or decrease GHG emissions associated with energy consumed for space heating, depending on local climate, site features, and building characteristics (Heisler 1986).

[1] See the WRI/WBCSD GHG Protocol for Project Accounting (Part I, Chapter 4) for a description of GHG reduction project accounting principles.
[2] For more information, please visit www.climateactionreserve.org.

When trees are disturbed, through events like fire, disease, pests, or harvest, some of their stored carbon may oxidize or decay over time, releasing CO_2 into the atmosphere. The quantity and rate of CO_2 that is emitted may vary, depending on the particular circumstances of the disturbance. Depending on how urban forests are managed or impacted by natural events, they can be a net source of emissions, resulting in a decrease to the reservoir, or a net sink of emissions, resulting in an increase of CO_2 to the reservoir. In other words, urban forests may have a net negative or net positive impact on the climate.

2 Urban Forest Management Definition and Requirements

For the purposes of this protocol, an Urban Forest Management (UFM) Project is a planned set of activities designed to increase removals of CO_2 from the atmosphere, or reduce or prevent emissions of CO_2 to the atmosphere, through increasing and/or conserving urban forest Carbon Stocks.

A glossary of terms used in this protocol is provided in Section 9. Throughout the protocol, important defined terms are capitalized (e.g., "Urban Forest Owner").

2.1 Project Definition

A UFM Project focuses on activities that maintain or increase carbon inventories relative to baseline levels, as defined in this protocol, of carbon within the project boundary. Eligible management activities may include, but are not limited to:

- Increasing the urban forest productivity by removing diseased and suppressed trees
- Reducing emissions by avoiding tree removals
- Planting additional trees on available and appropriate sites
- Monitoring, protecting, and treating trees to avoid premature mortality from stressors such as drought, pests, storm damage, and abiotic agents
- Reducing the vulnerability of trees to impacts of climate change by increasing resilience

2.2 Urban Forest Owners

Credits for a UFM Project must be quantified from carbon that is owned by participating entities. An Urban Forest Owner is a corporation, a legally constituted entity (such as a utility or special district), city, county, state agency, educational campus, individual(s), or a combination thereof that has legal control of any amount of urban forest carbon[3] within the Project Area.

Having legal control of urban forest carbon means that the Urban Forest Owner has the legal authority to effect changes to urban forest carbon quantities (right to plant or remove trees, for example). Legal control of urban forest carbon may be conveyed, for purposes of satisfying this protocol, through fee ownership, perpetual contractual agreements, deeded encumbrances, or other legal provisions. This protocol recognizes the fee owner as the default owner of urban forest carbon where no explicit legal encumbrance exists. Individuals or entities holding mineral, gas, oil, or similar *de minimis*[4] interests without fee ownership are precluded from the definition of Urban Forest Owner.

Only counties, municipalities, educational institutions, and utilities/special districts, or Urban Forest Owners that own a minimum of 50 acres, referred to as Large Urban Forest Owners, may develop a project independently. Urban Forest Owners are able to combine, or aggregate, forest carbon with other Urban Forest Owners to develop a UFM Project at increased scale. Urban Forest Owners must agree to a single Project Operator (see below) who is designated to manage the requirements of the project. A single Project Operator may aggregate projects across multiple areas that they own, if applicable. Aggregated projects may only include the carbon controlled by permission as described in Section 2.3.

[3] See definition of Carbon Stock in the glossary.

[4] *de minimis* control includes access right of ways and residential power line right of ways.

2.3 Project Operators

A Project Operator must be one of the Urban Forest Owners or a legal entity created to represent the Urban Forest Owners. The Project Operator is responsible for undertaking a project and registering it with the Reserve, and is ultimately responsible for all project listing, monitoring, reporting, and verification. The Project Operator is responsible for any Reversals associated with the project and is the entity that executes the Project Implementation Agreement (see below) with the Reserve.

In all cases where multiple Urban Forest Owners participate in a UFM Project, the Project Operator must secure an agreement from all other Urban Forest Owners that assigns authority to the Project Operator to include the carbon they own in the project. Such an agreement must provide any of the Urban Forest Owners the opportunity to opt out of the project.

2.4 Project Implementation Agreement

A Project Implementation Agreement (PIA) is a required agreement between the Reserve and a Project Operator setting forth the Project Operator's obligation (and the obligation of its successors and assigns) to comply with the terms of the protocol. Project Implementation Agreement forms can be found on the Climate Action Reserve's website.

3 Eligibility Rules

In addition to the definitions and requirements described in Section 2, UFM Projects must meet several other criteria and conditions to be eligible for registration with the Reserve, and must adhere to the following requirements related to their duration and crediting periods.

Section 3.1	Project Location	⟶	*Urban Areas (including Urban Clusters) and Places (including Incorporated Places and Census-Designated Places) within the U.S.*
Section 3.2	Limits to Site Preparation	⟶	*Disturbance on more than 2% of the Project Area annually not permitted*
Section 3.3	Project Start Date	⟶	*No more than six months prior to project submission*
Section 3.4	Additionality	⟶	*Meet legal requirements*
		⟶	*Meet performance standard*
Section 3.5	Project Crediting Period	⟶	*25 years*
Section 3.6	Minimum Time Commitment	⟶	*100 years*
Section 3.7	Regulatory Compliance	⟶	*Compliance with all applicable laws*
Section 3.8	Social and Environmental Co-Benefits	⟶	*Projects are encouraged to report on relevant co-benefits*

3.1 Project Location

Only those activities that occur within the Urban Areas[5] and Places[6] boundaries defined by the most recent publication of the United States Census Bureau,[7] are eligible to develop a project under this protocol. Projects must be entirely within defined Urban Area and/or Place boundaries as of Project Commencement.

3.1.1 Project Area

The Project Area is the geographic extent of the project. The Project Area may be made up of consolidated or disaggregated polygons (i.e., parcels, or portions of parcels) within an Urban Area and/or Place polygon established by the U.S Census Bureau. A map layer combining Urban Areas and Places is available on the Urban Forest Project Protocol webpage to assist with identifying eligible Project Areas. When determining the extent of the Project Area at the Project Start Date (see Section 3.3), the most recent Urban Areas and Places GIS layers must be used. These map layers are available from the U.S. Census Bureau website.[8]

[5] Urban Areas are composed of Urbanized Areas (areas with populations ≥50,000 people) and Urban Clusters (populations ≥2,500 and <50,000).
[6] Places are composed of Incorporated Places and Census-Designated Places, and defined by the U.S. Census Bureau. Generally, an Incorporated Place is an area that is legally incorporated under the laws of its respective state, whereas a Census-Designated Place is a community that lacks a separate government but otherwise resembles incorporated places, with a residential core, relatively high population density, and a degree of local identity.
[7] https://www.census.gov/geo/maps-data/
[8] https://www.census.gov/geo/maps-data/data/tiger-line.html

No part of the Project Area can be included if commercial harvesting of timber has occurred in the Project Area in the past 10 years where the canopy cover was reduced by more than 50% within a contiguous acre, excepting where the harvest occurred for safety or forest health purposes. Additionally, the issuance and transaction of credits will be suspended if commercial harvesting of timber products occurs any time during the project. Where the harvesting of commercial timber products is anticipated, the Project Operator should consider the use of a protocol that addresses the carbon stored in harvested wood products, such as the Reserve's Forest Project Protocol or the California Air Resources Board's Compliance Offset Protocol for U.S. Forest Projects. Exceptions to the prohibition are recognized where commercial timber products might be generated from harvests conducted primarily for safety, salvage of material when trees are in decline, and developing improved resilience to wildfire and pests.

A KML file must be submitted with the project to clearly identify the project boundaries. At a minimum, UFM Projects must be at least 25 acres. A project can be made up of one or many participating Urban Forest Owners. Project acreage shall be based on area calculations derived from GIS analysis, such as ArcGIS or Google Earth. GIS data are generally considered to be improvements over strict adherence to county parcel acreages since GIS data are based on aligning property boundaries to geographic characteristics and/or property corners as described in property deeds or official survey notes.

The project must list the county assessor's parcels (APs), the portion of each AP included in the project (as a percentage), the sum of acres derived from the county tax records for all included APs, and the sum of acres derived from the GIS analysis. The sum of acres should be compared between the AP and GIS sources, with the lesser of the two used for the Project Area. If there is a significant discrepancy between AP and GIS acres, the Project Operator may work with the county assessor to resolve any disputed AP acres. The GIS acreage may be used when greater than the AP acreage if the Project Operator provides evidence (e.g., boundary survey) substantiating the accuracy of the GIS acreage.

3.2 Limits to Site Preparation

UFM Projects that plow, till, or rip soils, resulting in the removal of the roots of herbaceous understory in preparation for planting trees where more than 2% of the Project Area is disturbed on an annual basis are not eligible, since soil-related emissions above baseline levels are not quantified in this protocol. Where such plowing, tilling, or ripping of soils occurs as described within an existing project in any one year, the transacting of credits will be suspended until the subsequent years and soil disturbance rates brings the average below the 2% threshold, after which time the 2% threshold in any given year is renewed.

3.3 Project Start Date

The start date for a project is the date at which the Project Operator initiates an activity that will lead to increased GHG reductions or removals with long-term security relative to the project baseline. The start date is initiated by activities that increase carbon inventories and/or decreases emissions relative to the baseline. Evidence of discrete and verifiable activities that justify a start date includes:

- Submitting the project to the Reserve. The Project Start Date is the date of submittal
- Dated planning documents that indicate the date in which the activities were initiated
- Recordation of a conservation easement

To be eligible, the project must be submitted to the Reserve no more than six months after the Project Start Date.[9] Projects may always be submitted for listing by the Reserve prior to their start date.

3.4 Additionality

The Reserve will only register projects that yield surplus GHG emission reductions and removals that are additional to what would have occurred in the absence of a carbon offset market (i.e., under "Business As Usual"). For a general discussion of the Reserve's approach to determining additionality, see the Reserve's Program Manual.[10]

Projects must satisfy the following tests to be considered additional.

3.4.1 Legal Requirement Test

UFM Projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from compliance with any federal, state, or local law, statute, rule, regulation, or ordinance. Projects must also achieve GHG reductions and removals above and beyond any GHG reductions or removals that would result from compliance with any court order or other legally binding mandates.

Deeded encumbrances, tree planting and management ordinances, provisions of management plans required by law, and contractual agreements, collectively referred to as Legal Agreements, may effectively control urban forest carbon and convey ownership rights to the carbon inventories controlled, affecting which party may claim ownership to any eligible GHG reductions or removals. Similarly, these same controls may have an effect on urban forest carbon inventories beyond the control of any of the Urban Forest Owners and, as such, must be considered to be legal constraints on the project.

The baseline trend for UFM Projects is based on comparison of historic data as described in the Quantification Guidance and includes the effects of legal requirements. This ensures that any GHG reductions or removals achieved by the project are above and beyond any GHG reductions or removals that would result from engaging in Business-As-Usual activities, thereby satisfying the legal requirement test.

3.4.2 Performance Standard Test

UFM Projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from engaging in Business-As-Usual activities. UFM Projects automatically satisfy the performance standard by maintaining carbon stocks above the baseline.

3.4.3 Enhancement Payments

Enhancement payments provide financial assistance to landowners in order to implement discrete practices that address natural resource concerns and deliver environmental benefits. Examples of relevant enhancement payments include:

- California Climate Investments (CCI), formerly called Greenhouse Gas Reduction Funds (GGRF)
- USFS grants and agreements

[9] Projects are considered submitted when the project developer has completed and uploaded the appropriate project submittal forms to the Reserve software.
[10] Available at http://www.climateactionreserve.org/how/program/program-manual/.

Urban Forest Owner(s) may pursue enhancement payments that support urban forest management carbon project activities. Because every available enhancement payment is not comprehensively addressed by the protocol at this time, the Urban Forest Owner(s) must still disclose any such payments to the verifier and the Reserve on an ongoing basis. The Reserve maintains the right to determine if payment stacking has occurred and whether it would impact project eligibility.

3.5 Project Crediting Period

The crediting period for a UFM Project is 25 years. Projects may be renewed for additional crediting periods with the prospect of incorporating updated technology into the project analysis. The initial baseline can be maintained for the life of the project. There is no limit to the number of times the crediting period may be renewed. Any previously issued credits must be monitored as described below.

3.6 Minimum Time Commitment

Projects must monitor, report, and undergo verification activities for 100 years following the last credit issued to the project.

3.7 Regulatory Compliance

Each time the UFM Project is verified, the Project Operator must attest that the project is in material compliance with all applicable laws relevant to the Project Activity. For this protocol, instances of non-compliance are likely to be considered "material" if they directly pertain to the management of project carbon stocks. Project Operators are required to disclose in writing to the verifier all instances of material non-compliance of the project with any law. If a verifier finds that a project is in a state of material non-compliance, then CRTs will not be issued for GHG reductions that occurred during the period of non-compliance. Non-compliance solely due to administrative or reporting issues, or due to "acts of nature," will not affect CRT crediting.

3.8 Social and Environmental Co-Benefits

All UFM Projects will provide climate benefits to the extent in which they generate credits. The ability to achieve additional environmental and social co-benefits depends on consideration of additional factors, some of which are described in this section. Only those projects where public and/or tribal entities participate in direct urban tree management activities (e.g., planting, tree distribution, etc.) are required to include the provisions for social and environmental co-benefits. However, these provisions may serve as suggestions to NGOs and other privately funded projects that may wish to enhance social and environmental co-benefits. Where required, the provisions must be described in the Project Design Document (PDD) and implemented throughout the Project Life. The Reserve has developed a PDD template that outlines elements that need to be addressed.[11]

3.8.1 Social Co-Benefits

Projects can create long-term climate benefits as well as providing other social and environmental benefits. Investment in projects has the potential to improve the quality of life for urban communities in a number of ways. Among other benefits, urban forest projects can improve air quality and reduce storm water runoff, provide shade, and increase property values by creating a more aesthetically pleasing environment. Projects also have the potential to create

[11] Available at http://www.climateactionreserve.org/how/protocols/urban-forest/.

negative social externalities, such as an uneven distribution of project benefits due to an uneven distribution of projects sites throughout a community (e.g., skewed toward more affluent communities). Therefore, social co-benefits should be taken into consideration during project design, in order to prevent these negative social externalities.

Table 3.1. Social Co-Benefits of Urban Forest Management Projects

Social Provisions	Elements to Include in the Project Design Document (PDD)
Equitable distribution of forest resources	Describe how the project will make progress toward achieving relatively equal distribution of tree canopy cover by neighborhood whenever possible.
Public participation	Establish guidelines to ensure adequate notification, opportunities for public participation, and documentation with regards to public activities with urban forest management.

3.8.2 Environmental Co-Benefits

The protocol has a goal of permanently removing greenhouse gases from the atmosphere by sustaining carbon benefits generated from urban forests for at least 100 years. Healthy urban forests can also provide environmental benefits as well as create negative externalities. Projects have the potential to improve air quality and reduce storm water runoff and energy usage. However, they can also contribute to reduced biodiversity, introduce invasive species, and damage infrastructure. Inefficient water usage during maintenance can also put pressure on local and regional water supplies. Projects should employ an evaluation of environmental co-benefits, as well as elements to prevent creating negative environmental externalities.

Table 3.2. Environmental Co-Benefits of Urban Forest Management Projects

Environmental Provisions	Elements to Include in the Project Design Document (PDD)
Biodiversity	Describe how UFM Project activities will maintain and enhance biodiversity, including: 1. Benefits of tree species selection and composition to biodiversity within the Project Area. 2. Use of specific tree species, sizes and/or distributions to support unique habitat elements.
Native species	Describe how UFM Project activities will promote the use of native species, including: 1. Strengths and limitations of using native trees in the project. 2. Preferential treatment of native species.
Non-native species	Describe how UFM Project activities will limit and target the use of any non-native species, including: 1. Strengths and limitations of using non-native trees in the project. 2. Resistance to insects and disease.
Climate change resilience	Describe how UFM Project activities will enhance the resilience of the urban forest to climate change, including: 1. Ability of urban forest to adapt to climate change. 2. Resistance to natural disturbances.

Environmental Provisions	Elements to Include in the Project Design Document (PDD)
Air quality	Describe how UFM Project activities will enhance air quality benefits, including: 1. Tree selection and distribution to reduce air pollutants. 2. Tree selection and distribution to reduce emissions of Biogenic Volatile Organic Compounds (BVOCs). 3. Design tree maintenance activities to reduce fossil fuel emissions.
Physical characteristics	Describe how UFM Project activities will enhance physical characteristics of the urban environment, including: 1. Tree shading. 2. Wind protection. 3. Minimize disturbance to city infrastructure (e.g., sidewalks, power lines, etc.).
Water management	Describe how UFM Project activities will improve water management, including: 1. Increase infiltration and recharge of groundwater. 2. Reduce stormwater runoff. 3. Conserve water from urban forest management.

4 GHG Assessment Boundaries

The quantification of all included sources, sinks, and reservoirs (SSR) (Table 4.1 below) are described in the Urban Forest Management Quantification Guidance on the Reserve's website.

Table 4.1. Description of all Sources, Sinks, and Reservoirs

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
UF-1	Standing live carbon (carbon in all portions of living trees)	Reservoir / Pool	CO_2	Included	Increases in standing live carbon stocks are likely to be a large Primary Effect of UFM Projects.
UF-2	Shrubs and herbaceous understory carbon	Reservoir / Pool	CO_2	Excluded	For crediting purposes shrubs and herbaceous understory are excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Furthermore, it is generally not practical to undertake measurements of shrubs and herbaceous understory accurate enough for crediting purposes.
UF-3	Standing dead carbon (carbon in all portions of dead, standing trees)	Reservoir / Pool	CO_2	Included	Standing dead wood is expected to be a small portion of UFM Projects, but may be substantial in rare cases.
UF-4	Lying dead wood carbon	Reservoir / Pool	CO_2	Excluded	For crediting purposes lying dead wood carbon is excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Changes associated with carbon projects are likely to increase lying dead wood. Furthermore, it is generally not practical to undertake measurements of lying dead wood accurate enough for crediting purposes.
UF-5	Litter and duff carbon (carbon in dead plant material)	Reservoir / Pool	CO_2	Excluded	Litter and duff carbon are excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Furthermore, it is generally not practical to undertake measurements of litter and duff accurate enough for crediting purposes.
UF-6	Soil carbon	Reservoir / Pool	CO_2	Excluded	Soil carbon is not anticipated to change significantly as a result of UFM Projects.

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
UF-7	Carbon in in-use forest products	Reservoir / Pool	CO_2	Excluded	Urban forests do not produce significant levels of wood products that persist for long enough periods of time to meet permanence requirements and projects will not substantially change wood product production.
UF-8	Forest product carbon in landfills	Reservoir / Pool	CO_2	Excluded	Urban forests do not produce significant levels of wood products and projects will not substantially change wood product production.
UF-9	Nutrient application	Source	N_2O	Excluded	The use of nitrogen-based fertilizers is not expected to be a significant source of emissions.
UF-10	Biological emissions from site preparation activities	Source	CO_2	Excluded	Biological emissions from site preparation are not quantified since projects that involve intensive site preparation activities are not eligible.
UF-11	Mobile combustion emissions from site preparation activities	Source	CO_2	Excluded	Mobile combustion CO_2 emissions from site preparation are not quantified since projects that involve intensive site preparation activities are not eligible.
			CH_4	Excluded	Changes in CH_4 emissions from mobile combustion associated with site preparation activities are not considered significant.
			N_2O	Excluded	Changes in N_2O emissions from mobile combustion associated with site preparation activities are not considered significant.
UF-12	Mobile combustion emissions from ongoing project operation and maintenance	Source	CO_2	Excluded	Mobile combustion CO_2 emissions from ongoing project operation and maintenance are unlikely to be significantly different from baseline levels and are therefore not included in the GHG Assessment Boundary.
			CH_4	Excluded	CH_4 emissions from mobile combustion associated with ongoing project operation and maintenance activities are not considered significant.
			N_2O	Excluded	N_2O emissions from mobile combustion associated with ongoing project operation and maintenance activities are not considered significant.

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
UF-13	Stationary combustion emissions from ongoing project operation and maintenance	Source	CO_2	Excluded	Stationary combustion CO_2 emissions from ongoing project operation and maintenance could include GHG emissions associated with electricity consumption or heating/cooling at Urban Forest Owner facilities or at facilities owned or controlled by contractors. These emissions are unlikely to be significantly different from baseline levels and are therefore not included in the GHG Assessment Boundary.
			CH_4	Excluded	CH_4 emissions from stationary combustion associated with ongoing project operation and maintenance activities are not considered significant.
			N_2O	Excluded	N_2O emissions from stationary combustion associated with ongoing project operation and maintenance activities are not considered significant.
UF-14	Biological emissions/ removals from changes in urban tree planting and management outside the Project Area	Source	CO_2	Excluded	Emissions due to leakage are unlikely to be significantly different from baseline levels and are considered to be de minimis. Therefore, this SSR is not included in the GHG Assessment Boundary.

5 Quantifying Net GHG Reductions and Removals

This section provides general requirements and guidance for quantifying a UFM Project's net GHG reductions and removals. Detailed methodological approaches to quantifying GHG reductions and removals are provided in the supplemental Quantification Guidance. The Reserve will issue Climate Reserve Tonnes (CRTs) to a project upon confirmation by an accredited and Reserve-approved verification body that the project's GHG reductions and removals have been quantified following the applicable requirements of this section (see Section 8 for verification requirements).

UFM Projects quantify carbon storage based on a relationship between canopy cover and carbon storage. The amount of carbon per acre of canopy cover is referred to as a ratio estimator. Projects may use default ratio estimators published by the Reserve, which have been organized by Assessment Area. Alternatively, projects may choose to sample their forest and generate project-specific ratio estimators. In either case, measuring or estimating project canopy cover is a crucial component of project quantification. This can be done via remote sensing, satellite imagery, and tools like iTree Canopy.[12] An overview of the steps for quantifying urban forest carbon is given below. For more information, refer to the Quantification Guidance document.

1. **Estimating baseline onsite carbon stocks**. The baseline is an estimate of what would have occurred in the absence of a UFM Project. To establish baseline onsite carbon stocks, the Project Operator must apply the appropriate methodology developed according to the guidelines established in the Quantification Guidance. Baseline estimates are developed for a 100-year period. Generally, baselines do not change during the life of the project, absent findings of errors in initial calculation or reconciliation associated with methodological updates.

2. **Determining actual onsite carbon stocks**. Each year, the Project Operator must determine the UFM Project's actual onsite carbon stocks. This must be done by updating the project's canopy estimate for the current year and applying the appropriate ratio estimator, following the guidance in this section and in the Urban Forest Management Quantification Guidance.

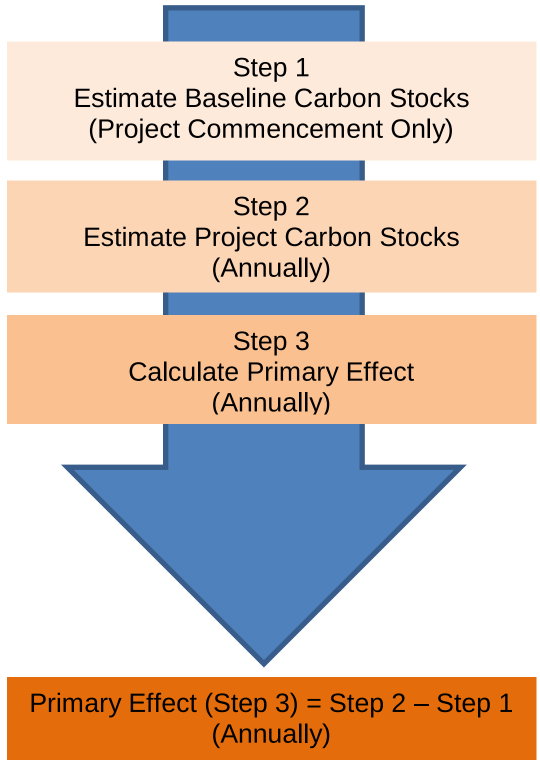
3. **Calculating the project's Primary Effect**. Each year, the Project Operator must quantify the actual change in GHG emissions or removals associated with the project's intended ("primary") effect. For any given year, the Primary Effect is calculated by:
    a. Estimating the change in canopy cover between the current year and prior year.
    b. Extrapolating the change in canopy cover to a change in carbon stocks, using the ratio estimators.
    c. Estimating the difference in baseline carbon stocks between the current year and the prior year.
    d. Subtracting (c) from (b) to establish the change in carbon sequestration between the baseline and project scenarios.

4. **Calculating total net GHG reductions and removals.** For each year, total net GHG reductions and removals are calculated by summing a UFM Project's Primary Effects. If

[12] https://canopy.itreetools.org/

the result is positive, then the project has generated GHG reductions and/or removals in the current year. If the result is negative, this may indicate a Reversal has occurred (see Section 6).[13]

The required formula for quantifying annual net GHG reductions and removals is presented in Equation 5.1. Net GHG reductions and removals must be quantified and reported in units of carbon dioxide-equivalent (CO_2e) metric tons.



Equation 5.1. Annual Net GHG Reductions and Removals

$$QR_y = (\Delta AC_{onsite} - \Delta BC_{onsite})$$

Where,

			Units
QR_y	=	Quantified GHG reductions and removals for year y	tCO_2e
ΔAC_{onsite}	=	$(AC_{onsite, y}) - (AC_{onsite, y-1})$	tCO_2e
		Where,	
		$AC_{onsite, y}$ = Actual carbon (CO_2e) as quantified for year y	tCO_2e
		$AC_{onsite, y-1}$ = Actual carbon (CO_2e) as inventoried for year y-1	tCO_2e
ΔBC_{onsite}	=	$(BC_{onsite, y}) - (BC_{onsite, y-1})$	tCO_2e
		Where,	
		$BC_{onsite, y}$ = Baseline onsite carbon (CO_2e) as estimated for year y	tCO_2e
		$BC_{onsite, y-1}$ = Baseline onsite carbon (CO_2e) as estimated for year y-1	tCO_2e

[13] A Reversal occurs only if: (1) total net GHG reductions and removals for the year are negative; and (2) CRTs have previously been issued to the project.

5.1 Urban Forest Management Baseline

To develop a project baseline for a UFM Project, a trend line is developed by calculating a historic estimate of carbon stocks and a recent estimate of carbon stocks. The trend line must pass through at least two historical inventory estimates that are at least 10 years apart and with the earliest point no earlier than 1990. For instance, if a project commences in 2018, the historical estimates may be done using aerial imagery from 2005 and 2015, since the two points pre-date the Project Start Date, are at least 10 years apart from one another, and do not pre-date 1990. Both estimates are developed by first estimating tree canopy area for each date from remotely sensed data and applying the ratio estimators. If historical imagery is not available, more recent images may be used, subject to Reserve approval. The resulting trend is extended 25 years into the future beginning from the Project Start Date, provided legal constraints have not changed substantially (other than changes associated with this protocol) during the 25-year period. The stocking amount is then held steady for the balance of the 100-year projection (75 years following the 25-year trend). A description of how legal constraints affect baseline considerations and technical issues associated with the baseline are described in the Quantification Guidance.

If there are unanticipated changes to legal constraints within the initial 25-year crediting period that will affect carbon stocks in the Project Area, projects are required to disclose the changes. Projects may be eligible to continue for the remaining 25-year crediting period but may not be eligible to renew the crediting period unless the project modifies its baseline to reflect the changes in legal constraints. A review of legal constraints will be performed during each verification, and determination of significance is ultimately subject to the discretion of the Reserve.

6 Ensuring the Permanence of Credited GHG Reductions and Removals

Changes in urban forest management have the potential to enhance the rate of CO_2 absorption, providing removals, and reducing or eliminating emissions associated with the loss of trees (reductions). Reductions may be possible with some UFM Projects. The Reserve requires that credited GHG reductions and removals be effectively "permanent." For UFM Projects, this requirement is met by ensuring that the carbon associated with credited GHG reductions and removals remains stored for at least 100 years.

The Reserve ensures the permanence of GHG reductions and removals through three mechanisms:

1. The requirement for all Project Operators to monitor onsite carbon stocks, submit regular monitoring reports, and submit to regular third-party verification of those reports along with periodic full verifications for the duration of the Project Life.
2. The requirement for all Project Operators to sign a Project Implementation Agreement with the Reserve which obligates Project Operators to retire CRTs to compensate for Reversals of GHG reductions and removals.
3. The maintenance of a Buffer Pool to provide insurance against Reversals of GHG reductions and removals due to unavoidable natural disturbances.

GHG reductions and removals can be "reversed" if the stored carbon associated with them is released (back) to the atmosphere. Many biological and non-biological agents, both natural and human-induced, can cause Reversals. Some of these agents cannot completely be controlled (and are therefore "unavoidable"), such as natural agents like fire, insects, pathogens, drought, and wind. Other agents can be controlled, such as human activities like land conversion. Under this protocol, Reversals due to controllable agents are considered "avoidable". If the quantified GHG reductions and removals in a given year are negative, and CRTs were issued to the UFM Project in any previous year, the Reserve will consider this to be a Reversal regardless of the cause of the decrease.

The Buffer Pool is a holding account for project CRTs, which is administered by the Reserve. All UFM Projects must contribute a percentage of CRTs to a Buffer Pool any time they are issued CRTs for verified GHG reductions and removals. A project that has an Unavoidable Reversal will use Buffer Pool CRTs proportionally from all projects that have contributed to the pool to compensate for the Reversal. Project Operators do not receive payment for their contributions to the Buffer Pool.

If a project experiences an Unavoidable Reversal of GHG reductions and removals (as defined in Section 6.2.2), the Reserve will retire a number of CRTs from the Buffer Pool equal to the total amount of carbon that was reversed (measured in metric tons of CO_2). The Buffer Pool therefore acts as a general insurance mechanism against Unavoidable Reversals for all projects registered with the Reserve.

6.1 Contributions to the Buffer Pool

Projects may be affected by financial risks, management risks, social risks, risks from pollution, and risks from natural disturbances (disease/insects, wildfire, flooding, drought etc.). To compensate for these risks, each project must contribute 6% of their issued CRTs to the Buffer

Pool. The Reserve may determine to re-distribute CRTs to Project Operators in the future, or modify the amount of contributions to the Buffer Pool, if actual Unavoidable Reversals deviate significantly from the current evaluation of risks.

6.2 Compensating for Reversals

The Reserve requires that all Reversals be compensated through the retirement of CRTs. If a Reversal associated with a UFM Project was unavoidable (as defined below), then the Reserve will compensate for the Reversal on the Project Operator's behalf by retiring CRTs from the Buffer Pool. If a Reversal was avoidable (as defined below) then the Project Operator must compensate for the Reversal by surrendering CRTs from its Reserve account, or surrender CRTs from another land use project registered with the Reserve in the event that the Project Operator does not have sufficient CRTs to cover the Reversal.

6.2.1 Avoidable Reversals

An Avoidable Reversal is any Reversal that is due to the Project Operator's negligence, gross negligence, or willful intent, including harvesting, development, and harm to the Project Area due to the Project Operator's negligence, gross-negligence or willful intent. Requirements for Avoidable Reversals are as follows:

1. If an Avoidable Reversal has been identified during annual monitoring, the Project Operator must give written notice to the Reserve within thirty days of identifying the Reversal. Additionally, if the Reserve determines that an Avoidable Reversal has occurred, it shall deliver written notice to the Project Operator.
2. Within thirty days of receiving the Avoidable Reversal notice from the Reserve, the Project Operator must provide a written description and explanation of the Reversal to the Reserve.
3. Within four months of receiving the Avoidable Reversal notice, the Project Operator must retire a quantity of CRTs from its Reserve account equal to the size of the Reversal in CO_2-equivalent metric tons (i.e., QR_y, as specified in Equation 5.1). In addition:
    a. The retired CRTs must be those that were issued to the project, or that were issued to other UFM Projects registered with the Reserve. If no other UFM CRTs are available, the Reserve will approve another appropriate source of credits, with a preference for land use projects.
    b. The retired CRTs must be designated in the Reserve's software system as compensating for the Avoidable Reversal.
4. Within one Reporting Period of receiving the Avoidable Reversal notice, the Project Operator must provide the Reserve with a verified estimate of current onsite carbon stocks and the estimated quantity of the Avoidable Reversal.

6.2.2 Unavoidable Reversals

An Unavoidable Reversal is any Reversal not due to the Project Operator's negligence, gross negligence or willful intent, including, but not limited to, the examples provided in Section 6 above. Requirements for Unavoidable Reversals are as follows:

1. If the Project Operator determines there has been an Unavoidable Reversal, it must notify the Reserve in writing of the Unavoidable Reversal within six months of its occurrence.
2. The Project Operator must explain the nature of the Unavoidable Reversal and provide a verified estimate of onsite carbon stocks within two Reporting Periods so that the Reversal can be quantified (in units of CO_2-equivalent metric tons).

If the Reserve determines that there has been an Unavoidable Reversal, it will retire a quantity of CRTs from the Buffer Pool equal to the size of the Reversal in CO_2-equivalent metric tons.

6.3 Disposition of Projects after a Reversal

If a Reversal lowers the UFM Project's carbon stocks below its approved baseline carbon stocks, the project will be terminated as the original baseline approved for the project would no longer be valid. If a project is terminated due to an Unavoidable Reversal, a new project may be initiated and submitted to the Reserve for registration on the same Project Area. New projects may not be initiated on the same Project Area if the project is terminated due to an Avoidable Reversal.

7 Project Monitoring, Reporting, and Verification

This section provides requirements and guidance on project monitoring, reporting rules, and procedures.

7.1 Project Documentation

Project Operators must provide the following documentation to the Reserve in order to register a UFM Project.

Table 7.1. Project Documentation Submittal Requirements

Document	When Submitted/Required
Project Submittal Form	Once, at project initiation when the Project Operator wishes to submit project concept to Reserve. Must be submitted within 6 months of the Project Start Date.
Project Design Document	Once, prior to initial verification.
Signed Attestation of Title Form	Prior to issuance of credits. Required at initial verification, full verification, and every optional desktop verification.
Signed Attestation of Regulatory Compliance Form	Prior to issuance of credits. Required at initial verification, full verification, and every optional desktop verification.
Signed Attestation of Voluntary Implementation Form	Once, prior to the issuance of credits as part of the initial verification.
Verification Report	Upon completion of verification and prior to issuance of credits. Required at initial verification, full verification, and every optional desktop verification.
Verification Statement	Upon completion of verification and prior to issuance of credits. Required at initial verification, full verification, and every optional desktop verification.
Project Implementation Agreement (PIA) and PIA Amendments	Upon completion of verification and prior to issuance of credits. Required at initial verification, full verification, and every optional desktop verification.

Project submittal forms can be found at http://www.climateactionreserve.org/how/program/documents/.

Projects using default ratio estimators need not enlist a Professional Forester, Certified Arborist, or Certified Forester for developing project reports. For projects that develop their own ratio estimators per the Quantification Guidance, all reports that reference carbon stocks must be submitted with the oversight of a Certified Arborist, a Certified Forester, or Professional Forester so that professional standards and project quality are maintained. Any Certified Arborist, a Certified Urban Forester, Professional Forester or Certified Forester preparing a project in an unfamiliar jurisdiction must consult with a Certified Arborist, a Certified Urban Forester, Professional Forester or Certified Forester practicing forestry in that jurisdiction to understand all laws and regulations that govern urban forest practices within the jurisdiction. This requirement does not preclude the project’s use of technicians or other unlicensed/uncertified persons working under the supervision of the Professional Forester, Certified Arborist, or Certified Forester.

All projects shall submit a shapefile as a KML that matches the maps submitted to depict the Project Area. The project's reported acres shall be based on the shapefile submitted to the Reserve.

7.1.1 Urban Forest Project Design Document

The Project Design Document (PDD) is a required document for reporting information about a project. The document is submitted at the initial verification. PDDs are intended to serve as the main project document that thoroughly describes how the project meets eligibility requirements, discusses summaries associated with developing data according to quantification requirements, outlines how the project complies with terms for additionality and describes how project Reversal risks are calculated. All methodologies used by Project Operators and descriptions in the PDD must be clear in a way that facilitates review by verifiers, Reserve staff, and the public. PDDs must be of professional quality and free of incorrect citations, missing pages, incorrect project references, etc. A PDD template has been prepared by the Reserve and is available on the Reserve's website.[14] The template is arranged to assist in ensuring that all requirements of the UFMPP are addressed. Use of the Reserve's template is optional, but strongly recommended for ease of verification.

7.2 Monitoring Report

Monitoring is the process of regularly collecting and reporting data related to a project's performance. Annual monitoring of UFM Projects is required to ensure up-to-date estimates of project carbon stocks and provide assurance that GHG reductions or removals achieved by a project have not been reversed. Project Operators must conduct monitoring activities and submit monitoring reports according to the schedule and requirements presented in Section 7.2. Monitoring is required for a period of 100 years following the final issuance of CRTs to a project for quantified GHG reductions or removals.

Monitoring activities consist primarily of updating a project's canopy cover estimates, forest carbon stock estimates, calculating emission reductions for the Reporting Period, and submitting the information in annual monitoring reports to the Reserve at frequencies defined in Section 7.3. CRTs are only issued in years that the project data are verified, as described in Section 7.4.

A monitoring report must be prepared for each Reporting Period. Monitoring reports must be provided to verification bodies whenever a project undergoes verification. The monitoring report must be completed and submitted to the Reserve within 12 months of the end of the Reporting Period. When required verifications must be conducted as explained below, both the verification report and the monitoring report must be completed and submitted to the Reserve within 12 months of the end of the Reporting Period. Monitoring reports must include an update of the project's calculations. The project's calculations must include the following:

1. An updated Project Inventory reflecting estimate of the current year's carbon stocks quantified for the project's Primary Effect. Acceptable methodologies for updating the project's inventory are provided in the Quantification Guidance. The update is determined by:
    a. Including any new forest field inventory data obtained during the Reporting Period (if applicable).
    b. Applying ratio estimators to updated canopy cover estimates.

[14] http://www.climateactionreserve.org/how/protocols/urban-forest/.

   c. Updating estimates for removals and/or disturbances that have occurred during the Reporting Period.
2. The baseline carbon stock estimates for the current Reporting Period, as determined following the requirements in Section 5 and approved at the time of the project's registration.
3. A preliminary calculation of total net GHG reductions and removals (or Reversals) for the Reporting Period, following the requirements in Section 5.
4. A preliminary calculation of the project's Buffer Pool contribution.
5. If a Reversal has occurred during the previous Reporting Period, the report must provide a written description and explanation of the Reversal, whether the Reserve classified the Reversal as Avoidable or Unavoidable, and the status of compensation for the Reversal.

7.3 Reporting and Verification Cycles

This section describes the required reporting and verification cycles. A UFM Project is considered automatically terminated as the result of an Avoidable Reversal (see Section 6.3) if the Project Operator chooses not to report data and undergo verification at required intervals.

7.3.1 Reporting Period Duration and Cycles

Projects must report their initial carbon stock data associated with the Project Start Date. Project Operators must report their project stocks annually with the exception of the Reporting Period immediately following the Project Start Date, which can be any length of time up to one year following the Project Start Date. This enables Project Operators to establish an annual reporting cycle that is convenient for the entity.

Reporting Periods must be contiguous, i.e., there must be no gaps in reporting during the crediting period of a project once the first Reporting Period has commenced.

7.3.2 Verification Cycles

A project must be initially verified within 12 months of the end of its initial Reporting Period which begins based on the Project Start Date. The initial verification must confirm the project's eligibility and confirm that the project's initial carbon stocks and baseline have been established in conformance with the UFMPP. Subsequent verifications may include multiple Reporting Periods, (in which case, the time period covered by the multiple Reporting Periods is referred to as the "Verification Period"). The end date of any Verification Period must correspond to the end date of a Reporting Period.

Verification has both required frequencies and optional frequencies. Required verification is established on a temporal framework to ensure that ongoing monitoring of urban forest carbon stocks are accurate and up-to-date. Optional verification is at the Project Operator's discretion and may be conducted in the years in which verification is not required and the Project Operator wishes to receive credits. Required verifications are referred to as full verifications. Optional verifications are referred to as desk review verifications. Details of verification scheduling requirements are provided within this section.

Verification must be completed within 12 months of the end of the Reporting Period(s) being verified. For required verifications, failure to complete verification within the 12-month time period will result in account activities being suspended until the verification is complete. The project will terminate if the required verification is not completed within 36 months of the end of the Reporting Period(s) being verified. There is no consequence for failure to complete verification activities within 12 months for optional verifications.

7.3.3 Full Verification Requirements

A full verification is a verification in which Project Inventory data are verified through a process that audits data in the office. Site visits are not required if the Reserve's default ratio estimators are used for inventory calculations, but the other components of a full verification must still take place. Projects developing their own ratio estimators must include a site visit as part of the full verification. The Reserve requires that an approved third-party verification body verify all reported data and information for a project and conduct a site visit for projects developing their own ratio estimators. Verification Periods shall comprise no more than five Reporting Periods, excepting the first Reporting Period, which must undergo a full verification.

7.3.4 Optional Desk Review Verification

In between required full verifications, the Project Operator may choose to have an approved third-party verification body conduct a desk review of annual monitoring reports as an optional verification. CRTs may be issued for GHG reductions/removals verified through such desk reviews. The desk review verifications are based on the reported data being within acceptable parameters. If the project has implemented significant changes to the quantification methodology since the last verification, the verification team must perform a full verification. Significant changes to the quantification methodology include, but are not limited to, changes to the ratio estimator value, changes to the Project Area, or a change to the technology used to assess canopy cover. The Reserve will determine whether a change to the quantification methodology rises to this level.

Submission of annual monitoring reports to the Reserve is required even if the Project Operator chooses to forego desk review verification.

7.4 Issuance and Vintage of CRTs

The Reserve will issue Climate Reserve Tonnes (CRTs) for quantified GHG reductions and removals that have been verified through either full verifications or desk reviews. Full verification may determine that earlier desk reviews overestimated full carbon stocks. Any resulting downward adjustment to carbon stock estimates will be treated as a Reversal (see Section 6). In this case, the Project Operator must retire CRTs in accordance with the requirements for compensating for a Reversal (Section 6.2). Vintages are assigned to CRTs based on the proportion of days in a calendar year within a Reporting Period.

7.5 Record Keeping

For purposes of independent verification and historical documentation, Project Operators are required to keep all documents and forms related to the project for a minimum of 100 years after the final issuance of CRTs from the Reserve. This information may be requested by the verification body or the Reserve at any time.

7.6 Transparency

The Reserve requires data transparency for all projects, including data that displays current carbon stocks, Reversals, and verified GHG reductions and removals. For this reason, all non-confidential project data reported to the Reserve will be publicly available on the Reserve's website.

8 Verification Guidance

This section provides guidance to Reserve-approved verification bodies for verifying GHG emission reductions associated with urban forest projects.

This section supplements the Reserve's Verification Program Manual,[15] which provides verification bodies with the general requirements for a standardized approach for independent and rigorous verification of GHG emission reductions and removals. The Verification Program Manual outlines the verification process, requirements for conducting verification, conflict of interest and confidentiality provisions, core verification activities, content of the verification report, and dispute resolution processes. In addition, the Verification Program Manual explains the basic verification principles of ISO 14064-3:2006 which must be adhered to by the verification body.

Verification bodies must read and be familiar with the following International Organization for Standardization (ISO) and Reserve documents and reporting tools:

- Urban Forest Management Project Protocol
- Urban Forest Management Quantification Guidance
- Reserve Program Manual
- Reserve Verification Program Manual
- Reserve software
- ISO 14064-3:2006 Principles and Requirements for Verifying GHG Inventories and Projects

Only Reserve-approved urban forest project verification bodies are eligible to verify UFM Project reports. To become a recognized urban forest project verifier, verification bodies must become accredited under ISO 14065. Information on the accreditation process can be found on the Reserve website at http://www.climateactionreserve.org/how/verification/how-to-become-a-verifier/.

8.1 Standard of Verification

The Reserve's standard of verification for UFM Projects is the Urban Forest Management Project Protocol (this document), Quantification Guidance, the Reserve Program Manual, and the Reserve Verification Program Manual. To verify a Project Operator's initial Project Design Document and annual monitoring reports, verification bodies apply the verification guidance in the Reserve's Verification Program Manual and this section of the UFMPP to the requirements and guidance described in Sections 2 through 7 of the UFMPP.

This section of the protocol provides requirements and guidance for the verification of UFM Projects. This section describes the core verification activities and criteria that must be undertaken and addressed by a verification body in order to provide a reasonable level of assurance that the GHG removals or reductions quantified and reported by Project Operators are materially correct.

Verification bodies will use the criteria in this section to determine if there exists a reasonable assurance that the data submitted on behalf of the Project Operator to the Reserve addresses

[15] Found on the Reserve website at http://www.climateactionreserve.org/how/program/program-manual/.

each requirement in the UFMPP, Sections 2 through 7. Project reporting is deemed accurate and correct if the Project Operator is in compliance with Sections 2 through 7.

Further information about the Reserve's principles of verification, levels of assurance, and materiality thresholds can be found in the Reserve's Verification Program Manual at http://www.climateactionreserve.org/how/program/program-manual/.

8.2 Project Verification Activities

Required verification activities for UFM Projects vary depending on whether the verification body is conducting an initial verification for registration on the Reserve, full verification, or an optional annual verification involving a desk review. The following sections contain guidance for all of these verification activities.

8.2.1 Initial Verification

Verifiers must ensure that the project has met the UFMPP criteria and requirements for eligibility, Project Area definition, additionality, quantification, and calculation of baseline. The verification body must assess and ensure the completeness and accuracy of all required reporting elements submitted in the Project Design Document.

8.2.2 Full Verification

Full verification involves review of the project's eligibility, quantification, relevant attestations, soil carbon emissions associated with management activities, adherence to environmental and social safeguards (if applicable), and buffer pool contribution. Site visits are not required for full verifications of projects that are using default ratio estimator values, as described in the Quantification Guidance.

8.2.3 Optional Desk Review Verification

Full verification is required every five Reporting Periods, at a minimum. Optional desk verifications can occur for interim Reporting Periods according to preferences of the Project Operator. Credits can be verified and registered as the result of an optional desk verification. The main focus of optional desk verifications is to assure that annual monitoring reports are complete, and that project quantification was performed correctly, as described in the Quantification Guidance. If the project has implemented significant changes to the quantification methodology since the last verification, the verification team must perform a full verification. See Section 7.3.4.

Table 8.1 displays the protocol sections that are verified at the initial verification, the full verification, and/or the optional annual verification.

Table 8.1. Verification Items and Related Schedules

Verification Items	Section of UFMPP	Initial	Full	Optional	Apply Professional Judgment[16]?
1. Project Definition	2.1 Urban Forest Management	X			No
2. Urban Forest Owner	2.2 Urban Forest Owners	X	X		No
3. Project Operator	2.3 Project Operators	X	X		No
4. Project Implementation Agreement	2.4 Project Implementation Agreement	X	X	X	No
5. Project Location	3.1 Project Location	X			No
6. Project Area	3.1.1 Project Area	X			No
7. Limits to Site Preparation	3.2 Limits to Site Preparation	X	X		Yes
8. Project Commencement	3.3 Project Commencement	X			Yes
9. Additionality	3.4.1 Legal Requirement Test 3.4.2 Performance Test	X	X		Yes
	3.4.3 Enhancement Payments	X			
10.Project Crediting Period	3.5 Project Crediting Period	X	X		No
11.Minimum Time Commitment	3.6 Minimum Time Commitment	X	X		No
12. Social and Environmental Co-Benefits	3.7 Social and Environmental Co-Benefits	X	X		Yes, for public or tribal entities only
13. Social Co-Benefits	3.8.1 Social Co-Benefits	X	X		Yes, for public or tribal entities only
14. Environmental Co-Benefits	3.8.2 Environmental Co-Benefits	X	X		Yes, for public or tribal entities only
15. GHG Assessment Boundaries	4 GHG Assessment Boundaries	X	X		No
The verification topics below are linked to quantification requirements. The verification of project inventories is described in detail below this table. Verifiers shall assure that requirements associated with the references in this table have been satisfied and implement the specific guidance requirements for verifying inventories below.					
16. Quantifying Net GHG Reductions and Removals	5 Quantifying Net GHG Reductions and Removals Urban Forest Management Quantification Guidance	X	X	X	No
17. Urban Forest Protocol Baselines	5.1 Urban Forest Management Baseline Urban Forest Management Quantification Guidance	X			No
18. Permanence and Buffer Pool Contributions	6.1 Contributions to the Buffer Pool	X	X	X	No
19. Permanence and Compensating for Reversals	6.2 Compensating for Reversals 6.2.1 Avoidable Reversals 6.2.2 Unavoidable Reversals	X	X	X	No

Table 8.1 comprises the full list of verification items required to be part of verification activities. To assist with performing verifications, the Reserve provides Verification Elements tables below (Tables 8.2, 8.3, 8.4) that include additional details on verification standards and periodicity.

[16] Verifiers must use professional judgment to verify protocol criteria which are not quantitative or can be measured completely with objective analysis.

Table 8.2. Verification Guidance

Verification Element	Description	Verification Frequency
I	All items in Table 8.1 have been reviewed and deemed satisfactory by the verifier, both in terms of clear presentation and aligned with the protocol requirements.	Initial full verification only. For projects using project-specific ratio estimators, full site verification is required during the initial verification.
II	Review project Assessment Area(s) or stratum. Verifier shall inspect the project map and determine if the entire Project Area is assigned using the correct Assessment Area(s), or are employing the appropriate methodology per the Quantification Guidance for stratification (if stratifying) for projects developing project-specific ratio estimators. Determination of the appropriateness of the Assessment Area used or stratification will occur during review of evidence provided by the Project Operator (such as aerial imagery) or through a site visit, if applicable.	Initial full verification. For projects using project-specific ratio estimators, full site verification is required during the initial verification, and each time the project opts to update its field-based inventory and ratio estimator(s).
III	Confirm Project Area boundaries are within eligible Project Areas, including evaluation of the accuracy and conservativeness of the project acreage. Determination will occur during review of evidence provided by the Project Operator (such as aerial imagery) or through a site visit, if applicable. A comparison between the acreage of the Project Area identified by AP and GIS sources has been made and the lesser of the two has been used for the final Project Area. However, if the Project Operator opts to use GIS acres, an evaluation of the accuracy of GIS acres must be performed based on a review of supporting documentation (e.g., boundary survey) and ground-truthing activities and will require a site visit.	Initial full verification. For projects using project-specific ratio estimators, full site verification is required during the initial verification, and each time the project opts to update its field-based inventory and ratio estimator(s).
IV	Confirm all aspects of the Quantification Guidance have been implemented correctly.	Each verification.
V	Confirm that the calculation or identification of ratio estimators, expansion to Assessment Area(s) or stratum (for projects developing their own ratio estimators), and expansion to overall Project Area, for historical estimates and current estimates, were implemented correctly.	Each verification.
VI	Confirm that confidence statistics for canopy cover were correctly calculated and meet minimum requirements per the Quantification Guidance.	Each verification.

8.3 Verifying Urban Forest Management Carbon Estimates

The method of verification of carbon estimates varies depending on whether the verification is part of the initial verification, full verification, or an optional desk review verification. The verification elements and their periodicity are explained in this section.

Table 8.3. Verification Guidance for Quantification

Verification Element	Description	Verification Frequency
I (Legal Constraints in the Baseline)	Assess applicable legal constraints that may affect carbon stocks in the Project Area. Confirm that such legal constraints are appropriately modeled into the baseline, per the Quantification Guidance.	Initial full verification.
II (Legal Constraints Review)	Confirm whether there are new, unanticipated legal constraints that may affect carbon stocks in the Project Area.	Each verification.
III (Historical Tree Canopy Area)	Confirming that the methodology for quantifying the historical tree canopy area specified in the Quantification Guidance was implemented correctly as stated in the quantification guidance, as part of the initial full verification. The verifier must independently calculate the canopy area for each applicable Assessment Area (or stratum) using a randomized selection of points used by the Project Operator. The points must be overlaid on the remote sensing image the Project Operator used to generate their estimate/measurement of canopy area. The verifier shall determine if each point 'hits' or 'misses' a tree crown. The verifier shall sample enough points (or plots for projects developing their own ratio estimators) to arrive at a determination of canopy area with +/- 5% at 1 Standard Error for each Assessment Area. The percentage canopy area determined by the verifier must be within 10% of the estimate provided by the Project Operator. The verifier may repeat their effort if the Project Operator is not in conformance with the verifier. Failure to find conformance after three efforts results in failure of the ability to verify the reported canopy area. The Project Operator must resample/re-measure the canopy area and prior to renewing verification activities. The i-Tree Canopy tool may be used to perform the analysis. The Reserve recommends the verifier replicate the approach used by the Project Operator, but verifiers should use professional judgement to determine whether the approach is sound.	Initial full verification.
IV (Current Tree Canopy Area)	Confirming that the methodology for quantifying current tree canopy area specified in the Quantification Guidance was implemented correctly as stated in the quantification guidance. The verifier must independently calculate the canopy area for each Assessment Area if the project spans multiple Assessment Areas, or the Project Area using a randomized or systematic	Each verification.

Verification Element	Description	Verification Frequency
	application of points used by the Project Operator. The points must be overlaid on the remote sensing image the Project Operator used to generate their estimate/measurement of canopy area. The verifier shall determine if each point ‘hits’ or ‘misses’ a tree crown. The verifier shall sample enough plots to arrive at a determination of canopy area with +/-10% at 90% confidence interval. The percentage canopy area determined by the verifier must be within 10% of the estimate provided by the Project Operator. The verifier may repeat their effort if the Project Operator is not in conformance with the verifier. Failure to find conformance after three efforts results in failure of the ability to verify the reported canopy area. The Project Operator must resample/re-measure the canopy area and prior to renewing verification activities. The i-Tree Canopy tool may be used to perform the analysis.	
V (Carbon Estimates for Ratio Estimators)	Confirming that the methodology and requirements for quantifying carbon estimates specified in the Quantification Guidance were implemented correctly.	Each verification.
VI (Ratio Estimators and Summary Calculations)	Confirming that ratio estimators are correctly calculated (or selected, if default ratio estimators are used) and expansions to the Project Area are performed correctly.	Initial full verification.
VII (Updated Project Data)	Confirming that updated emission reduction estimates are accurate, and the project is continuing to use the same ratio estimator as previous verifications.	Each verification following the initial full verification.

8.3.1 Field-Based Inventory Verification Activities

This section applies only to projects that choose to calculate and use their own ratio estimators. For these projects, verification bodies are required to conduct a site visit and verify carbon stock inventory calculations of all sampled and/or measured carbon pools within the Project Area. Inventories of carbon stocks may be used to determine the project baseline and to quantify GHG reductions and removals against the project baseline over time. In these cases, the verification activities must include re-measurement of a randomly selected subset of project data used to calculate the inventory estimate for the project. The data sampled by verifiers are the tree canopy measurements and the ground-based plot measurements. The verification approach for all metrics derived from measured and/or sampled data is based on a randomly selected comparison of verifier data to Project Operator data in a process referred to as sequential sampling.

Verification using the sequential sampling methodology requires the verification body to sequentially sample successive plots. Sequential approaches have stopping rules rather than fixed sample sizes. Verification is successful after a minimum number of successive plots in a sequence indicate agreement according to the tolerance thresholds established in the sequential sampling workbook provided by the Reserve. The evaluation of the three themes that utilize sequential sampling (CO_2e estimates from plots, current tree canopy area, and historical tree canopy area) shall utilize separate worksheets and include a copy of the results within the verification report.

Where sequential data calculated from the verifier result in a trend of agreement with the Project Operator, verification can proceed toward a finding of accuracy. The minimum number of plots measured by the verifier and the tolerance bounds are established by the Reserve and described in the Quantification Guidance. Where a high level of agreement is found between the Project Operator and the verifier, a finding of acceptable accuracy may be established with the minimal number of plots required by the Reserve. As divergence between verifier estimates and Project Operators increases, the number of plots measured by the verifier must increase in order to work toward establishing a finding of acceptable accuracy. In cases where continued verifier effort does not result in convergence, the Project Operator must decide whether continued investment in verification effort is justified. Alternatively, verification can be suspended while the Project Operator improves the quality of the inventory and revises related project documentation. Verification of measured and/or sampled data must be reinitiated following any modifications to measured and/or sampled data during verification activities.

The sequential sampling workbook provided by the Reserve includes the established stopping rules. Where agreement between the verifier estimates and the Project Operator estimates is within specified tolerance bounds, verification of plot data is successful. Sequential sampling is described in greater detail in the next section.

For the verification of canopy area used to generate ratio estimators, CO_2e estimates from ground-based plots and stratification of urban forest classes, the verifier must randomly select an initial set of 40 ground-based sample plots from the full set of plots measured by the Project Operator, maintaining the order of their selection in sequential order (1 – 40). The verifier must develop an initial strategy to efficiently visit (both in the office and in the field) the first 20 plots (1 – 20) in the list. The plots do not need to be visited and measured sequentially, but they all need to be visited prior to entering the data in the sequential sampling works. The entries of plot summaries into the sequential sampling workbook provided by the Reserve must be in the same order the plots were randomly selected.

The verifier shall visit the same plots in the field to continue verification for the following elements in Table 8.4.

Table 8.4. Verification Guidance for Field Inventories

Verification Element	Description	Verification Frequency
I	If a project has chosen to implement stratification within the Project Area, the verification of accurate stratification must occur simultaneously with the verification of ground-based plots (described below) for carbon estimates. The verifier must determine if the stratum identified for each plot is appropriate or not based on characteristics present during the field visit using professional judgment with the consideration for minimum mapping units described in the Quantification Guidance. The project must achieve a 90% approval rating from the set of the 20 selected plots. **Consequences of failing to meet the accuracy requirements for stratification:** In the event that adequate accuracy cannot be confirmed from the first 20 plots, the verifier must visit and evaluate the second set of 20 randomly selected plots as above. The 90% approval rating must be achieved by the full set of 40 visited plots. If the project does not succeed following evaluation of 40 plots, the Project Operator must refine their stratification and update the plot association with urban forest classes before continuing with verification activities.	Initial full verification. For projects using project-specific ratio estimators, full site verification is required each time the project opts to update its field-based inventory and ratio estimator(s).
II	Ensuring that the CO_2e estimates from individual plots are accurate. The verifier must independently calculate per-acre estimates of CO_2e for each of the 20 plots randomly selected by the verifier, utilizing the sampling methodology described in the Quantification Guidance. The verifier shall measure the trees on each plot, calculating the CO_2e values represented by the trees using the appropriate biomass equations (provided on the Reserve's website), conversion and expansion factors (provided in the Quantification Guidance). The results from the verifier's calculations shall be compared with the Project Operator's estimates for the same 20 plots using the sequential sampling worksheet provided by the Reserve. Measurement standards for verifiers include: a. Measuring every diameter (DBH) to the nearest inch. b. Measuring every height (total height) to the nearest foot. Measuring every tree that is 'borderline' to determine if the tree is either in the plot or out of the plot.	Initial full verification. For projects using project-specific ratio estimators, full site verification is required each time the project opts to update its field-based inventory and ratio estimator(s).

Where the Project Operator and verifier are not in agreement after the verifier data from the 20 initial verification plots has been inputted into the sequential sampling worksheets for each of the themes, additional sets of 20 plots (in 20 plot lots as described for the initial set) may be randomly selected to add to the total set of verification plots. The decision to add additional plots to the total set of verification plots is primarily the Project Operators, based on an assumption that random chance caused the initial test to fail and convergence towards agreement would occur with additional verification effort.

The results of any additional verification plot may also be inconclusive and require additional verification plots for a determination to be made. For effective application of the sequential sampling statistics in the field, the determination of when the stopping rule is met is done at the end of the measurement of a batch of plots (20 plots) in the field.

Worksheets are provided on the Reserve's website[17] for use by verifiers to assist in verifying sampled data. The Reserve has established a ten percent allowance as an acceptable level of agreement between the verifier and the Project Operator.

8.4 Completing the Verification Process

After completing the core verification activities for a project, the verification body must do the following to complete the verification process:

1. Complete a detailed List of Findings containing both immaterial and material findings (if any) and deliver it to the Project Operator (private document).
2. Exchange correspondence as necessary to resolve issues detailed in the List of Findings, until all material misstatements and nonconformances have been addressed.
3. If a reasonable level of assurance opinion is successfully obtained, complete a Verification Report to be delivered to the Project Operator (public document).
4. Complete the Verification Statement form, detailing the vintage and the number of GHG reductions and removals verified and deliver it to the Project Operator (public document).
5. Verify that the number of GHG reductions and removals, as well as the reversal risk rating, specified in the Verification Report and Statement match the number entered into the Reserve software.
6. Conduct an exit meeting with the Project Operator to discuss the Verification Report, List of Findings, and Verification Statement.
7. Upload electronic copies of the Verification Report, List of Findings, Verification Statement, and Verification Activity Log into the Reserve.

The recommended content for the verification report, list of findings, and verification statement can be found in the Reserve's Verification Program Manual.[18] The Verification Program Manual also provides further guidance on quality assurance, negative verification statements, use of an optional project verification activity log, goals for exit meetings, dispute resolution, and record keeping.

[17] Available at http://www.climateactionreserve.org/how/protocols/urban-forest/.
[18] Available at http://www.climateactionreserve.org/how/program/program-manual/.

9 Glossary of Terms

Additionality	GHG emission reductions should occur as a result of specific GHG mitigation incentives; additionality is achieved when GHG reductions are beyond what would occur under business as usual operation and result from activities that are not mandated by regulation.
Assessment Area	Geographically discrete regions used to identify appropriate default ratio estimators for projects. Such regions are defined by the Reserve based on sampled cities and terrestrial ecoregions. Maps of the Assessment Areas and the associated data may be found on the Reserve's website.
Avoidable Reversal	An avoidable reversal is any reversal that is due to the project operator's negligence, gross negligence, or willful intent, including harvesting, development, and harm to the project area.
Baseline	An estimate of GHG emissions and removals that would have occurred in absence of the project under business as usual operations.
Best Management Practices	Management practices determined by a state or designated planning agency to be the most effective and practicable means (including technological, economic, and institutional considerations) of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals.[19]
Biological Emissions	For the purposes of the Urban Forest Management Project Protocol, biological emissions are GHG emissions that are released directly from forest biomass, both live and dead, including forest soils. Biological emissions are deemed to occur when the reported tonnage of onsite carbon stocks, relative to baseline levels, declines from one year to the next.
Biomass	The amount of living matter comprising, in this case, a tree.
Bole	The trunk or main stem of a tree.
Buffer Pool	The buffer pool is a holding account for urban forest project CRTs administered by the Reserve. It is used as a general insurance mechanism against unavoidable reversals for all UFM projects registered with the Reserve.
Business As Usual	The activities, and associated GHG reductions and removals that would have occurred in the project area in

[19] Helms, J.A. (1998). The dictionary of forestry. Bethesda, MD: Society of American Foresters.

	the absence of incentives provided by a carbon offset market.
Carbon Pool	A reservoir that has the ability to accumulate and store carbon or release carbon. In the case of forests, a carbon pool is the forest biomass, which can be subdivided into smaller pools. These pools may include above-ground or belowground biomass or roots, litter, soil, bole, branches and leaves, among others.
Carbon Sink	A carbon sink is any process, activity or mechanism that removes carbon dioxide from the atmosphere.
Carbon Source	A carbon source is any process or activity that releases carbon dioxide into the atmosphere.
Carbon Stock	A pool of stored carbon. Urban forest carbon stocks include biomass of the project trees. Include living and standing dead vegetation, woody debris and litter, organic matter in the soil, and harvested stocks such as wood for wood products and fuel.
Carbon Stock Change or Carbon Sequestration	The annual incremental change in carbon stocks.
CO_2-equivalent (CO_2e)	The quantity of a given GHG multiplied by its total global warming potential. This is the standard unit for comparing the degree of warming which can be caused by different GHGs.
Certified Arborist	Certified Arborist is the rank of a Registered Consulting Arborist (or above), as certified by the International Society of Arboriculture.
Certified Forester	A professional with certified forester credentials managed by the Society of American Foresters (see www.certifiedforester.org). See also, Professional Forester.
Certified Urban Forester	An urban forester meeting the criteria and having passed the test created by the California Urban Forests Council, and now administered nationally by the Society of American Foresters.
Climate Reserve Tonnes (CRT)	One metric ton (tonne) of verified CO_2 equivalent emission reduction or sequestration.
Entity	The individual, organization, agency or corporation that owns, controls, or manages urban trees.
Global Warming Potential (GWP)	Factors used to convert emissions from GHGs other than carbon dioxide to their equivalent carbon dioxide emissions.

Greenhouse Gas (GHG)	Greenhouse gases mean carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).
GHG Assessment Boundary	The GHG Assessment Boundary defines all the GHG sources, sinks, and reservoirs that must be accounted for in quantifying a project's GHG reductions and removals.
KML	KML (Keyhole Markup Language) is an XML-based file format used to display geographic data in an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile.
Leakage	According to the Intergovernmental Panel on Climate Change: "the unanticipated decrease or increase in greenhouse gas benefits outside of the project's accounting boundary as a result of project activities."
Municipality	A city or town that has corporate status and local government
Permanence	The requirement that GHGs must be permanently reduced or removed from the atmosphere to be credited as carbon offsets. For UFM projects, this requirement is met by ensuring that the carbon associated with credited GHG reductions and removals remains stored for at least 100 years.
Places	Places are defined by the U.S. Census Bureau and are composed of Incorporated Places and Census-Designated Places. Generally, an Incorporated Place is an area that is legally incorporated under the laws of its respective state, whereas a Census-Designated Place is a community that lacks a separate government but otherwise resemble incorporated places, with a residential core, relatively high population density, and a degree of local identity. The most recent definition provided by the U.S. Census Bureau can be found at https://www.census.gov/geo/reference/gtc/gtc_place.html
Primary Effect	The project's intended change in carbon stocks, GHG emissions or removals.
Professional Forester	A professional engaged in the science and profession of forestry. A professional forester is credentialed in jurisdictions that have professional forester licensing laws and regulations. Where a jurisdiction does not have a professional forester law or regulation then a professional forester is defined as having the certified forester credentials managed by the Society of American Foresters (see www.certifiedforester.org).
Project Activity	The carbon storage, emission reductions, and emissions due to an urban forest management project.

Project Area	The area inscribed by the geographic boundaries of a project.
Project Start Date	The start date is initiated by activities that increase carbon inventories and/or decrease emissions relative to the baseline.
Project Life	Refers to the duration of a project and its associated monitoring and verification activities.
Project Inventory	The inventory of trees eligible to generate emission reductions or removals in a project. Developed according to the guidelines in the Quantification Guidance.
Project Operator	One of the urban forest owners or a legally created entity to represent the urban forest owners that is responsible for undertaking a project.
Project Submission Date	The date that a project is submitted for listing in the Reserve program. The Reserve considers a project to be "submitted" when all of the appropriate forms have been uploaded to the Reserve's software system, and the project operator has paid a project submission fee.
Registered Consulting Arborist	An arborist meeting the criteria and having passed all the qualification requirements of the American Society of Consulting Arborists (http://www.asca-consultants.org/about/rca.cfm).
Reporting Period	The time period for which an entity is reporting its project activity and quantifying GHG reductions. This period will typically be 12 months, except for 1) the initial reporting period which begins at the project commencement date and may be more than 12 months, and 2) the second reporting period, which may be less than 12 months.
Reversal	A reversal is a decrease in the stored carbon stocks associated with quantified GHG reductions and removals that occurs before the end of the project life. Under this protocol, a reversal is deemed to have occurred if there is a decrease in the difference between project and baseline onsite carbon stocks from one year to the next, regardless of the cause of this decrease (i.e., if the result of (Δ AC_{onsite} - Δ BC_{onsite}) in Equation 5.1 is negative).
Sampled Cities	Places and urban areas, as defined by the U.S. Census Bureau, that have been discretely sampled for the development of ratio estimators and serve as the basis, along with terrestrial ecoregions, for the definition of Assessment Areas.
Secondary Effects	Unintended changes in carbon stocks, GHG emissions, or GHG removals caused by the project.
Sequestration	The process by which trees remove carbon dioxide from the atmosphere and transform it into biomass.

Terrestrial Ecoregions	Areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources, as delineated by the Commissions for Environmental Cooperation, which serve as the basis, along with sampled cities, for the definition of Assessment Areas.
Tree	A woody perennial plant, typically large and with a well-defined stem or stems carrying a more or less definite crown with the capacity to attain a minimum diameter at breast height of five inches and a minimum height of 15 feet with no branches within three feet from the ground at maturity.[20]
Unavoidable Reversal	An unavoidable reversal is any reversal not due to the project operator's negligence, gross negligence or willful intent, including windstorms or disease that are not the result of the project operator's negligence, gross negligence or willful intent.
Urban Area	Urban areas are defined by the U.S. Census Bureau and are composed of urbanized areas (areas with populations ≥50,000 people) and urban clusters (populations ≥2,500 and <50,000). The most recent urbanized area definition provided by the U.S. Census Bureau can be found at http://www.census.gov/geo/maps-data/maps/2010ua.html.
Urban Forest Management Project (UFM Project, project)	A planned set of activities designed to increase removals of CO_2 from the atmosphere, or reduce or prevent emissions of CO_2 to the atmosphere, through increasing and/or conserving urban forest carbon stocks. An urban forest management (UFM) project focuses on activities that maintain or increase carbon inventories relative to baseline levels of carbon within the project boundary. Eligible activities may include, but are not limited to, increasing the urban forest productivity by removing diseased and suppressed trees, reducing emissions by avoiding tree clearing, and planting additional trees on available and appropriate sites.
Urban Forest Owner	A corporation, legally constituted entity (such as a utility), city, county, state agency, individual(s), or combination thereof that has legal control (e.g., right to plant or remove, etc.) of any amount of urban forest carbon within the project area.
Verification	The process of reviewing and assessing all of a project's reported data and information by an ISO-accredited and Reserve-approved verification body, to confirm that the project operator has adhered to the requirements of this protocol.

[20] Helms, J.A. (1998). The dictionary of forestry. Bethesda, MD: Society of American Foresters.

Verification Cycle	The Reserve requires full verification of projects every five reporting periods, but project operators can choose to have more frequent 'desktop' verifications. In between site visits, desk reviews of project reports can be completed by an approved verification body. The Reserve will only issue CRTs for verified emission reductions.
Verification Period	The period of time over which GHG reductions/removals are verified. A verification period may cover up to five reporting periods. The end date of any verification period must correspond to the end date of a reporting period.

CLIMATE ACTION RESERVE

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Urban Tree Planting

Project Protocol

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Abbreviations and Acronyms

C	Carbon
CAL FIRE	California Department of Forestry and Fire Protection
CH_4	Methane
CO_2	Carbon dioxide
CRT	Climate Reserve Tonne
DBH	Diameter at Breast Height
FIA	Forest Inventory and Analysis Program of the U.S. Forest Service
GHG	Greenhouse gas
GIS	Geographical Information System
ISO	International Organization for Standardization
KML	Keyhole Markup Language (see glossary)
N_2O	Nitrous oxide
PDD	Project Design Document
PIA	Project Implementation Agreement
Reserve	Climate Action Reserve
RPF	Registered Professional Forester (California only)
SSR	Source, sink, or reservoir
UFM	Urban forest management
USFS	United States Forest Service
UTP	Urban tree planting
VOC	Volatile Organic Compound

1 Introduction

The Urban Tree Planting (UTP) Project Protocol provides requirements and guidance for quantifying the net climate benefits of activities that sequester carbon in woody biomass within an urban environment. The protocol provides project eligibility rules, methods to calculate a project's net effects on greenhouse gas (GHG) emissions and removals of carbon dioxide (CO_2) from the atmosphere ("removals"), procedures for assessing the risk that carbon sequestered by a project may be reversed (i.e. released back to the atmosphere), and approaches for long term project monitoring and reporting.

The goal of this protocol is to ensure that the net GHG reductions and removals caused by a project are accounted for in a complete, consistent, transparent, accurate, and conservative manner[1] and may therefore be reported to the Climate Action Reserve (Reserve) as the basis for issuing carbon offset credits (called Climate Reserve Tonnes, or CRTs). Additionally, it is the goal of the Reserve to ensure the protocol is as efficient and practical as possible for Project Operators.

As the premier carbon offset registry for the North American carbon market, the Reserve encourages action to reduce GHG emissions by ensuring the environmental integrity and financial benefit of emission reduction projects. The Reserve establishes high quality standards for carbon offset projects, oversees independent third-party verification bodies, issues carbon credits generated from such projects, and tracks the transaction of credits over time in a transparent, publicly-accessible system. The Reserve is a private 501(c)(3) nonprofit organization based in Los Angeles, California.[2]

Only projects that are eligible under and comply with the UTP Project Protocol may be registered with the Reserve. Section 8 of this protocol provides requirements and guidance for verifying the performance of project activities and their associated GHG reductions and removals reported to the Reserve.

1.1 About Urban Forests, Carbon Dioxide and Climate Change

Urban forests have the capacity to both emit and absorb CO_2, a leading greenhouse gas that contributes to climate change. Trees, through the process of photosynthesis, naturally absorb CO_2 from the atmosphere and store the gas as carbon in their biomass, i.e. trunk (bole), leaves, branches, and roots. Carbon may also be stored in the soils that support the urban forest, as well as the understory plants and litter on the urban forest floor. After trees are removed, their wood residue may be converted into mulch, with CO_2 gradually released to the atmosphere through decomposition. Carbon may continue to be sequestered for a substantial amount of time in wood products and in landfills. Carbon from urban forests may also be used to provide fuel for biomass energy. Urban trees can reduce summertime air temperatures and building energy use for air conditioning, thus reducing GHG emissions from electricity generation (Akbari 2002). In winter, trees can increase or decrease GHG emissions associated with energy consumed for space heating, depending on local climate, site features, and building characteristics (Heisler 1986).

[1] See the WRI/WBCSD GHG Protocol for Project Accounting (Part I, Chapter 4) for a description of GHG reduction project accounting principles.
[2] For more information, please visit www.climateactionreserve.org.

When trees are disturbed, through events like fire, disease, pests, or harvest, some of their stored carbon may oxidize or decay over time, releasing CO_2 into the atmosphere. The quantity and rate of CO_2 that is emitted may vary, depending on the particular circumstances of the disturbance. Depending on how urban forests are managed or impacted by natural events, they can be a net source of emissions, resulting in a decrease to the reservoir, or a net sink of emissions, resulting in an increase of CO_2 to the reservoir. In other words, urban forests may have a net negative or net positive impact on the climate.

2 Urban Tree Planting Definition and Requirements

For the purposes of this protocol, an Urban Tree Planting (UTP) Project is a planned set of activities designed to increase removals of CO_2 from the atmosphere, or reduce or prevent emissions of CO_2 to the atmosphere, through increasing and/or conserving urban forest carbon stocks.

A glossary of terms used in this protocol is provided in Section 9. Throughout the protocol, important defined terms are capitalized (e.g. "Urban Forest Owner").

2.1 Project Definition

A UTP Project is a project where new trees are planted in areas where trees have not been harvested with a primary commercial interest during the 10 years prior to the Project Commencement Date. Only planted trees and trees that regenerate from planted trees are eligible to be quantified for credits. Benefits from urban tree planting activities occur when the net CO_2e (CO_2e stored minus CO_2e emitted) associated with planted trees exceeds baseline tree planting CO_2e levels.

2.2 Urban Forest Owners

Credits for a UTP Project must be quantified from carbon that is owned by participating entities. An Urban Forest Owner is a corporation, a legally constituted entity (such as a utility or special district), city, county, state agency, educational campus, individual(s), or a combination thereof that has legal control of any amount of urban forest carbon[3] within the Project Area.

Control of urban forest carbon means the Urban Forest Owner has the legal authority to effect changes to urban forest carbon quantities (right to plant or remove, for example). Control of urban forest carbon occurs, for purposes of satisfying this protocol, through fee ownership, perpetual contractual agreements, and/or deeded encumbrances. This protocol recognizes the fee owner as the default owner of urban forest carbon where no explicit legal encumbrance exists. Individuals or entities holding mineral, gas, oil, or similar *de minimis*[4] interests without fee ownership are precluded from the definition of Urban Forest Owner.

2.3 Project Operators

A Project Operator must be one of the Urban Forest Owners or a legally created entity to represent the Urban Forest Owners. The Project Operator is responsible for undertaking a UTP Project and registering it with the Reserve, and is ultimately responsible for all project listing, monitoring, reporting, and verification. The Project Operator is responsible for any reversals associated with the project and is the entity that executes the Project Implementation Agreement (see below) with the Reserve.

In all cases where multiple Urban Forest Owners participate in a UTP Project, the Project Operator must secure an agreement from all other Urban Forest Owners that assigns authority to the Project Operator to include the carbon they own in the project, subject to any conditions imposed by any of the Urban Forest Owners to include or disallow any carbon they control and any provisions to opt out of the project.

[3] See definition of Carbon Stock in the glossary.
[4] *de minimis* control includes access right of ways and residential power line right of ways.

2.4 Project Implementation Agreement

A Project Implementation Agreement (PIA) is a required agreement between the Reserve and a Project Operator setting forth the Project Operator's obligation (and the obligation of its successors and assigns) to comply with the UTP Project Protocol.

3 Eligibility Rules

In addition to the definitions and requirements described in Section 2, projects must meet several other criteria and conditions to be eligible for registration with the Reserve, and must adhere to the following requirements related to their duration and crediting periods.

3.1 Project Location

Only those activities that occur within the Urban Area boundaries, defined by the most recent publication of the United States Census Bureau (http://www.census.gov/geo/maps-data/maps.html), are eligible to develop a project under this protocol. Projects must be entirely within the Urban Area boundary as of Project Commencement.

3.2 Project Area

The Project Area is the geographic extent of the UTP Project. The Project Area may be made up of consolidated or disaggregated polygons. A KML file must be submitted with the project to clearly identify the project boundaries. There are no size limits for UTP Projects.

No part of the Project Area can be included if commercial harvesting of timber has occurred in the Project Area in the past 10 years. Additionally, the issuance and transaction of credits will be suspended if commercial harvesting of timber products occurs any time during the project. Where the harvesting of commercial timber products is anticipated, the OPO should consider the use of a protocol that addresses the carbon stored in harvested wood products, such as the Reserve's Forest Protocol or the California Air Resource's Board Compliance Forest Protocol. Exceptions to the prohibition of harvesting commercial timber products are recognized where the provision of commercial timber products might be generated where harvests are conducted primarily for safety, salvage of material when trees are in decline, and developing improved resilience to wildfire and pests.

3.3 Project Commencement

The commencement date for a project is the date at which the Project Operator initiates an activity that will lead to increased GHG reductions or removals with long-term security relative to the project baseline. The earliest acceptable activity that demonstrates the commencement of project activities is a formal planning process by the Project Operator. Subsequent activities to planning, including the purchase of equipment for tree planting, site preparation, or planting trees, with a plan in place, also demonstrate a project has commenced. Once a UTP Project has commenced, new plantings can occur within the Project Area throughout the Project Life. Discrete and verifiable evidence that acceptable activity has occurred includes signed contracts and/or direct evidence of the recent activity.

To be eligible, the project must be submitted to the Reserve no more than six months after the project commencement date.[5] Projects may always be submitted for listing by the Reserve prior to their start date.

3.4 Additionality

The Reserve will only register projects that yield surplus GHG emission reductions and removals that are additional to what would have occurred in the absence of a carbon offset

[5] Projects are considered submitted when the project developer has completed and uploaded the appropriate project submittal forms to the Reserve software.

market (i.e. under "Business As Usual"). For a general discussion of the Reserve's approach to determining additionality, see the Reserve's Program Manual.[6]

Projects must satisfy the following tests to be considered additional.

3.4.1 Legal Requirement Test

UTP Projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from compliance with any federal, state, or local law, statute, rule, regulation, or ordinance. Projects must also achieve GHG reductions and removals above and beyond any GHG reductions or removals that would result from compliance with any court order or other legally binding mandates. Deeded encumbrances, tree-planting and management ordinances, and contractual agreements, collectively referred to as Legal Agreements, may effectively control urban forest carbon and possess ownership rights to the carbon inventories controlled. Similarly, deeded encumbrances, tree planting and management ordinances, and contractual agreements may have an effect on urban forest carbon inventories beyond the control of any of the Urban Forest Owners.

Trees planted to fulfill a legal requirement are ineligible under this protocol. Legal requirements include any requirement issued by authority of a federal, state, or local jurisdiction to plant trees for any reason.

3.4.2 Performance Test

Projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from engaging in Business As Usual activities, as defined by the requirements described below.

3.4.2.1 Performance Standard for Urban Tree Planting Projects

The performance standard metrics are based on the averages of data between the 50th and 100th percentiles. The data are based on the following data:

1. For Municipalities/counties: trees per capita.
2. Educational institutions: trees per acre of maintained landscaping.
3. Utilities: trees per ratepayer

Project Operators must include the performance standard level of planting in their baseline calculations as described in the Quantification Guidance supplemental to this protocol.

3.5 Project Crediting Period

The crediting period for UTP Projects is 25 years. Projects may be renewed for additional crediting periods with the prospect of incorporating updated technology into the project analysis. The initial baseline can be maintained for the crediting period. While the project can be renewed indefinitely, the baseline must be renewed at the end of the crediting period. Any previously issued credits are respected for the life of the project.

3.6 Minimum Time Commitment

Projects must monitor, report, and undergo verification activities for 100 years following the last credit issued to the project.

[6] Available at http://www.climateactionreserve.org/how/program/program-manual/.

3.7 Social and Environmental and Co-Benefits

All projects will provide climate benefits to the extent in which they generate credits. Urban forests provide many additional benefits, including environmental, social, and public health benefits. The ability to achieve additional environmental and social co-benefits depends on consideration of additional factors, some of which are described in this section. Only those projects where public and/or tribal entities participate in direct urban tree management activities (e.g., planting, tree distribution, etc.) are required to include the provisions for social and environmental co-benefits. However, these provisions may serve as suggestions to NGOs and other privately funded projects that may wish to enhance social and environmental co-benefits. Where required, the provisions must be described in the Project Design Document (PDD) and implemented throughout the Project Life. The Reserve has developed a tree-planting template that outlines elements that need to be addressed and provides important considerations that may be helpful in decision-making.[7] The template provides considerations that will enable verifiers to ensure progress is being achieved over time.

3.7.1 Social Co-Benefits

UTP Projects can create long-term climate benefits as well as providing other social and environmental benefits. Investment in projects has the potential to improve the quality of life for urban communities in a number of ways. Among other benefits, tree planting projects can improve air quality and reduce storm water runoff, provide shade, and increase property values by creating a more aesthetically pleasing environment. Projects also have the potential to create negative social externalities such as an uneven distribution of project benefits due to an uneven distribution of projects sites throughout a community (e.g. skewed toward more affluent communities).

Table 3.1. Social Co-Benefits of Urban Tree Planting Projects

Social Provisions	Elements to Include in the Project Design Document (PDD)
Equitable distribution of forest resources	Describe how the project will make progress toward achieving relatively equal distribution of tree canopy cover by neighborhood whenever possible.
Public participation	Establish guidelines to ensure adequate notification, opportunities for public participation, and documentation with regards to public activities with urban forest management.

3.7.2 Environmental Co-Benefits

The protocol has a goal of permanently removing greenhouse gases from the atmosphere by sustaining carbon benefits generated from urban forests for at least 100 years. Healthy urban forests can also provide a number of environmental benefits as well as create negative externalities. Projects have the potential to improve air quality and reduce storm water runoff and energy usage. They can also contribute to reduced biodiversity, introduce invasive species, and damage infrastructure. Inefficient water usage during maintenance can also put pressure on local and regional water supplies.

[7] Available at http://www.climateactionreserve.org/how/protocols/urban-forest/.

Table 3.2. Environmental Co-Benefits of Urban Tree Planting Projects

Environmental Provisions	Elements to Include in the Project Design Document (PDD)
Biodiversity	Describe how UTP Project activities will maintain and enhance biodiversity, including: 1. Benefits of tree species selection and composition to biodiversity within the project area. 2. Use of specific tree species, sizes and/or distributions to support unique habitat elements.
Native species	Describe how UTP Project activities will promote the use of native species, including: 1. Strengths and limitations of using native trees in the UTP Project. 2. Preferential treatment of native species.
Non-native species	Describe how UTP Project activities will limit and target the use of any non-native species, including: 1. Strengths and limitations of using non-native trees in the UTP Project. 2. Resistance to insects and disease.
Climate change resilience	Describe how UTP Project activities will enhance the resilience of the urban forest to climate change, including: 1. Ability of urban forest to adapt to climate change. 2. Resistance to natural disturbances.
Air quality	Describe how UTP Project activities will enhance air quality benefits, including: 1. Tree selection and distribution to reduce air pollutants. 2. Tree selection and distribution to reduce emissions of Biogenic Volatile Organic Compounds (BVOCs). 3. Design tree maintenance activities to reduce fossil fuel emissions.
Physical characteristics	Describe how UTP Project activities will enhance physical characteristics of the urban environment, including: 1. Tree shading. 2. Wind protection. 3. Minimize disturbance to city infrastructure (e.g. sidewalks, power lines, etc.)
Water Management	Describe how UTP Project activities will improve water management, including: 1. Increase infiltration and recharge of groundwater. 2. Reduce stormwater runoff. 3. Conserve water from urban forest management.

4 GHG Assessment Boundaries

The quantification of all included sources, sinks, and reservoirs (SSR) (Table 4.1 below) is described in the supplemental Quantification Guidance available on the Reserve's website.[8]

Table 4.1. Description of all Sources, Sinks, and Reservoirs

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
UF-1	Standing live carbon (carbon in all portions of living trees)	Reservoir / Pool	CO_2	Included	Increases in standing live carbon stocks are likely to be a large Primary Effect of UTP Projects
UF-2	Shrubs and herbaceous understory carbon	Reservoir / Pool	CO_2	Excluded	For crediting purposes shrubs and herbaceous understory are excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Furthermore, it is generally not practical to undertake measurements of shrubs and herbaceous understory accurate enough for crediting purposes.
UF-3	Standing dead carbon (carbon in all portions of dead, standing trees)	Reservoir / Pool	CO_2	Included	Standing dead wood is expected to be a small, but in rare cases substantial, portion of UTP Projects.
UF-4	Lying dead wood carbon	Reservoir / Pool	CO_2	Excluded	For crediting purposes lying dead wood carbon is excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Changes associated with carbon projects are likely to increase lying dead wood. Furthermore, it is generally not practical to undertake measurements of lying dead wood accurate enough for crediting purposes.
UF-5	Litter and duff carbon (carbon in dead plant material)	Reservoir / Pool	CO_2	Excluded	Litter and duff carbon is excluded since changes in this reservoir are unlikely to have a significant effect on total quantified GHG reductions or removals. Furthermore, it is generally not practical to undertake measurements of litter and duff accurate enough for crediting purposes.

[8] http://www.climateactionreserve.org/how/protocols/urban-forest/

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
UF-6	Soil carbon	Reservoir / Pool	CO_2	Excluded	Soil carbon is not anticipated to change significantly as a result of UTP Projects.
UF-7	Carbon in in-use forest products	Reservoir / Pool	CO_2	Excluded	Urban forests do not produce significant levels of wood products that persist for long enough periods of time to meet permanence requirements and UTP Projects will not substantially change wood product production.
UF-8	Forest product carbon in landfills	Reservoir / Pool	CO_2	Excluded	Urban forests do not produce significant levels of wood products and UTP Projects will not substantially change wood product production.
UF-9	Nutrient application	Source	N_2O	Excluded	The use of nitrogen-based fertilizers is not expected to be a significant source of emissions.
UF-10	Biological emissions from site preparation activities	Source	CO_2	Excluded	Biological emissions from site preparation are not quantified since projects that involve intensive site preparation activities are not eligible.
UF-11	Mobile combustion emissions from site preparation activities	Source	CO_2	Excluded	Mobile combustion CO_2 emissions from site preparation are not quantified since projects that involve intensive site preparation activities are not eligible.
			CH_4	Excluded	Changes in CH_4 emissions from mobile combustion associated with site preparation activities are not considered significant.
			N_2O	Excluded	Changes in N_2O emissions from mobile combustion associated with site preparation activities are not considered significant.
UF-12	Mobile combustion emissions from ongoing project operation and maintenance	Source	CO_2	Excluded	Mobile combustion CO_2 emissions from ongoing project operation and maintenance are unlikely to be significantly different from baseline levels, and are therefore not included in the GHG Assessment Boundary.
			CH_4	Excluded	CH_4 emissions from mobile combustion associated with ongoing project operation and maintenance activities are not considered significant.

SSR	Source Description	Type	Gas	Included (I) or Excluded (E)	Justification/Explanation
			N_2O	Excluded	N_2O emissions from mobile combustion associated with ongoing project operation and maintenance activities are not considered significant.
UF-13	Stationary combustion emissions from ongoing project operation and maintenance	Source	CO_2	Excluded	Stationary combustion CO_2 emissions from ongoing project operation and maintenance could include GHG emissions associated with electricity consumption or heating/cooling at Urban Forest Owner facilities or at facilities owned or controlled by contractors. These emissions are unlikely to be significantly different from baseline levels, and are therefore not included in the GHG Assessment Boundary.
			CH_4	Excluded	CH_4 emissions from stationary combustion associated with ongoing project operation and maintenance activities are not considered significant.
			N_2O	Excluded	N_2O emissions from stationary combustion associated with ongoing project operation and maintenance activities are not considered significant.

5 Quantifying Net GHG Reductions and Removals

This section provides general requirements and guidance for quantifying a UTP Project's net GHG reductions and removals. Detailed methodological approaches to quantifying GHG reductions and removals are provided in the Quantification Guidance document. The Reserve will issue Climate Reserve Tonnes (CRTs) to a project upon confirmation by an ISO-accredited and Reserve-approved verification body that the project's GHG reductions and removals have been quantified following the applicable requirements of this section (see Section 8 for verification requirements). The Reserve provides an Urban Tree Planting Calculation Tool on its website[9] to assist with the annual calculation of reductions and removals.

Quantification proceeds according to the steps below.

1. **Estimating baseline onsite carbon stocks**. The baseline is an estimate of what would have occurred in the absence of a project. To establish baseline onsite carbon stocks, the Project Operator must apply the appropriate performance test from Section 3.4.2 of this protocol to the Project Onsite Inventory at Project Commencement. The Project Onsite Inventory must have been developed according to the guidelines established in the Quantification Guidance. Baseline estimates are developed for a 100-year period. Generally, baselines do not change during this period absent findings of errors in initial calculation or reconciliation associated with methodological updates.

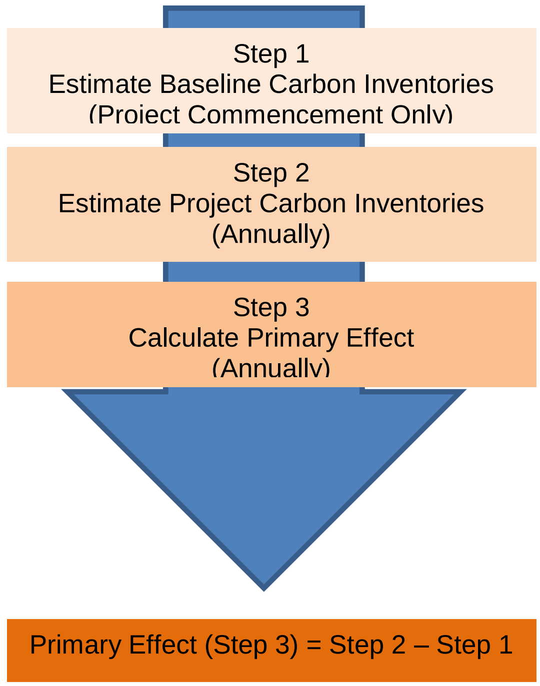
2. **Determining actual onsite carbon stocks**. Each year, the Project Operator must determine the project's actual onsite carbon stocks. This must be done by updating the UTP Project's forest carbon inventory for the current year, following the guidance in this section and in the Quantification Guidance. The estimate of actual onsite carbon stocks must be adjusted by an appropriate confidence deduction, as described in the Quantification Guidance.

3. **Calculating the project's Primary Effect**. Each year, the Project Operator must quantify the actual change in GHG emissions or removals associated with the project's intended ("primary") effect. For any given year, the Primary Effect is calculated by:
    a. Taking the difference between actual onsite carbon stocks for the current year and actual onsite carbon stocks for the prior year.[10]
    b. Subtracting from (a) the difference between baseline onsite carbon stocks for the current year and baseline onsite carbon stocks for the prior year.

4. Calculating total net GHG reductions and removals. For each year, total net GHG reductions and removals are calculated by summing a project's Primary and Secondary Effects. If the result is positive, then the project has generated GHG reductions and/or removals in the current year. If the result is negative, this may indicate a reversal has occurred (see Section 6).[11]

[9] http://www.climateactionreserve.org/how/protocols/urban-forest/
[10] For the purposes of calculating the project's Primary Effect, actual and baseline carbon stocks prior to the Project Commencement Date are assumed to be zero.
[11] A reversal occurs only if: (1) total net GHG reductions and removals for the year are negative; and (2) CRTs have previously been issued to the UTP Project.

The required formula for quantifying annual net GHG reductions and removals is presented in Equation 5.1. Net GHG reductions and removals must be quantified and reported in units of carbon dioxide-equivalent (CO_2e) metric tons.



Equation 5.1. Annual Net GHG Reductions and Removals

$$QR_y = (\Delta\, AC_{onsite} - \Delta\, BC_{onsite})$$

Where, <u>Units</u>

QR_y	=	Quantified GHG reductions and removals for year y	tCO_2e
$\Delta\ AC_{onsite}$	=	$(AC_{onsite,\ y}) - (AC_{onsite,\ y-1})$	tCO_2e
		Where,	
		$AC_{onsite,\ y}$ = Actual carbon (CO_2e) as inventoried for year y (y may be less than a year for the first Reporting Period following Project Commencement).	tCO_2e
		$AC_{onsite,\ y-1}$ = Actual carbon (CO_2e) as inventoried for year y-1	tCO_2e
$\Delta\ BC_{onsite}$	=	$(BC_{onsite,\ y}) - (BC_{onsite,\ y-1})$	tCO_2e
		Where,	
		$BC_{onsite,\ y}$ = Baseline onsite carbon (CO_2e) as estimated for year y (y may be less than a year for the first Reporting Period following Project Commencement).	tCO_2e
		$BC_{onsite,\ y-1}$ = Baseline onsite carbon (CO_2e) as estimated for year y-1	tCO_2e

5.1 Urban Tree Planting Baseline

To develop a project baseline for a UTP Project, Project Operators must provide a qualitative characterization of the regulatory framework governing tree planting activities within the Project Area and explain why trees planted as part of the project are outside of any framework requiring the planting of trees.

Projects use a performance standard value which provides guidance to quantifying baselines. The performance standard value is a value that represents the averages of data between the 50th and 100th percentiles for trees planted annually for classes based on the entity type (county, municipality, educational institution, or utility/special district), the entity's size (population, landscaped area, or ratepayer population), and the entity's geo-political region. Project Operators must match their entity with an urban forest class on the Reserve's Urban Forest Project Protocol webpage.

The performance standard value[12] is compared to the actual project trees planted and the resulting proportion is calculated in terms of CO_2e to calculate the baseline contribution. The baseline calculation contains provisions for the potential eventuality that the Project Area is saturated with planted trees. The Reserve's Urban Tree Planting Calculation Tool[13] assists Project Operators with the baseline calculation. A more technical description of the quantification of the UTP Project baseline can be found in the Quantification Guidance supplemental to this protocol.

[12] Available at http://www.climateactionreserve.org/how/protocols/urban-forest/.
[13] Available at http://www.climateactionreserve.org/how/protocols/urban-forest/.

6 Ensuring the Permanence of Credited GHG Reductions and Removals

Changes in urban forest management have the potential to enhance the rate of CO_2 absorption, providing removals, and reducing or eliminating emissions associated with the loss of trees (reductions). Reductions are not possible with UTP Projects. The Reserve requires that credited GHG reductions and removals be effectively "permanent." For UTP Projects, this requirement is met by ensuring that the carbon associated with credited GHG reductions and removals remains stored for at least 100 years.

The Reserve ensures the permanence of GHG reductions and removals through three mechanisms:

1. The requirement for all Project Operators to monitor onsite carbon stocks, submit regular monitoring reports, and submit to regular third-party verification of those reports along with periodic onsite verifications for the duration of the Project Life.
2. The requirement for all Project Operators to sign a Project Implementation Agreement with the Reserve which obligates Project Operators to retire CRTs to compensate for reversals of GHG reductions and removals.
3. The maintenance of a Buffer Pool to provide insurance against reversals of GHG reductions and removals due to unavoidable causes (including natural disturbances such a fires, pest infestations or disease outbreaks).

GHG reductions and removals can be "reversed" if the stored carbon associated with them is released (back) to the atmosphere. Many biological and non-biological agents, both natural and human-induced, can cause reversals. Some of these agents cannot completely be controlled (and are therefore "unavoidable"), such as natural agents like fire, insects, pathogens, drought, and wind.

Other agents can be controlled, such as the human activities like land conversion. Under this protocol, reversals due to controllable agents are considered "avoidable". As described in this section, Project Operators must contribute to the Reserve Buffer Pool to insure against reversals. If the quantified GHG reductions and removals in a given year are negative, and CRTs were issued to the UTP Project in any previous year, the Reserve will consider this to be a reversal regardless of the cause of the decrease.

The Buffer Pool is a holding account for project CRTs, which is administered by the Reserve. All UTP Projects must contribute a percentage of CRTs to a Buffer Pool any time they are issued CRTs for verified GHG reductions and removals. A project that has an Unavoidable Reversal will use Buffer Pool CRTs proportionally from all projects that have contributed to the pool to compensate for the reversal. Project Operators do not receive compensation for their contributions to the Buffer Pool.

If a project experiences an Unavoidable Reversal of GHG reductions and removals (as defined in Section 6.2.2), the Reserve will retire a number of CRTs from the Buffer Pool equal to the total amount of carbon that was reversed (measured in metric tons of CO_2). The Buffer Pool therefore acts as a general insurance mechanism against Unavoidable Reversals for all UTP Projects registered with the Reserve. The Reserve may determine to re-distribute CRTs to Project Operators in the future, or modify the amount of contributions to the Buffer Pool, if actual Unavoidable Reversals fluctuate significantly from the current evaluation of risks.

6.1 Contributions to the Buffer Pool

Projects may be affected by financial risks, management risks, social risks, risks from pollution, and risks from natural disturbances (disease/insects, wildfire, flooding, drought etc.). To compensate for these risks, each project must contribute 6% of their issued CRTs to the Buffer Pool.

6.2 Compensating for Reversals

The Reserve requires that all reversals be compensated through the retirement of CRTs. If a Reversal associated with a UTP Project was unavoidable (as defined below), then the Reserve will compensate for the reversal on the Project Operator's behalf by retiring CRTs from the Buffer Pool. If a reversal was avoidable (as defined below) then the Project Operator must compensate for the reversal by surrendering CRTs from its Reserve account.

6.2.1 Avoidable Reversals

An Avoidable Reversal is any reversal that is due to the Project Operator's negligence, gross negligence, or willful intent, including harvesting, development, and harm to the Project Area due to the Project Operator's negligence, gross-negligence or willful intent. Requirements for Avoidable Reversals are as follows:

1. If an Avoidable Reversal has been identified during annual monitoring, the Project Operator must give written notice to the Reserve within thirty days of identifying the reversal. Additionally, if the Reserve determines that an Avoidable Reversal has occurred, it shall deliver written notice to the Project Operator.
2. Within thirty days of receiving the Avoidable Reversal notice from the Reserve, the Project Operator must provide a written description and explanation of the reversal to the Reserve.
3. Within four months of receiving the Avoidable Reversal notice, the Project Operator must retire a quantity of CRTs from its Reserve account equal to the size of the reversal in CO_2-equivalent metric tons (i.e. QR_y, as specified in Equation 5.1). In addition:
   a. The retired CRTs must be those that were issued to the project, or that were issued to other UTP Projects registered with the Reserve.
   b. The retired CRTs must be designated in the Reserve's software system as compensating for the Avoidable Reversal.
4. Within a year of receiving the Avoidable Reversal notice, the Project Operator must provide the Reserve with a verified estimate of current onsite carbon stocks and the estimated quantity of the Avoidable Reversal.

6.2.2 Unavoidable Reversals

An Unavoidable Reversal is any reversal not due to the Project Operator's negligence, gross negligence or willful intent, including, but not limited to, wildfires or disease that are not the result of the Project Operator's negligence, gross negligence or willful intent. Requirements for Unavoidable Reversals are as follows:

1. If the Project Operator determines there has been an Unavoidable Reversal, it must notify the Reserve in writing of the Unavoidable Reversal within six months of its occurrence.
2. The Project Operator must explain the nature of the Unavoidable Reversal and provide a verified estimate of onsite carbon stocks within one year so that the reversal can be quantified (in units of CO_2-equivalent metric tons).

If the Reserve determines that there has been an Unavoidable Reversal, it will retire a quantity of CRTs from the Buffer Pool equal to size of the reversal in CO_2-equivalent metric tons.

6.3 Disposition of Projects after a Reversal

If a reversal lowers the UTP Project's carbon stocks below its approved baseline carbon stocks, the project will be terminated as the original baseline approved for the project would no longer be valid. If a project is terminated due to an Unavoidable Reversal, a new project may be initiated and submitted to the Reserve for registration on the same Project Area. New projects may not be initiated on the same Project Area if the project is terminated due to an Avoidable Reversal.

7 Project Monitoring, Reporting, and Verification

This section provides requirements and guidance on project monitoring, reporting rules and procedures.

7.1 Project Documentation

Project Operators must provide the following documentation to the Reserve in order to register a UTP Project.

Table 7.1. Project Documentation Submittal Requirements

Document	When Submitted/Required
Project Submittal Form	Once, at project initiation when the Project Operator wishes to submit project concept to Reserve. Must be submitted within 6 months of the Commencement Date.
Project Design Document	Once, prior to initial verification.
Signed Attestation of Title Form	Prior to issuance of credits. Required at initial verification, onsite verification, and every optional desktop verification.
Signed Attestation of Regulatory Compliance Form	Prior to issuance of credits. Required at initial verification, onsite verification, and every optional desktop verification.
Signed Attestation of Voluntary Implementation Form	Once, prior to the issuance of credits as part of the initial verification.
Verification Report	Upon completion of verification and prior to issuance of credits. Required at initial verification, onsite verification, and every optional desktop verification.
Verification Statement	Upon completion of verification and prior to issuance of credits. Required at initial verification, onsite verification, and every optional desktop verification.
Project Implementation Agreement	Upon completion of verification and prior to issuance of credits. Required at initial verification, onsite verification, and every optional desktop verification.

Project submittal forms can be found at http://www.climateactionreserve.org/how/program/documents/.

All reports that reference carbon stocks must be submitted with the oversight of a Certified Arborist, a Certified Forester, a Certified Urban Forester, or Professional Forester so that professional standards and project quality are maintained. Any Certified Arborist, Certified Urban Forester, Professional Forester or Certified Forester preparing a project in an unfamiliar jurisdiction must consult with a Certified Arborist, Professional Forester or Certified Forester practicing forestry in that jurisdiction to understand all laws and regulations that govern urban forest practices within the jurisdiction. This requirement does not preclude the project's use of technicians or other unlicensed/uncertified persons working under the supervision of the Professional Forester, Certified Arborist, or Certified Forester.

All projects shall submit a shapefile as a KML that matches the maps submitted to depict the Project Area. The project's reported acres shall be based on the shapefile submitted to the

Reserve. The Reserve will create a file of all verified forest carbon projects on Google Maps for public dissemination.

7.1.1 Urban Forest Project Design Document

The Project Design Document (PDD) is a required document for reporting information about a project. The document is submitted at the initial verification. A PDD template has been prepared by the Reserve and is available on the Reserve's website.[14] The template is arranged to assist in ensuring that all requirements of the UTP Project Protocol are addressed. The template is required to be used by all projects. The template is designed to manage the varying requirements based on project type.

Each project must submit a PDD at the project's first verification. PDDs are intended to serve as the main project document that thoroughly describes how the project meets eligibility requirements, discusses summaries associated with developing data according to quantification requirements, outlines how the project complies with terms for additionality and describes how project reversal risks are calculated. All methodologies used by Project Operators and descriptions in the PDD must be clear in a way that facilitates review by verifiers, Reserve staff, and the public. PDDs must be of professional quality and free of incorrect citations, missing pages, incorrect project references, etc.

7.2 Monitoring Report

Monitoring is the process of regularly collecting and reporting data related to a project's performance. Annual monitoring of UTP Projects is required to ensure up-to-date estimates of project carbon stocks and provide assurance that GHG reductions or removals achieved by a project have not been reversed. Project Operators must conduct monitoring activities and submit monitoring reports according to the schedule and requirements presented in Section 7.2. Monitoring is required for a period of 100 years following the final issuance of CRTs to a project for quantified GHG reductions or removals.

Monitoring activities consist primarily of updating a project's forest carbon inventory, entering the updated inventory into the project's calculation worksheet, and submitting it to the Reserve at frequencies defined in Section 7.3. CRTs are only issued in years that the project data are verified, as described in Section 7.4.

A monitoring report must be prepared for each Reporting Period. Monitoring reports must be provided to verification bodies whenever a project undergoes verification. The monitoring report must be completed and submitted to the Reserve within 12 months of the end of the Reporting Period. When required verifications must be conducted as explained below, both the verification report and the monitoring report must be completed and submitted to the Reserve within 12 months of the end of the Reporting Period. Monitoring reports must include an update of the project's calculation worksheet. The project's calculation worksheet includes:

1. An updated estimate of the current year's carbon stocks in the reported carbon pools. Acceptable methodologies for updating the project's inventory are provided in the Quantification Guidance. The update is determined by:
    a. Including any new forest inventory data obtained during the Reporting Period.
    b. Applying growth estimates to existing inventory.

[14] http://www.climateactionreserve.org/how/protocols/urban-forest/

   c. Updating inventory estimates for removals and/or disturbances that have occurred during the Reporting Period.
2. The baseline carbon stock estimates for the current year, as determined following the requirements in Section 5 and approved at the time of the project's registration.
3. A preliminary calculation of total net GHG reductions and removals (or reversals) for the year, following the requirements in Section 5.
4. *A preliminary calculation of the project's Buffer Pool contribution.

In addition to data reported using the project calculation worksheet, the following must be submitted to the Reserve as part of a monitoring report.

Conditional reporting, as pertinent:

1. If a reversal has occurred during the previous year, the report must provide a written description and explanation of the reversal, whether the Reserve classified the reversal as Avoidable or Unavoidable, and the status of compensation for the reversal.

7.3 Reporting and Verification Cycles

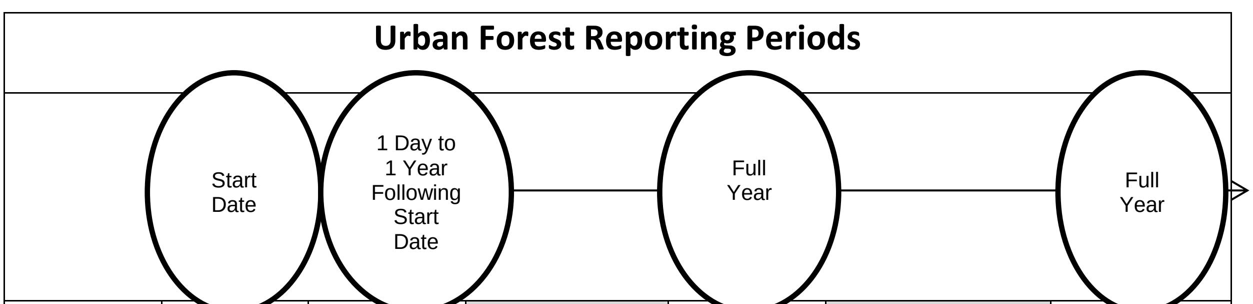
This section describes the required reporting and verification cycles. A UTP Project is considered automatically terminated (see Section 6.3) if the Project Operator chooses not to report data and undergo verification at required intervals.

7.3.1 Reporting Period Duration and Cycles

Projects must report their initial inventory data associated with the Project Commencement Date. Project Operators must report their project inventories annually with the exception of the Reporting Period immediately following Project Commencement, which can be any length of time up to one year. This enables Project Operators to establish an annual reporting cycle that is convenient for the entity.

Figure 7.1 displays the Reporting Periods in graphical form.

Reporting Periods must be contiguous, i.e. there must be no gaps in reporting during the crediting period of a project once the first Reporting Period has commenced.



Initial Report (for Start Date)/ Reporting Period	1	2		3		4
Time from last report date:	NA	As desired to establish a reporting cycle		1 year		1 year

Reported Data

Project Onsite Carbon Stocks	Yes	Yes		Yes		Yes
CRTs Issued upon Successful Verification?	No	Yes		Yes		Yes

Figure 7.1. Urban Tree Planting Reporting Periods

7.3.2 Verification Cycles

All projects must be initially verified within 30 months of being submitted to the Reserve. The initial verification of all project types must include a site visit, confirm the project's eligibility, and confirm that the project's initial inventory and the baseline have been established in conformance with the UTP Project Protocol. Subsequent verification may include multiple Reporting Periods and is referred to as the "Verification Period." The end date of any Verification Period must correspond to the end date of a Reporting Period.

Verification has both required frequencies and optional frequencies. Required verification is established on a temporal framework to ensure that ongoing monitoring of urban forest carbon stocks are accurate and up-to-date. Optional verification is at the Project Operator's discretion and may be conducted in the years in which verification is not required and the Project Operator wishes to receive credits. Required verifications are referred to as onsite verifications. Optional verifications are referred to as desk review verifications. Details of verification scheduling requirements are provided within this section.

Verification must be completed within 12 months of the end of the Reporting Period(s) being verified. For required verifications, failure to complete verification within the 12 month time period will result in account activities being suspended until the verification is complete. The project will terminate if the required verification is not completed within 36 months of the end of the Reporting Period(s) being verified. There is no consequence for failure to complete verification activities within 12 months for optional verifications.

7.3.3 Requirements of Onsite Verifications

Onsite verification is a verification in which project inventory data are verified through a process that audits data in the office as well as data in the field. The Reserve requires that an approved third-party verification body verify all reported data and information for a project and conduct a site visit for the Verification Period that coincides with Project Commencement and the end of every fifth Reporting Period following the Project Commencement Date. Buffer Pool contributions are also verified during onsite verifications.

7.3.4 Desk Review Verification

In between onsite verifications, the Project Operator may choose to have an approved third-party verification body conduct a desk review of annual monitoring reports as an optional verification. CRTs may be issued for GHG reductions/removals verified through such desk reviews.

Submission of annual monitoring reports to the Reserve is required even if the Project Operator chooses to forego desk review verification.

7.4 Issuance and Vintage of CRTs

The Reserve will issue Climate Reserve Tonnes (CRTs) for quantified GHG reductions and removals that have been verified through either onsite verifications or desk reviews. Onsite verification may determine that earlier desk reviews overestimated onsite carbon stocks. Any resulting downward adjustment to carbon stock estimates will be treated as a reversal (see Section 6). In this case, the Project Operator must retire CRTs in accordance with the requirements for compensating for a reversal (Section 6.2). Vintages are assigned to CRTs based on the proportion of days in a calendar year within a Reporting Period.

7.5 Record Keeping

For purposes of independent verification and historical documentation, Project Operators are required to keep all documents and forms related to the project for a minimum of 100 years after the final issuance of CRTs from the Reserve. This information may be requested by the verification body or the Reserve at any time.

7.6 Transparency

The Reserve requires data transparency for all projects, including data that displays current carbon stocks, reversals, and verified GHG reductions and removals. For this reason, all non-confidential project data reported to the Reserve will be publicly available on the Reserve's website.

8 Verification Guidance

This section provides guidance to Reserve-approved verification bodies for verifying GHG emission reductions associated with urban forest projects.

This section supplements the Reserve's Verification Program Manual,[15] which provides verification bodies with the general requirements for a standardized approach for independent and rigorous verification of GHG emission reductions and removals. The Verification Program Manual outlines the verification process, requirements for conducting verification, conflict of interest and confidentiality provisions, core verification activities, content of the verification report, and dispute resolution processes. In addition, the Verification Program Manual explains the basic verification principles of ISO 14064-3:2006 which must be adhered to by the verification body.

Verification bodies must read and be familiar with the following International Organization for Standardization (ISO) and Reserve documents and reporting tools:

- Urban Tree Planting Project Protocol (this document)
- Reserve Program Manual
- Reserve Verification Program Manual
- Reserve software
- ISO 14064-3:2006 Principles and Requirements for Verifying GHG Inventories and Projects

Only Reserve-approved urban forest project verification bodies are eligible to verify UTP Project reports. To become a recognized urban forest project verifier, verification bodies must become accredited under ISO 14065. Information on the accreditation process can be found on the Reserve website at http://www.climateactionreserve.org/how/verification/how-to-become-a-verifier/.

The verification of reports that reference carbon stocks must be conducted with the oversight of a Certified Arborist, a Professional Forester, or a Certified Forester,[16] managed by the Society of American Foresters, so that professional standards and project quality are maintained. Any Certified Arborist, Professional Forester or Certified Forester who is not currently working with urban forest activities within the Project Area must consult with a Certified Arborist, a Professional Forester, Certified Forester, or planning agency familiar with the practice of urban forestry in that jurisdiction to understand all laws and regulations that govern urban forest practice within the jurisdiction. The Reserve may evaluate and approve alternative professional credentialing requirements if requested, but only for jurisdictions where laws or regulations that govern professional urban forest management do not exist.

8.1 Standard of Verification

The Reserve's standard of verification for UTP Projects is the Urban Tree Planting Project Protocol, the Reserve Program Manual, and the Reserve Verification Program Manual. To verify a Project Operator's initial Project Design Document and annual monitoring reports, verification bodies apply the verification guidance in the Reserve's Verification Program Manual and this

[15] Found on the Reserve website at http://www.climateactionreserve.org/how/program/program-manual/.
[16] See www.certifiedforester.org.

section of the UTP Project Protocol to the requirements and guidance described in Sections 2 through 7 of the UTP Project Protocol.

This section of the protocol provides requirements and guidance for the verification of UTP Projects. This section describes the core verification activities and criteria that must be undertaken and addressed by a verification body in order to provide a reasonable level of assurance that the GHG removals or reductions quantified and reported by Project Operators are materially correct.

Verification bodies will use the criteria in this section to determine if there exists a reasonable assurance that the data submitted on behalf of the Project Operator to the Reserve addresses each requirement in the UTP Project Protocol, Sections 2 through 7. Project reporting is deemed accurate and correct if the Project Operator is in compliance with Sections 2 through 7.

Further information about the Reserve's principles of verification, levels of assurance, and materiality thresholds can be found in the Reserve's Verification Program Manual at http://www.climateactionreserve.org/how/program/program-manual/.

8.2 Project Verification Activities

Required verification activities for UTP Projects vary depending on whether the verification body is conducting an initial verification for registration on the Reserve, onsite verification, or an optional annual verification involving a desk review. The following sections contain guidance for all of these verification activities.

8.2.1 Initial Verification

Verifiers must ensure that the project has met the UTP Project Protocol criteria and requirements for eligibility, Project Area definition, additionality, quantification and calculation of baseline. The initial verification must include onsite verification. The verification body must assess and ensure the completeness and accuracy of all required reporting elements submitted in the Project Design Document.

8.2.2 Onsite Verification

Onsite verification involves review of the UTP Project's quantification, relevant attestations, soil carbon emissions associated with management activities, adherence to environmental and social safeguards (if applicable), and risk of reversal ratings. After a project's initial verification, subsequent site visits must assess and assure accuracy in measurement and monitoring techniques and onsite record keeping practices. Onsite verifications must be completed during the initial verification and for every fifth subsequent reporting cycle. That is, onsite verification is required every 5-years.

8.2.3 Optional Annual Verification

Optional annual verifications can occur according to preferences of the Project Operator. Credits can be verified and registered as the result of an optional annual verification. Optional annual verification occurs in the interim years between onsite verifications. The main focus of optional annual verifications is to assure that annual monitoring reports are complete and that reported project carbon inventories are within acceptable bounds, as described in the Quantification Guidance.

Table 8.1 displays the protocol sections that are verified at the initial verification, the onsite verification, and/or the optional annual verification.

Table 8.1. Verification Items and Related Schedules

Verification Items	Section of UTP Project Protocol	Initial	Site	Optional	Apply Professional Judgment[17]?
1. Project Definition	2.1 Urban Tree Planting	X			Yes
2. Urban Forest Owner	2.2 Urban Forest Owners	X	X		Yes
3. Project Operator	2.3 Project Operators	X	X		No
4. Project Implementation Agreement	2.4 Project Implementation Agreement	X	X	X	No
5. Project Location	3.1 Project Location	X			No
6. Project Area	3.2 Project Area	X			No
8. Project Commencement	3.3 Project Commencement	X			Yes
9. Additionality	3.4.1 Legal Requirement Test 3.4.2 Performance Test	X	X		Yes
	3.4.2.1 Performance Standard for Urban Tree Planting Projects	X			
10.Project Crediting Period	3.5 Project Crediting Period	X	X		No
11.Minimum Time Commitment	3.6 Minimum Time Commitment	X	X		No
12. Social and Environmental Co-Benefits	3.7 Social and Environmental Co-Benefits	X	X		Yes for public entities only
13. Social Co-Benefits	3.7.1 Social Co-Benefits	X	X		Yes for public entities only
14. Environmental Co-Benefits	3.7.2 Environmental Co-Benefits	X	X		Yes for public entities only
15. GHG Assessment Boundaries	4 GHG Assessment Boundaries	X	X		No
The verification topics below are linked to quantification requirements. The verification of project inventories is described in detail below this table. Verifiers shall assure that requirements associated with the references in this table have been satisfied and implement the specific guidance requirements for verifying inventories below.					
16. Quantifying Net GHG Reductions and Removals	5 Quantifying Net GHG Reductions and Removals 8.3 Verifying Carbon Inventories Urban Tree Planting Quantification Guidance	X	X	X	No
17. Urban Forest Protocol Baselines	5.1 Urban Tree Planting Baseline Urban Tree Planting Quantification Guidance: Baseline Development for Urban Tree Planting Projects	X			No
18. Permanence and Buffer Pool Contributions	6.1 Contributions to the Buffer Pool	X	X		No
19. Permanence and Compensating for Reversals	6.2 Compensating for Reversals 6.2.1 Avoidable Reversals 6.2.2 Unavoidable Reversals	X	X	X	No

[17] Verifiers must use professional judgment to verify protocol criteria which are not quantitative or can be measured completely with objective analysis.

8.3 Verifying Carbon Inventories

Verification bodies are required to verify carbon stock inventory calculations of all sampled and/or measured carbon pools within the Project Area. Inventories of carbon stocks are used to determine the project baseline and to quantify GHG reductions and removals against the project baseline over time. The method of verification of carbon inventories varies depending on whether the verification is part of the initial verification, onsite verification, or an optional verification. The verification elements and their periodicity are explained in this section.

Verification Item	Description	Verification Frequency
1 – Quantification of Carbon Estimates	Confirming that the methodology and requirements for quantifying carbon estimates specified in the Urban Tree Planting Quantification Guidance were implemented correctly and that the field measurements, use of biomass equations, and summary of project data meet minimum tolerance standards for accuracy, as part of onsite verification.	Initial onsite verification and every subsequent 5 years following initial onsite verification.
2 – Updated Data	Confirming that updated data are within acceptable bounds.	Optional, in years in between onsite verifications.

8.3.1 Verification of Urban Tree Planting Project Inventories

8.3.1.1 Office-Based Inventory Verification Activities

The verifier must progress through each successive step according to the guidance below. Verification activities may only proceed to field verification activities once the following items have been successfully verified:

1. Prior to verification of project inventories, **items 1 – 16** in Table 8.1 must be reviewed and deemed satisfactory by the verifier, both in terms of clear presentation and aligned with the protocol requirements.
2. Confirm that the **tree records** used in producing the project-level estimate of CO_2e are in a database, have latitude and longitude for each tree, and that the sum of individual CO_2e estimates for each tree equals the reported value for the project.
3. Confirm that the **confidence statistics** for canopy cover were correctly calculated and meet minimum requirements.

8.3.1.2 Field-Based Inventory Verification Activities

The verification effort must include a re-measurement of a subset of project data used to calculate the inventory estimate for the project. The data sampled by verifiers are individual trees. The verification strategy for all measured data is based on a comparison of randomly selected verifier measurements to Project Operator measurements in a process referred to as sequential sampling. Individual diameters (DBH) and total height must be measured for each tree. The minimum standards of measurement for verifiers are:

1. To the nearest inch for DBH measurements. DBH must be measured per the Urban Tree Planting Quantification Guidance.
2. To the nearest foot for height measurements.

Verification using the sequential sampling methodology requires the verification body to sequentially sample successive plots. Sequential approaches have stopping rules rather than fixed sample sizes. Verification is successful after a minimum number of successive plots in a sequence indicate agreement according to the tolerance thresholds established in the sequential sampling workbook. The evaluation of the three themes that utilize sequential sampling (CO_2e estimates from plots, current tree canopy area, and historical tree canopy area) shall utilize separate worksheets and include a copy of the results within the verification report.

Where sequential measurements from the verifier result in a trend of agreement with the Project Operator's data, as defined by established tolerance bounds, verification can proceed toward a finding of adequate accuracy. The number of trees measured by the verifier is based on stopping rules established by the Reserve. Where a high level of agreement is found between the Project Operator and the verifier, a finding of accuracy may be established with the minimal number of trees required by the Reserve. As variation between verifier estimates and Project Operators increases, the number of trees measured by the verifier must increase in order to work toward establishing a finding of accuracy. In cases where continued verifier effort does not result in agreement, the Project Operator must decide whether continued investment in verification effort is justified. Alternatively, verification can be suspended while the Project Operator improves the quality of the inventory and revises related project documentation.

The worksheet provided by the Reserve includes the established stopping rules. Where agreement between the verifier and the Project Operator is within specified tolerance bounds, verification of plot data is successful. For the field-based verification activities, the verifier must randomly select an initial set of 40 individual trees sampled by the Project Operator, maintaining the order of their selection in sequential order (1 – 40).

Verification Element	Description	Verification Frequency
1	**Measurement of Field Data**: The verifier must develop an initial strategy to efficiently visit the first 20 trees (1-20) in the list. The trees to not need to be visited and measured sequentially, but they all need to be visited prior to entering the data in the sequential sampling works. The verifier must measure the individual trees and calculate the CO_2e associated with each tree. The entries of tree summaries into the sequential sampling worksheet provided by the Reserve must be in the same order the trees were randomly selected.	Initial verification and each subsequent 5-year onsite verification.
2	**Data Quality Control**: Confirm that the tree records used in producing the project-level estimate of CO_2e are in a database, have latitude and longitude for each tree, and that the sum of individual CO_2e estimates for each tree equals the reported value for the project.	Initial verification and each subsequent 5-year onsite verification.
3	Confirm that the **confidence statistics** for canopy cover were correctly calculated and meet minimum requirements.	Initial verification and each subsequent 5-year onsite verification.

8.3.1.3 Optional Verification for Interim Years between Onsite Verifications

In the interim years between onsite verifications, OPOs can optionally have project stocks verified and receive credits. Verifiers shall compare current reported data with previously verified data and calculate if the reported data are within acceptable tolerance bounds. The tolerance bound is defined within 5% of the previous year's reported carbon stocks. Projects that utilize the optional verification must provide contribute 20% of the credits generated during the optional verification to a holding account. The holding account is reconciled to the project accounting in the reporting year that the project undergoes onsite verification. Data that are not within tolerance bounds must undergo the requirements for a 5-year onsite verification.

8.4 Completing the Verification Process

After completing the core project verification activities for a UTP Project, the verification body must do the following to complete the verification process:

1. Complete a verification report to be delivered to the Project Operator (public document).
2. Complete a detailed list of findings containing both immaterial and material findings (if any), and deliver it to the Project Operator (private document).
3. Prepare a concise verification statement detailing the vintage and the number of CRTs verified, and deliver it to the Project Operator (public document).
4. Verify that the number of CRTs specified in the verification report and statement match the number entered into the Reserve software.
5. Conduct an exit meeting with the Project Operator to discuss the verification report, list of findings, and verification statement and determine if material misstatements (if any) can be corrected. If so, the verification body and Project Operator should schedule a second set of verification activities after the Project Operator has revised the project submission.
6. If a reasonable level of assurance opinion is successfully obtained, upload electronic copies of the verification report, list of findings, verification statement, and verification activity log into the Reserve.
7. Return important records and documents to the Project Operator for retention.

The recommended content for the verification report, list of findings, and verification statement can be found in the Reserve's Verification Program Manual.[18] The Verification Program Manual also provides further guidance on quality assurance, negative verification statements, use of an optional project verification activity log, goals for exit meetings, dispute resolution, and record keeping.

[18] Available at http://www.climateactionreserve.org/how/program/program-manual/.

9 Glossary of Terms

Additionality	GHG emission reductions should occur as a result of specific GHG mitigation incentives; additionality is achieved when GHG reductions are beyond what would occur under business as usual operation and result from activities that are not mandated by regulation.
Allometric Equation	An equation that utilizes the genotypical relationship among tree components to estimate characteristics of one tree component from another. Allometric equations allow the below ground root volume to be estimated using the above-ground bole volume.
Avoidable Reversal	An avoidable reversal is any reversal that is due to the project operator's negligence, gross negligence, or willful intent, including harvesting, development, and harm to the project area.
Baseline	An estimate of GHG emissions and removals that would have occurred in absence of the project under business as usual operations.
Best Management Practices	Management practices determined by a state or designated planning agency to be the most effective and practicable means (including technological, economic, and institutional considerations) of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals.[19]
Biological Emissions	For the purposes of the UTP Project Protocol, biological emissions are GHG emissions that are released directly from forest biomass, both live and dead, including forest soils. Biological emissions are deemed to occur when the reported tonnage of onsite carbon stocks, relative to baseline levels, declines from one year to the next.
Biomass	The amount of living matter comprising, in this case, a tree.
Bole	The trunk or main stem of a tree.
Buffer Pool	The buffer pool is a holding account for urban forest project CRTs administered by the Reserve. It is used as a general insurance mechanism against unavoidable reversals for all UTP projects registered with the Reserve.
Business As Usual	The activities, and associated GHG reductions and removals that would have occurred in the project area in the absence of incentives provided by a carbon offset market.

[19] (Helms, 1998)

Carbon Pool	A reservoir that has the ability to accumulate and store carbon or release carbon. In the case of forests, a carbon pool is the forest biomass, which can be subdivided into smaller pools. These pools may include above-ground or belowground biomass or roots, litter, soil, bole, branches and leaves, among others.
Carbon Sink	A carbon sink is any process, activity or mechanism that removes carbon dioxide from the atmosphere.
Carbon Source	A carbon source is any process or activity that releases carbon dioxide into the atmosphere.
Carbon Stock	A pool of stored carbon. Urban forest carbon stocks include biomass of the project trees. Include living and standing dead vegetation, woody debris and litter, organic matter in the soil, and harvested stocks such as wood for wood products and fuel.
Carbon Stock Change or Carbon Sequestration	The annual incremental change in carbon stocks.
C_{emis}	CO_2 and other GHG emissions from project maintenance activities, for example, due to vehicular or equipment use.
C_{proj}	Project carbon, i.e. carbon stored annually in project trees, reported as CO_2.
Certified Arborist	An arborist meeting the criteria having passed the test given by the International Society of Arboriculture (http://www.isa-arbor.com/certification/index.aspx).
Certified Forester	A professional with certified forester credentials managed by the Society of American Foresters (see www.certifiedforester.org). See also, Professional Forester.
Certified Urban Forester	An urban forester meeting the criteria and having passed the test created by the California Urban Forests Council, and now administered nationally by the Society of American Foresters.
Climate Reserve Tonnes (CRT)	One metric ton (tonne) of verified CO_2 equivalent emission reduction or sequestration.
CO_2-equivalent (CO_2e)	The quantity of a given GHG multiplied by its total global warming potential. This is the standard unit for comparing the degree of warming which can be caused by different GHGs.
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.

Entity	The individual, organization, agency or corporation that owns, controls, or manages urban trees.
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. The Reserve assumes that the moisture content of fresh weight biomass is 30%.
Global Warming Potential (GWP)	Factors used to convert emissions from GHGs other than carbon dioxide to their equivalent carbon dioxide emissions.
Greenhouse gas (GHG)	Greenhouse gases mean carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).
GHG Assessment Boundary	The GHG Assessment Boundary defines all the GHG sources, sinks, and reservoirs that must be accounted for in quantifying a project's GHG reductions and removals.
Inherent Uncertainty	The scientific uncertainty associated with calculating carbon stocks and greenhouse gas emissions.
KML	KML (Keyhole Markup Language) is an XML based file format used to display geographic data in an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile.
Leakage	According to the Intergovernmental Panel on Climate Change: "the unanticipated decrease or increase in greenhouse gas benefits outside of the project's accounting boundary as a result of project activities."
Permanence	The requirement that GHGs must be permanently reduced or removed from the atmosphere to be credited as carbon offsets. For UTP projects, this requirement is met by ensuring that the carbon associated with credited GHG reductions and removals remains stored for at least 100 years.
Primary Effects	The project's intended changes in carbon stocks, GHG emissions or removals.
Professional Forester	A professional engaged in the science and profession of forestry. A professional forester is credentialed in jurisdictions that have professional forester licensing laws and regulations. Where a jurisdiction does not have a professional forester law or regulation then a professional forester is defined as having the certified forester credentials managed by the Society of American Foresters (see www.certifiedforester.org).
Project Activity	The carbon storage, emission reductions and emissions

	due to an urban tree planting project.
Project Area	The area inscribed by the geographic boundaries of a project.
Project Commencement (Project Commencement Date)	The commencement date is initiated by activities that increase carbon inventories and/or decrease emissions relative to the baseline.
Project Life	Refers to the duration of a project and its associated monitoring and verification activities.
Project Onsite Inventory	The inventory of trees eligible to generate emission reductions or removals in a project. Developed according to the guidelines in the Quantification Guidance.
Project Operator	One of the urban forest owners or a legally created entity to represent the urban forest owners that is responsible for undertaking a project.
Project Submission Date	The date that a project is submitted for listing in the Reserve program. The Reserve considers a project to be "submitted" when all of the appropriate forms have been uploaded to the Reserve's software system, and the project operator has paid a project submission fee.
Registered Consulting Arborist	An arborist meeting the criteria and having passed all the qualification requirements of the American Society of Consulting Arborists (http://www.asca-consultants.org/about/rca.cfm).
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.
Reporting Period	The time period for which an entity is reporting its project activity and quantifying GHG reductions. This period will typically be 12 months, except for 1) the initial reporting period which begins at the project commencement date and may be more than 12 months, and 2) the second reporting period, which may be less than 12 months.
Reversal	A reversal is a decrease in the stored carbon stocks associated with quantified GHG reductions and removals that occurs before the end of the project life. Under this protocol, a reversal is deemed to have occurred if there is a decrease in the difference between project and baseline onsite carbon stocks from one year to the next, regardless of the cause of this decrease (i.e. if the result of ($\Delta\ AC_{onsite}$ - $\Delta\ BC_{onsite}$) in Equation 5.1 is negative).
Secondary Effects	Unintended changes in carbon stocks, GHG emissions, or GHG removals caused by the project.
Sequestration	The process by which trees remove carbon dioxide from

	the atmosphere and transform it into biomass.
Start Date	See Project Commencement.
Tree	A woody perennial plant, typically large and with a well-defined stem or stems carrying a more or less definite crown with the capacity to attain a minimum diameter at breast height of five inches and a minimum height of 15 feet with no branches within three feet from the ground at maturity.[20]
Tree Residue	Aboveground biomass from urban trees (as distinguished from construction debris) that can be salvaged for reuse, such as mulch, wood products, or fuel for biomass power plant.
Unavoidable Reversal	An unavoidable reversal is any reversal not due to the project operator's negligence, gross negligence or willful intent, including windstorms or disease that are not the result of the project operator's negligence, gross negligence or willful intent.
Urban Area	The most recent Urbanized Area definition provided by the United States Census Bureau at http://www.census.gov/geo/maps-data/maps/2010ua.html.
Urban Forest Owner	A corporation, legally constituted entity (such as a utility), city, county, state agency, individual(s), or combination thereof that has legal control (e.g. right to plant or remove, etc.) of any amount of urban forest carbon within the project area.
Urban Tree Planting Project (UTP Project, project)	A planned set of activities designed to increase removals of CO_2 from the atmosphere, or reduce or prevent emissions of CO_2 to the atmosphere, through increasing and/or conserving urban forest carbon stocks. An urban tree planting (UTP) project involves new trees being planted in areas where trees have not been harvested with a primary commercial interest over the past 10 years prior to project commencement. This does not include harvesting where the primary concern is for human safety or forest health. Only planted trees and trees that regenerate from planted trees are eligible to be quantified for credits. Benefits from urban tree planting activities occur when the CO_2e associated with planted trees exceeds baseline tree planting CO_2e levels.
Verification	The process of reviewing and assessing all of a project's reported data and information by an ISO-accredited and Reserve-approved verification body, to confirm that the project operator has adhered to the requirements of this protocol.

[20] (Helms 1998)

Verification Cycle	The Reserve requires onsite verification of projects every five years, but project operators can choose to have more frequent 'desktop' verifications. In between site visits, desk reviews of project reports can be completed by an approved verification body. The Reserve will only issue CRTs for verified emission reductions.
Verification Period	The period of time over which GHG reductions/removals are verified. A verification period may cover multiple reporting periods. The end date of any verification period must correspond to the end date of a reporting period.

RESTORATION ECOLOGY

The global tree restoration potential

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The restoration of trees remains among the most effective strategies for climate change mitigation. We mapped the global potential tree coverage to show that 4.4 billion hectares of canopy cover could exist under the current climate. Excluding existing trees and agricultural and urban areas, we found that there is room for an extra 0.9 billion hectares of canopy cover, which could store 205 gigatonnes of carbon in areas that would naturally support woodlands and forests. This highlights global tree restoration as our most effective climate change solution to date. However, climate change will alter this potential tree coverage. We estimate that if we cannot deviate from the current trajectory, the global potential canopy cover may shrink by ~223 million hectares by 2050, with the vast majority of losses occurring in the tropics. Our results highlight the opportunity of climate change mitigation through global tree restoration but also the urgent need for action.

Photosynthetic carbon capture by trees is likely to be among our most effective strategies to limit the rise of CO_2 concentrations across the globe (*1*–*3*). Consequently, a number of international initiatives [such as the Bonn Challenge, the related AFR100, and the New York Declaration on Forests (*4*, *5*)] have established ambitious targets to promote forest conservation, afforestation, and restoration at a global scale. The latest special report (*1*) by the Intergovernmental Panel on Climate Change (IPCC) suggests that an increase of 1 billion ha of forest will be necessary to limit global warming to 1.5°C by 2050. However, it remains unclear whether these restoration goals are achievable because we do not know how much tree cover might be possible under current or future climate conditions or where these trees could exist.

Previous efforts to estimate global tree cover potential have scaled existing vegetation estimates to the biome or ecoregion levels to provide coarse approximations of global forest degradation (*6*, *7*). However, quantitatively evaluating which environments could support trees requires that we build models using direct measurements of tree cover (independent of satellite-derived models) from protected areas, where vegetation cover has been relatively unaffected by human activity. With enough observations that span the entire range of environmental conditions, from the lowest to the highest possible tree cover, we can interpolate these "natural tree cover" estimates across the globe to generate a predictive understanding of the potential tree cover in the absence of human activity.

To explore the determinants of potential tree cover, we used 78,774 direct photo-interpretation measurements (data file S1) (*8*) of tree cover across all protected regions of the world (fig. S1) (*9*, *10*). Using global environmental layers (table S1) (*11*), we examined how climate, edaphic, and topographic variables drive the variation in natural tree cover across the globe. The focus on protected areas is intended to approximate natural tree cover. Of course, these regions are not entirely free of human activity (*11*), presenting slightly lower tree cover than expected in some regions or higher tree cover than expected in other regions because of low fire frequency, but these ecosystems represent areas with minimal human influence on the overall tree cover. We then used a random forest machine-learning approach (*12*) to examine the dominant environmental drivers of tree cover and generated a predictive model (Fig. 1) that enables us to interpolate potential tree cover across terrestrial ecosystems. The resulting map—Earth's tree carrying capacity—defines the tree cover per pixel that could potentially exist under any set of environmental conditions, with minimal human activity (Fig. 2A). This work is directly underpinned by our systematic dataset of direct tree cover measurements (entirely independent of climate and modeled remote sensing estimates) (*13*) across the globe (fig. S1) (*10*).

Across the world's protected areas (fig. S2), tree cover ranged between peaks of 0% in dry desert and 100% in dense equatorial forest, with fewer values falling between these two extremes (figs. S2 and S3). We paired these tree cover measurements with 10 global layers of soil and climate data (table S1) (*11*). Our resulting random forest model had high predictive power [coefficient of determination (R^2) = 0.86; intercept = –2.05% tree cover; slope = 1.06] (Fig. 1); rigorous *k*-fold cross-validation (fig. S4A) (*11*) revealed that our model could explain ~71% of the variation in tree cover without bias (R^2 = 0.71; intercept = 0.34% tree cover; slope = 0.99) (fig. S3, B and C). Our *k*-fold cross-validation approach also allows us to generate a spatially explicit understanding of model uncertainty (figs. S5 and S6) (*11*). Across all pixels, the mean standard deviation around the modeled estimate is ~9% in tree cover (28% of the mean tree cover) (figs. S5 and S6) (*11*). As such, these models accurately reflected the distribution of tree cover across the full range of protected areas. We then interpolated this random forest model across all terrestrial ecosystems using all 10 soil and climate variables to project potential tree cover across the globe under existing environmental conditions.

The resulting map reveals Earth's tree carrying capacity at a spatial resolution of 30 arc sec (Fig. 2A). The model accurately predicts the presence of forest in all existing forested land on the planet (fig. S7A) but also reveals the extent of tree cover that could naturally exist in regions beyond existing forested lands. The most recent Food and Agriculture Organization of the United Nations (FAO) definition of "forest" corresponds to a land of at least 0.5 ha covered by at least 10% tree

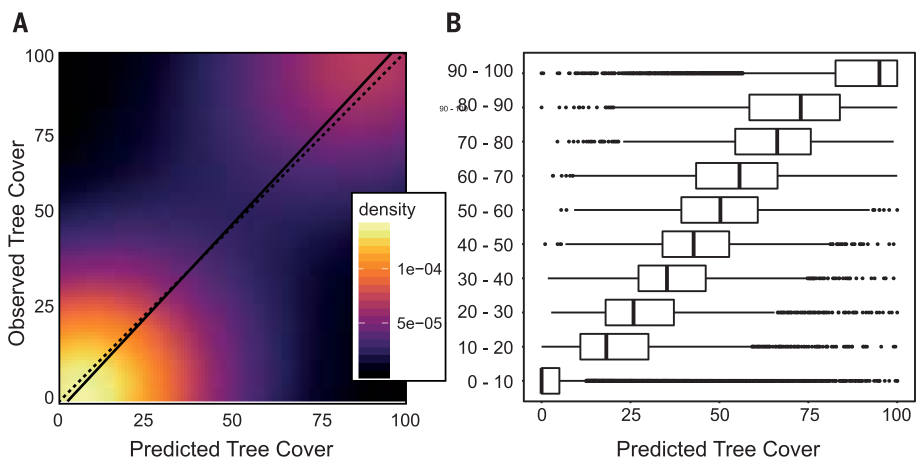

Fig. 1. Predicted vs. observed tree cover. (**A** and **B**) The predicted tree cover (*x* axes) compared with the observed tree cover (*y* axes). (A) Results as a density plot, with the 1:1 line in dotted black and the regression line in continuous black (intercept = −2% forest cover; slope = 1.06; R^2 = 0.86), which shows that the model is un-biased. (B) Results as boxplots, to illustrate the quality of the prediction in all tree cover classes.

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cover and without agricultural activity or human settlements (*14*). Using this definition, our map reveals that about two-thirds of terrestrial land, 8.7 billion ha, could support forest (table S2). That value is 3.2 billion ha more than the current forested area (fig. S7A) (*11*, *15*). We estimate that 1.4 billion ha of this potential forest land is located in croplands (>99%) and urban areas (<1%), as delineated by the European Space Agency's global land cover model (fig. S7B and table S2) (*16*), and 1.5 billion ha with croplands as delineated by Fritz *et al.* (fig. S7C and table S2) (*17*). Therefore, ~1.7 billion to 1.8 billion ha of potential forest land (defined as >10% tree cover) exists in areas that were previously degraded, dominated by sparse vegetation, grasslands, and degraded bare soils.

To avoid the pitfalls of categorical forest definitions, we also evaluated the tree canopy cover in a truly continuous scale (fig. S8). We refer to "canopy cover" as the area of the land that is covered by tree crown vertically projected to the ground (for example, 50% of tree cover over 1 ha corresponds to 0.5 ha of canopy cover) (fig. S8). By accounting for all levels of tree cover (from 0 to 100%), this approach balances the relative contribution of different forest types (such as woodlands, open forest, and dense forest) and of wooded lands outside forests (such as savannas) across the globe.

In total, 4.4 billion ha of canopy cover can be supported on land under existing climate conditions (pixel uncertainty = 28%; global uncertainty <1%) (table S2) (*11*). This value is 1.6 billion ha more than the 2.8 billion ha existing on land today (*10*, *15*). Of course, much of the land that could potentially support trees across the globe is currently used for human development and agriculture, which are necessary for supporting an ever-growing human population. On the basis of both the European Space Agency's global land cover model (*16*) and on Fritz and colleagues cropland layer (*17*), we estimate that 0.9 billion hectares are found outside cropland and urban regions (Fig. 2, B and C, and table S2) (*11*) and may represent regions for potential restoration. More than 50% of the tree restoration potential can be found in only six countries (in million hectares: Russia, +151; United States, +103; Canada, +78.4; Australia, +58; Brazil, +49.7; and China, +40.2) (data file S2), stressing the important responsibility of some of the world's leading economies. By comparing our country-level results to the commitments of 48 countries in the Bonn Challenge (*4*), we can provide a scientific evaluation of the country-level restoration targets. Approximately 10% of countries have committed to restoring an area of land that considerably exceeds the total area that is available for restoration (data file S2). By contrast, over 43% of the countries have committed to restore an area that is less than 50% of the area available for restoration. These results reinforce the need for better country-level forest accounting, which is critical for developing effective management and restoration strategies. Of course, it remains unclear what proportion of this land is public or privately owned, and so we cannot identify how much land is truly available for restoration. However, at a global scale, our model suggests that the global forest restoration target proposed by the IPCC (*1*) of 1 billion ha (defined as >10% tree cover) is undoubtedly achievable under the current climate. By scaling these forest area calculations by biome-level mean estimates of carbon storage (*18*, *19*), we estimate that vegetation in the potential restoration areas could store an

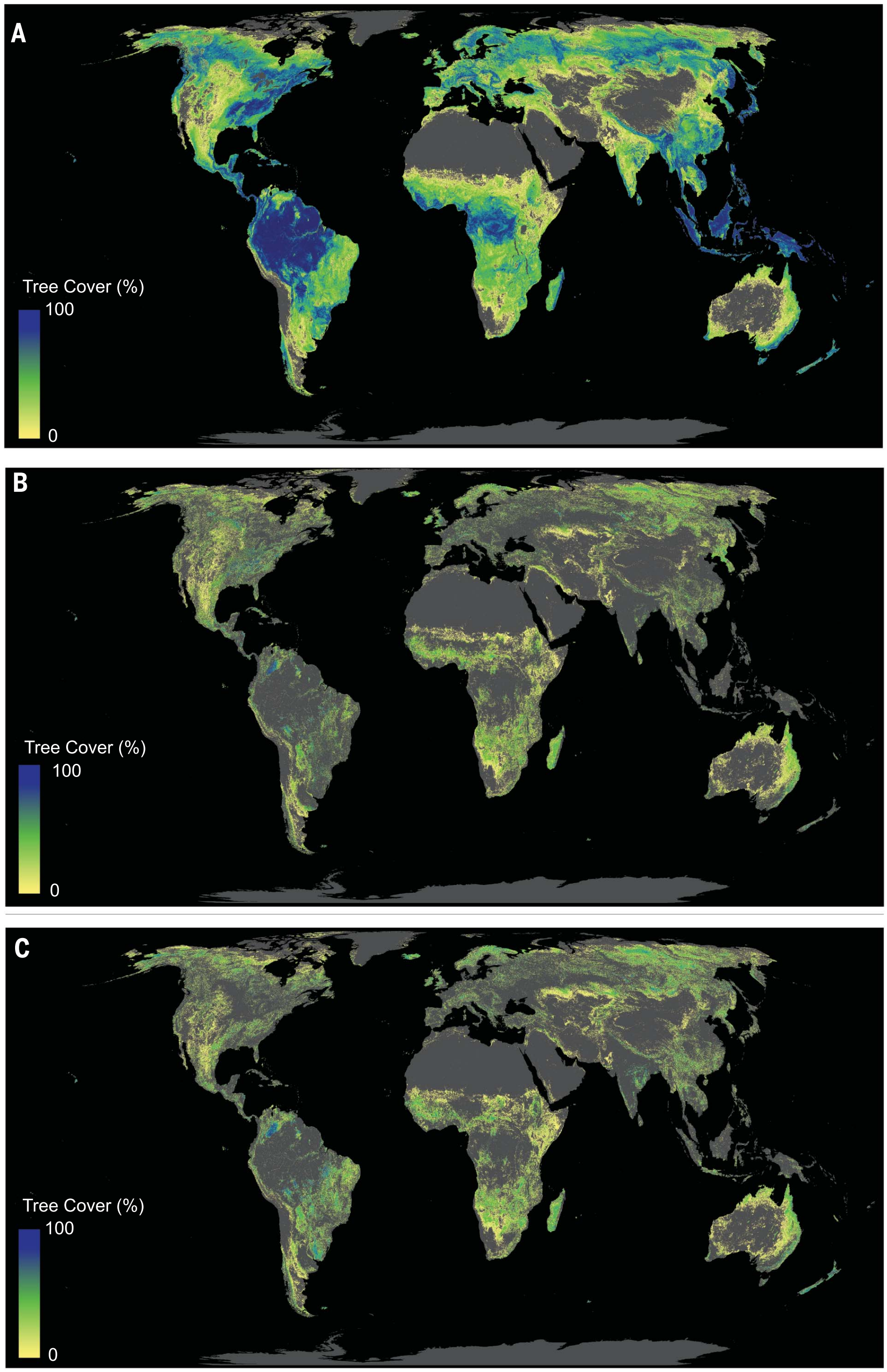

Fig. 2. The current global tree restoration potential. (**A**) The global potential tree cover representing an area of 4.4 billion ha of canopy cover distributed across the world. (**B** and **C**) The global potential tree cover available for restoration. Shown is the global potential tree cover (A), from which we subtracted existing tree cover (*15*) and removed agricultural and urban areas according to (B) Globcover (*16*) and (C) Fritz *et al*. (*17*). This global tree restoration potential [(B) and (C)] represents an area of 0.9 billion ha of canopy cover (table S2).

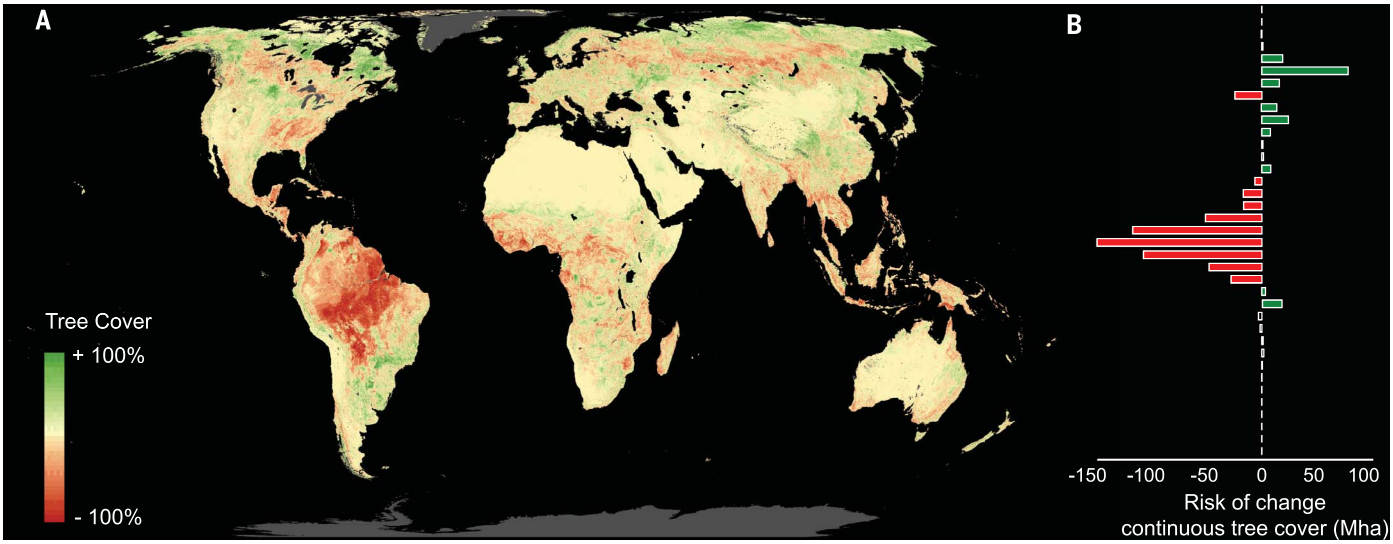

Fig. 3. Risk assessment of future changes in potential tree cover. (**A**) Illustration of expected losses in potential tree cover by 2050, under the "business as usual" climate change scenario (RCP 8.5), from the average of three Earth system models commonly used in ecology (cesm1cam5, cesm1bgc, and mohchadgem2es). (**B**) Quantitative numbers of potential gain and loss are illustrated by bins of 5° along a latitudinal gradient.

additional 205 gigatonnes of carbon (GtC) if they were restored to the status of existing forests (table S2).

Our model accurately depicts the regions where tree growth is possible under existing environmental conditions. However, changing climate conditions may alter the area of land that could support forest growth over the rest of the century, a point that needs to be considered when developing long-term restoration projects. We tested this possibility by rerunning our potential tree cover model under future climate conditions, projected under three Earth System Models (*10*) and two Representative Concentration Pathways (RCP) scenarios (RCP 4.5 and 8.5) (*1*). Under both scenarios, the global tree carrying capacity is lower than the present day potential because of reductions in the potential area of tropics. This is in stark contrast to most current model predictions, which expect global tree cover to increase under climate change (*20*). Although warming is likely to increase tree cover in cold regions with low tree cover (for example, in northern boreal regions such as Siberia) or with existing open forests (such as in tropical drylands) (Fig. 3), our model highlights the high probability of consistent declines of tropical rainforests with high tree cover. Because the average tree cover in the expanding boreal region (30 to 40%) is lower than that in declining tropical regions (90 to 100%), our global evaluation suggests that the potential global canopy cover will decrease under future climate scenarios, even if there is a larger total forest area with >10% tree cover. Therefore, despite potential increases in canopy cover in boreal (~130 Mha), desertic (~30 Mha), montane (~30 Mha), and temperate (~30 Mha) regions, the potential loss of forest habitat in tropical regions (~450 Mha) leads to a global loss of 223 Mha of potential canopy cover by 2050, corresponding to 46 GtC (Fig. 3B and table S3). Such risks of loss do not account for future changes in land use, such as pasture and cattle raising (*7*), which might also contribute to the urgency of the situation.

These models of future changes in tree cover potential reveal insights into how the structure of vegetation might change over time. Of course, these models are characterized by high uncertainty because, unlike the present-day interpolations, we rely on extrapolation of our machine-learning models outside of the existing range of global climate conditions. These extrapolations cannot be considered to be future projections of potential forest extent because they do not incorporate any of the ecological, hydrological, and biogeochemical feedbacks that would be associated with changes in forest cover. For example, it is possible that elevated CO_2 concentrations under future climate scenarios might enhance the growth of those existing trees, although recent evidence suggests that increased growth rate does not necessarily translate to increase of carbon storage (*21*). However, our approach has a strong predictive power to describe the potential tree cover in the absence of humans under any given set of future climate scenarios.

The global photointerpretation dataset offers the capacity to characterize the potential tree cover under any given set of environmental conditions. The resulting openly accessible map can serve as a benchmark map to assess restoration opportunities (such as tree planting and natural assisted regeneration) around the globe, with a tree cover of reference that respects the natural ecosystem type (for example, from wooded savannah to dense forest). However, restoration initiatives must not lead to the loss of existing natural ecosystems, such as native grasslands, that can support huge amounts of natural biodiversity and carbon. Using existing global land-cover layers (*15*–*17*), our maps reveal that there is likely to be space for at least an additional 0.9 billion ha of canopy cover. If these restored woodlands and forests were allowed to mature to a similar state of existing ecosystems in protected areas, they could store 205 GtC. Of course, the carbon capture associated with global restoration could not be instantaneous because it would take several decades for forests to reach maturity. Nevertheless, under the assumption that most of this additional carbon was sourced from the atmosphere, reaching this maximum restoration potential would reduce a considerable proportion of the global anthropogenic carbon burden (~300 GtC) to date (*1*). This places ecosystem restoration as one of the most effective solutions at our disposal to mitigate climate change.

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SUPPLEMENTARY MATERIALS

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Materials and Methods
Figs. S1 to S12
Tables S1 to S3
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Data Files S1 and S2

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The global tree restoration potential

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The potential for global forest cover

The restoration of forested land at a global scale could help capture atmospheric carbon and mitigate climate change. Bastin *et al.* used direct measurements of forest cover to generate a model of forest restoration potential across the globe (see the Perspective by Chazdon and Brancalion). Their spatially explicit maps show how much additional tree cover could exist outside of existing forests and agricultural and urban land. Ecosystems could support an additional 0.9 billion hectares of continuous forest. This would represent a greater than 25% increase in forested area, including more than 200 gigatonnes of additional carbon at maturity.Such a change has the potential to store an equivalent of 25% of the current atmospheric carbon pool.

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A Sustainability Initiative to Quantify Carbon Sequestration by Campus Trees

Helen M. Cox

Abstract

Over 3,900 trees on a university campus were inventoried by an instructor-led team of geography undergraduates in order to quantify the carbon sequestration associated with biomass growth. The setting of the project is described, together with its logistics, methodology, outcomes, and benefits. This hands-on project provided a team of students with several learning opportunities including an introduction to carbon sequestration, basic arboriculture, field-based measurements, mapping, geographic information systems, and biogeography concepts. A GIS geodatabase was produced containing information on tree location, species, size, biomass, carbon content, and annual CO_2 sequestration, which was later customized for integration into campus facilities management.

Key Words: *tree, GIS, carbon sequestration, sustainability, environmental education*

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Introduction

California is the twelfth largest emitter of carbon dioxide in the world (among all states and nations). Recognizing the effects of global warming, on September 27, 2006, Governor Arnold Schwarzenegger signed AB 32, the Global Warming Solutions Act, into law. This law sets the road map for California to reduce its greenhouse gas (GHG) emissions over the next fifty years with targets of a reduction to 1990 levels by 2020 (a 25% reduction in current levels) and to 80 percent below 1990 levels by 2050. Significant GHG sources are mandated to reduce emissions in accordance with this law, and even nonmandated entities can realize benefits by conducting a GHG inventory. These include tracking, verifying, and achieving organizational social responsibility goals, identifying opportunities to reduce waste and costs, and participating in GHG reporting programs and emission markets. In 2008 the Institute for Sustainability was formed at California State University, Northridge (CSUN), and embarked on a campuswide effort to conduct a GHG inventory.

A GHG inventory typically includes direct (Scope 1) emissions from mobile and stationary sources as a result of the combustion of fuels, and indirect (Scope 2) emissions incurred by utility companies as a result of the electricity consumed. So-called Scope 3 emissions incurred from business travel and commuting are sometimes included, but seldom is carbon sequestration from vegetation a component. However, in California, the Urban Forest Protocol established by the California Climate Action Registry (CCAR 2008) permits municipalities and educational campuses to offset carbon dioxide emissions by participating in forestry projects in which tree planting beyond normal replacement is planned and undertaken for the purpose of sequestering carbon dioxide from the atmosphere. In the interests of assessing the feasibility of such a plan, and to answer other interesting research questions—such as whether differences in CO_2 uptake by different species are significant enough to consider in making planting choices—an inventory of trees was initiated on the CSUN campus in spring 2009. The inventory data were utilized in carbon sequestration calculations to compute the carbon offset afforded by the trees and to analyze their relative contributions.

The trees that sequester the most carbon dioxide from the atmosphere are those that grow the most rapidly. Trees grow through the process of photosynthesis, whereby they take in carbon dioxide and water from their environment and use sunlight to process these into glucose, releasing oxygen as a byproduct. Cellulose is formed by the tree when it links up chains of the glucose molecules. The carbon stored in their woody mass is released back to the atmosphere when the tree dies unless it becomes buried underground. The amount of carbon stored by a tree depends on its species (since all trees have slightly different chemical compositions), but roughly 50 percent of the tree's dry weight, or 25 percent of its fresh (wet) weight is carbon (Lieth 1963). Since each carbon molecule combines with two oxygen molecules to form carbon dioxide, the mass of carbon dioxide sequestered during growth or produced during decay is 3.6 times that of carbon alone. Thus the amount of carbon dioxide consumed by a tree during growth, or produced upon decay, is roughly 1.8 times its dry weight or 0.9 times its fresh (wet) weight. Most trees sequester carbon at the highest rate during the mid to later phase of their life. At a very young age, even though they are growing rapidly, their size is too small to account for much mass growth. At maturity, the rate of growth slows and thus the carbon sequestration rate diminishes. Eventually the tree reaches its maximum size, and carbon sequestration ceases.

Benefits of Study

Although the tree inventory was originally conceived as part of the carbon footprinting process, it is also closely aligned with the other goals of the Institute for Sustainability and the university, namely education and research. The project, undertaken by a professor (the author) and team of students in the geography department, afforded a unique educational opportunity for students to learn about research methods, field measurements, mapping, and biogeography. In addition students gained valuable experience in geographic information systems (GIS), carbon calculations, and project management. This project covered three types of environmental education—education *about* the environment (tree types and benefits, carbon sequestration), education *in* the environment (field-based measurements and mapping), and education *for* the environment (to select and place appropriate trees) (Vowless 2002).

In educating *about* the environment, students were introduced to the many benefits of trees, including social ones (Gold 1976; Akbari 2002). TreePeople (2010) provided instructional material and data on other benefits including shade, energy reductions for cooling in summer, reduction of stormwater runoff, erosion control, pollutant removal, and habitat provision for many insects, birds, and animals. Students were challenged to think about the role of nature in their lives, and encouraged to engage in further biogeographical research. This research has included one thesis project to look at the native distributions of the tree species found on campus and another in which the role of trees in mitigating the urban heat island effect is being examined.

Educating *in* the environment includes the use of field methods. In addition to fieldwork, students were involved in the GIS mapping of tree locations and beginning students learned new skills such as the joining of tabular data to locational data using unique keys, database management in a shared environment, and the use of metadata for documentation. GIS is well known to meet many educational goals including supporting the inquiry process, facilitating learning across a range of subjects, and increasing motivation (Audet and Abegg 1996; National Research Council 2006; Hagevik 2008).

Educating *for* the environment includes an analysis of the carbon sequestration benefits of trees, and the exploration of what-if analyses through the creation of a database and tool, which allows students to study the carbon benefits of alternative scenarios. Students were challenged to think about the factors that should be considered in the selection of tree species for planting, including their water consumption, native climate, the habitat they provide, their ability to provide shade, their rate of growth, maintenance requirements, and practicality in a campus setting. In one project they were asked to recommend tree selections for the campus based on their findings.

The campus community in general also benefitted from one end product, an interactive tree atlas, that provides a botanical guide to all the trees on campus and information on carbon sequestration. The guide describes the process by which CO_2 is removed from the atmosphere and stored by trees, together with specific amounts of carbon sequestered by each tree annually and how this is computed.

The tree inventory served other purposes—it produced a database for physical plant management use in tree maintenance; provided data for facilities management to utilize in campus planning; has been incorporated into self-guided and educational tour maps; and has been used by university advancement to locate memorial trees. The GIS database was expanded to facilitate tree management and maintenance by the addition of data fields for storing dates, tree condition, and comments.

Study Area

The CSUN campus is located in the San Fernando Valley northwest of Los Angeles. Fifty years ago the Valley was a rich farming region producing fruit and vegetables for Los Angeles and the surrounding districts. Today one of last vestiges of this agricultural history is a small orange grove preserved on the southeast corner of the CSUN campus. The San Fernando Valley has become a vast (260-square-mile) area of urban sprawl supporting multiple industrial, manufacturing, and service activities. Although there are suburban neighborhoods around the campus providing pockets of greenery, urban land cover dominates the proximate area. The campus itself is relatively green, containing large expanses of lawn, shrubbery, and over 3,900 trees on its 353 acres.

The campus enjoys a Mediterranean climate characterized by hot, dry summers and mild, wet winters with an average summer maximum temperature of 32°C, and average winter minimum temperature of 6°C. The average annual precipitation is 14.5 inches, with 90 percent falling between November and April. Vegetation native to the region includes chaparral, sagebrush, and oak woodland. Although native trees supported in Southern California include maple (*Acer*), alder (*Alnus*), fir (*Abies*) and pine (*Pinus*), at the elevation of the university campus native tree species are restricted primarily to ash (*Fraxinus*), sycamore (*Platanus*), cottonwood (*Populus*), cherry (*Prunus*), oak (*Quercus*), and willow (*Salix*). Although the campus includes some native trees, the majority are ornamental.

Project Description

A plant atlas was produced by the CSUN geography department (Gohstand 1989) in 1989 after almost a decade of mapping by students and faculty. The atlas included locations and identification of all vegetation on campus including shrubbery. However, the 1994 Northridge earthquake rendered this outdated only a few years after its publication. Since then the easy accessibility of digital data including high resolution imagery and CAD (computer-aided design) building data, together with the massive expansion in GIS technology, prompted the production of a new atlas in an electronic format.

Between March and September 2009 an instructor-led group of geography students, tagged, mapped, measured, and identified over 3,900 trees on the CSUN south campus. They recorded data in a spreadsheet and mapped tree locations on an aerial image in the field. Tree identification (genus and species) was carried out with the aid of botanical guides, books, staff, faculty, and alumni. Carbon sequestration calculations employed an algorithm from the CUFR (Center for Urban Forest Research), a branch of the U.S. Forest Service (CUFR 2008), and were subsequently incorporated in the tree geodatabase, together with data fields for recording maintenance information. Interactive and printed versions of the atlas were produced, and the GIS geodatabase was handed over to campus facilities staff for management and updates. The carbon sequestration computations were incorporated in the university's GHG inventory.

Methodology

Fieldwork and Mapping

To facilitate mapping, the campus was divided into twenty-five quads, each containing roughly one to two hundred trees. Twelve students from the geography department were recruited to participate in the mapping, and divided into groups of two or three for fieldwork. Each group was supplied with a dbh (diameter at breast height) calibrated measurement tape, numbered aluminum tree tags, nails, wire, a hammer, an aerial photo of the quad, and a data entry sheet. The tree tags, lightweight aluminum nails (minimally damaging to trees), and dbh tape were obtained from a forestry supplier, and used to tag, number, and measure the diameter of the trees. For trees less than six inches in diameter, tags were wired rather than nailed. Measurements of tree diameter were made at a height of 4.5 ft., and each individual stem of multistemmed trees was recorded. The method for measurement follows that of the U.S. Forest Service (2005). While one team member conducted the size measurement, other members of the team identified tree species (when able), marked the tree's precise location and tag number on an aerial photo, and recorded dbh and species on a spreadsheet.

In carrying out the fieldwork, the primary challenges that the students encountered were carrying everything they needed while keeping it all accessible; handling multistemmed trees in an efficient manner; gaining access to trees when overgrown shrubbery was present or trees had sharp or prickly foliage; and identifying species. The first problem was addressed by using tool belts and/or using student groups of three rather than two. To address the second problem, which was particularly common in the campus's orange grove of almost six hundred multistemmed trees, a compromise was made in the measurement method and students were instructed to measure the tree below the point at which it became forked, rather than measuring each stem individually. Although this does not strictly follow the U.S. Forest Service guidelines, computations indicated that the differences in equivalent diameter were very minor. Boots and gloves were used to access areas within prickly foliage. The problem of identifying species was one that was postponed for the most part to a second round of surveying by students with botanical knowledge, and experts on and off campus who volunteered their time.

Another implementation decision made was the utilization of a high resolution aerial photograph of the campus to map tree locations rather than the use of a global positioning satellite (GPS) unit. Accurate mapping (within a meter or better) by GPS requires a high caliber unit, the reception of signals from multiple satellites, and postprocessing capability using differential correction data. On-campus buildings make reception difficult, but an even more significant problem in tree mapping is the blockage of the GPS signal by the tree canopy. Even if a high-precision unit is used, a separate antenna must be mounted on a rod long enough to penetrate through the tree canopy in order to receive the GPS signal. Campus surveyors found it necessary to install a roof-mounted base station for precise mapping on campus and so this method was rejected in favor of marking locations on printed maps generated from a high resolution georeferenced aerial image. Although free downloadable one-meter National Agriculture Imagery Program imagery (NAIP 2005) provided an adequate base map, the project benefitted from an eight-inch resolution aerial image of the campus taken by a contracted flight in summer 2009, which aided in the precise positioning of trees because of its high resolution and accuracy (recentness).

Field data were recorded electronically on spreadsheets in the lab and tree location data from the marked-up aerial image were recorded in a GIS. Spreadsheet data from all quads were "joined" to the point location data within a GIS, using the tag number as the "join" (common) field. The GIS geodatabase was then used to generate a series of printed maps, highlighting those trees that lacked species identification. With the aid of a reference book (Hatch 2007), species identification was undertaken by four students and an alumnus over the following two-month period. Where students were unable to identify species in the field they took photographs and collected leaves that were brought back to the lab. Reference books, online databases (Hickman 1993; USDA 2010), and knowledgeable staff, alumni, and faculty helped in identification. A complete quality check was carried out in fall 2009 to address tree location misplacements, misidentifications, and missing tags. After completion, the tree geodatabase was corrected and exported back into an Excel spreadsheet format in order to execute the carbon calculations.

Carbon Sequestration Calculations

The Center for Urban Forestry Research Carbon Tree Calculator (CCTC) software available from the U.S. Forest Service (CUFR 2008) facilitated the carbon sequestration calculations. This is a free, downloadable application programmed in an Excel spreadsheet that provides a menu-driven interface to determine carbon uptake and storage for a variety of trees in different climate zones, and is the only tool approved by CCAR for quantifying carbon dioxide sequestration from tree planting projects.

Computations of carbon dioxide sequestration rates can vary greatly depending on assumptions made about tree growth rates, which depend significantly on climate and irrigation. The CCTC software used in this analysis bases growth rates on species, age (or size) of tree, and climate.

In these computations tree volume is first estimated from dbh using empirical species-specific volumetric equations from Pillsbury, Reimer, and Thompson (1998) and Lefsky and McHale (2008), e.g., for *Quercus ilex*:

$$V = 0.0283168466\left(0.025169\left(\frac{\text{dbh}}{2}\cdot 54\right)^2\cdot 607285\right)$$

where V is in m^3 and dbh is in cm. Volume is then converted to dry weight or fresh weight biomass through multiplication by density and by a factor of 1.28 to account for below ground biomass (Husch, Miller, and Beers 1982; Tritton and Hornbeck 1982; Wenger 1984). Once the total biomass is estimated, carbon storage can be computed assuming 50 percent of dry weight, or 25 percent of fresh weight, is carbon. The CCTC volumetric equations were based on trees grown in a forest setting, but adjusted by a factor of 0.80 because open-grown urban trees tend to be less massive (Nowak 1994).

To compute tree growth rates, the CCTC software uses regression to fit empirical data on 650–1,000 street trees from six different reference cities. For each city, samples of 30–60 trees from each of the most abundant species in the city were employed. Linear and nonlinear regression equations were fitted to dbh as a function of age for each species in each city, and then employed in predictive models (Peper and McPherson 2003). These models form the basis of the growth and sequestration rate estimates.

The embedded models do not cover the full spectrum of species found on campus, thus it was necessary to construct a look-up table in which each species found in the field was modeled by one available in the software. Using reference material, students classified campus trees into leaf/species types (broadleaf, conifer, or palm and deciduous or evergreen) and size (small, medium, or large at maturity) and selected a representative species for each type and size among those available.

The menu-driven interface of the CCTC software provides ease of use for single tree entry but is cumbersome for application to some 3,900 trees. Unfortunately the CCTC software is also protected, preventing edits to the embedded source code. To work around this limitation, a macro was programmed in Visual Basic within a separate Excel workbook, which iterated through the hundreds of tree records one at a time, each time calling the CCTC application that was running in a separate instance of Excel. After each call to the CCTC spreadsheet, the output was captured and moved into a location in a separate worksheet where it would not be overwritten by the subsequent iteration through the tree records. The computation for all 3,900 trees took several hours to complete on a desktop PC.

Data Output

Once the carbon sequestration calculations were completed, the tree records were exported to the geodatabase and rejoined to tree location data in a GIS. A flow chart detailing the general steps in the project is shown in Figure 1.

In order to provide online access for users without GIS software, the tree dataset was exported to a .kml format for display in free downloadable applications like Google Earth (2010). The .kml file is posted on the university's Web site for download or can be viewed on the Web site directly within the browser (CSUN 2011). Clicking the mouse on a tree symbol immediately displays a pop-up window showing its attributes, including size, species, carbon content, and CO_2 sequestration rate (Fig. 2).

Findings

The project took approximately 1,000 hours of student labor to tag, measure, map, identify, and carry out the GIS work for the 3,900 trees. The fieldwork accounted for roughly 750 hours of this, or five trees per student-hour. This rate is misleadingly slow because trees were surveyed by teams of students, so the actual rate was about three times this (approximately four minutes per tree). The other 250 hours were spent on GIS tasks, quality control, and species identification. Approximately 200 hours of additional time was spent in project management and carbon calculations. Initial miscommunication between project staff and the ground staff led to a number of tree tags being removed, which necessitated additional inspections and tagging. A small amount of vandalism of tags has also occurred. The following provides a summary of the data.

The CSUN campus is home to over two hundred different species of trees in the southern (academic buildings) portion of campus, an area of some 250 acres. The north campus, which houses the student dormitories, was not included. Some 3,900 trees were tagged, mapped, and measured, and of these, only twelve (all exotic species within the botanic garden) are currently unidentified.

The most common species on campus is the Valencia orange (*Citrus sinensis 'Valencia'*) of which there are almost six hundred examples, a remnant of the Valley's agricultural past. The second and third most common species on the campus are the Canary Island pine (*Pinus canariensis*) and the Mexican fan palm (*Washingtonia robusta*), with approximately two hundred examples of each, followed by coast live oak (*Quercus agrifolia*), Deodar cedar (*Cedrus deodara*), crape myrtle (*Lagerstroemia indica*), and bottle tree (*Brachychiton populneum*), each with over a hundred examples.

The most common native trees on campus are the coast live oak (*Quercus agrifolia*) and California sycamore (*Platanus racemosa*). Other Southern California natives can be found on the campus but in smaller numbers, primarily

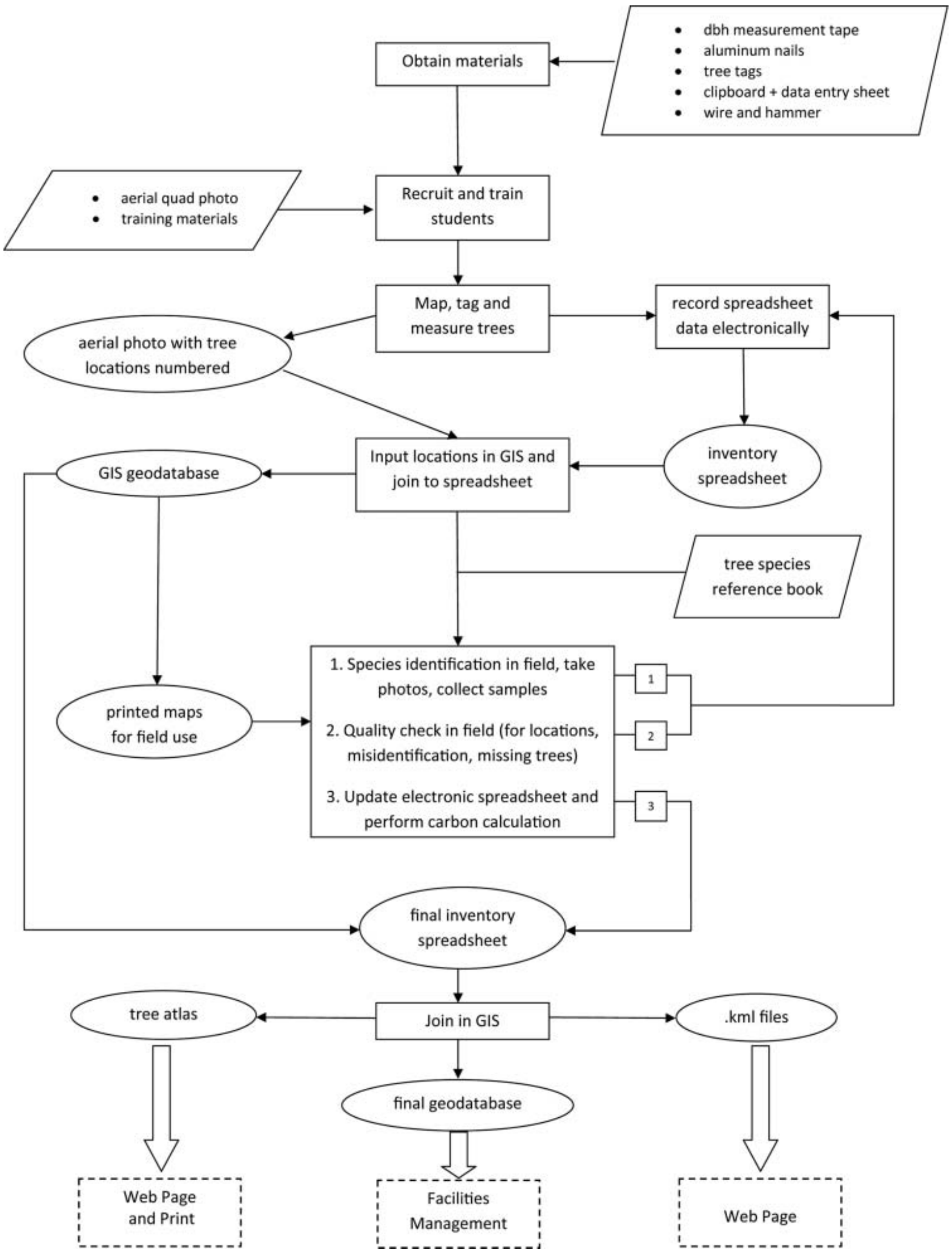

Figure 1. Flow chart showing the tree inventory process using a GIS and spreadsheet-driven CCTC carbon calculator.

The largest (by diameter) trees on the CSUN campus are two chinaberries (*Melia azedarach*) with dbhs of 54 and 62 inches, and an aleppo pine (*Pinus halepensis*) with a dbh of 58 inches. Most trees have dbhs between 5 and 15 inches, with a mean overall value of 11.4 inches and a median of 9.2 inches. A histogram of tree dbhs is shown in Figure 3.

From a carbon sequestration standpoint, those trees that sequester the most carbon dioxide from the atmosphere are those that grow (by volume) the most rapidly. Large trees such as eucalyptus (*Eucalyptus)*, cedar (*Cedrus*), plane, or sycamore (*Platanus*) can sequester carbon dioxide at a rate of between 300 and 550 kg/yr each. For the first few years of life, trees less than ten inches in diameter sequester only up to about a tenth of this. Many smaller trees (e.g., jacaranda (*Jacaranda*), yew pine (*Podocarpus macrophyllus*), carrotwood (*Cupaniopsis anacardioides*)) sequester carbon dioxide at a maximum rate of about 25 kg/yr, whereas medium-sized trees (e.g., camphor (*Cinnamomum camphora)*, carob (*Ceratonia siliqua)*, magnolia (*Magnolia*)) sequester at a maximum rate of 70–150 kg/yr. There is significant variation from species to species. Figures 4 and 5 show the computed carbon sequestration amounts in kg CO_2 per year, and a map of the distribution of these over part of campus.

The typical (median) campus tree sequesters about 10 kg CO_2 per year, has an estimated height of 24 feet and an aboveground dry weight of about 100 kg. It stores roughly 65 kg of carbon including its biomass, and upon decay or combustion will release 235 kg of carbon dioxide into the atmosphere. The total carbon dioxide sequestration for all the trees on campus is computed to be 154 tonnes per year, an average of 40 kg per tree.

It is useful to consider this number in the context of carbon dioxide emissions. Annual U.S. per capita emissions (for 2006) were 19.3 tonnes (CAIT (Climate Analysis Indicators Tool) 2010). Thus campus trees offset the emissions of eight typical U.S. residents. In 2006 CSUN reported total CO_2 Scope 1 and 2 emissions of 22,640 tonnes. Thus

other species of oak (*Q. engelmannii, Q. ilex, Q. kelloggi, Q. laurifolia, Q. lobata, Q. suber*), white alder (*Alnus rhombifolia*), hollyleaf cherry (*Prunus ilicifolia*), ash (*Fraxinus velutina, F. uhdei),* and walnut (*Juglans californica*). Native trees were cleared when the area was developed for agriculture and for the planting of the first citrus orchards in the mid-to-late nineteenth century. These orchards were later cleared when the campus was developed in 1958, and ornamental trees typical of those from the Mediterranean and Australia, which do well in the southern Californian climate, were planted.

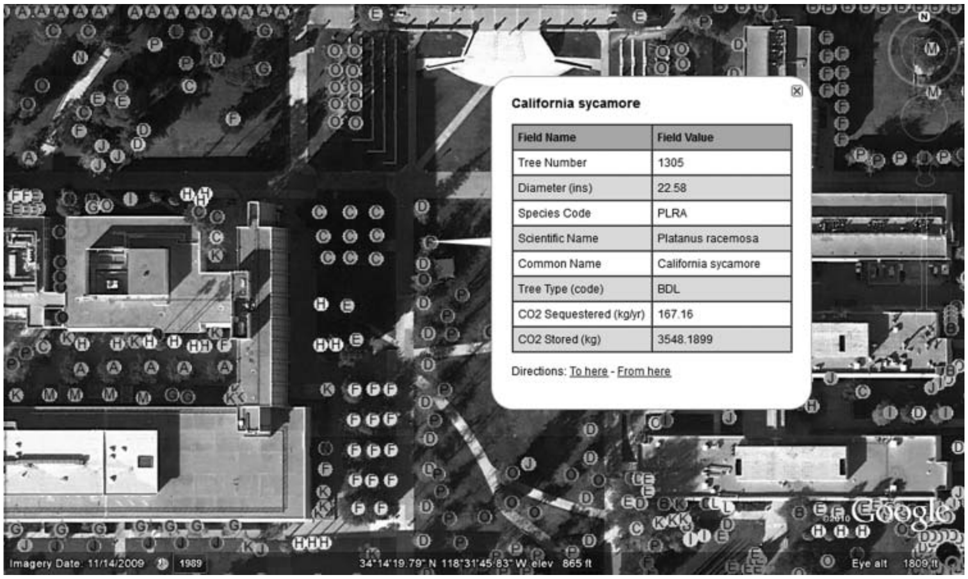

Figure 2. Web browser image of Google Earth plug-in showing pop-up window with selected tree information.

sequestration by trees can offset less than one percent of this. An average CSUN student emits roughly one tonne of carbon dioxide per year in commuting to the campus (CSUN 2010), so campus trees offset the commutes of approximately 150 students—a small fraction of the roughly 35,000 student commuters.

DISCUSSION

Carbon Sequestration

Carbon sequestration amounts presented above are based on (volume) tree growth rates. From these, the mass growth per year can be computed using data on the density and the chemical composition of the woody material (Sedjo 1989; Lamlom and Savidge 2003). The uncertainty in sequestration rates stems primarily from the variability of growth rate between and within species. These are based on three parameters—species, climate zone, and diameter (dbh) (Pillsbury, Reimer, and Thompson 1998). The U.S. Forest Service used six reference cities in California, each representative of a different climate zone. For the CSUN campus the South Coast and Valley climate zone is represented by Santa Monica (McPherson *et al.* 2001). Because Santa Monica is a coastal location it is cooler and wetter than Northridge; however, campus growth rates may exceed the samples because of warmer weather and ample irrigation. As mentioned earlier, the CTCC growth curves for each city are derived from field samples using regression. One significant limitation encountered is that only 10 percent of our species are represented in the sample trees, and thus it was necessary to map each species to the closest CTCC equivalent (by type and growth rate). This leads to uncertainty in the calculated carbon sequestration rates.

Another factor contributing to error is that growth of each species is terminated at a maximum size—determined by the largest sample tree encountered in the study. Many trees

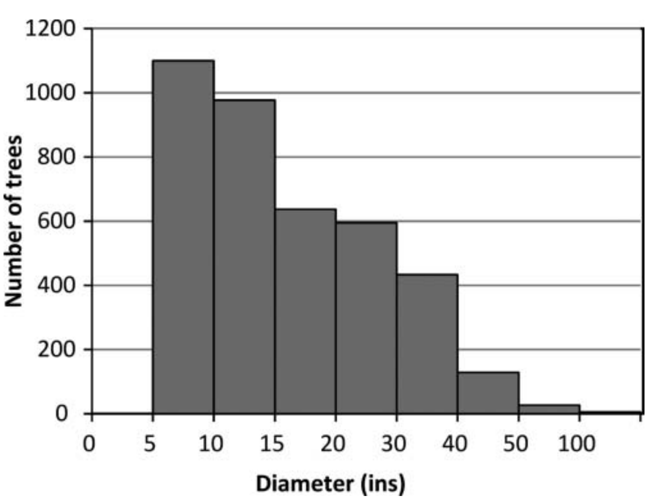

Figure 3. Histogram of tree diameters on campus.

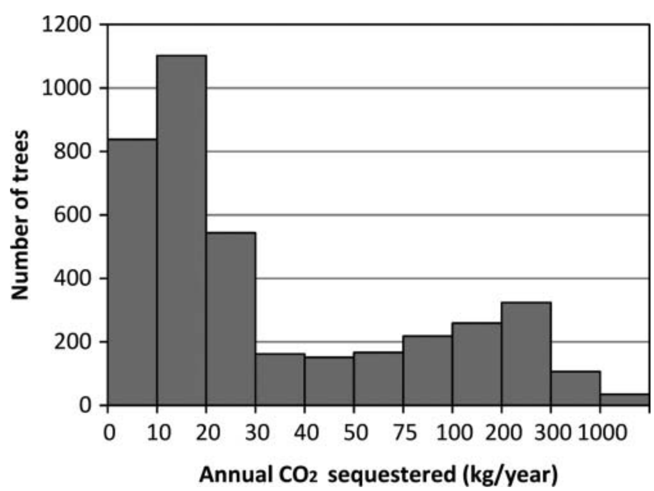

Figure 4. Histogram of computed annual carbon sequestration amounts (kg CO_2/yr).

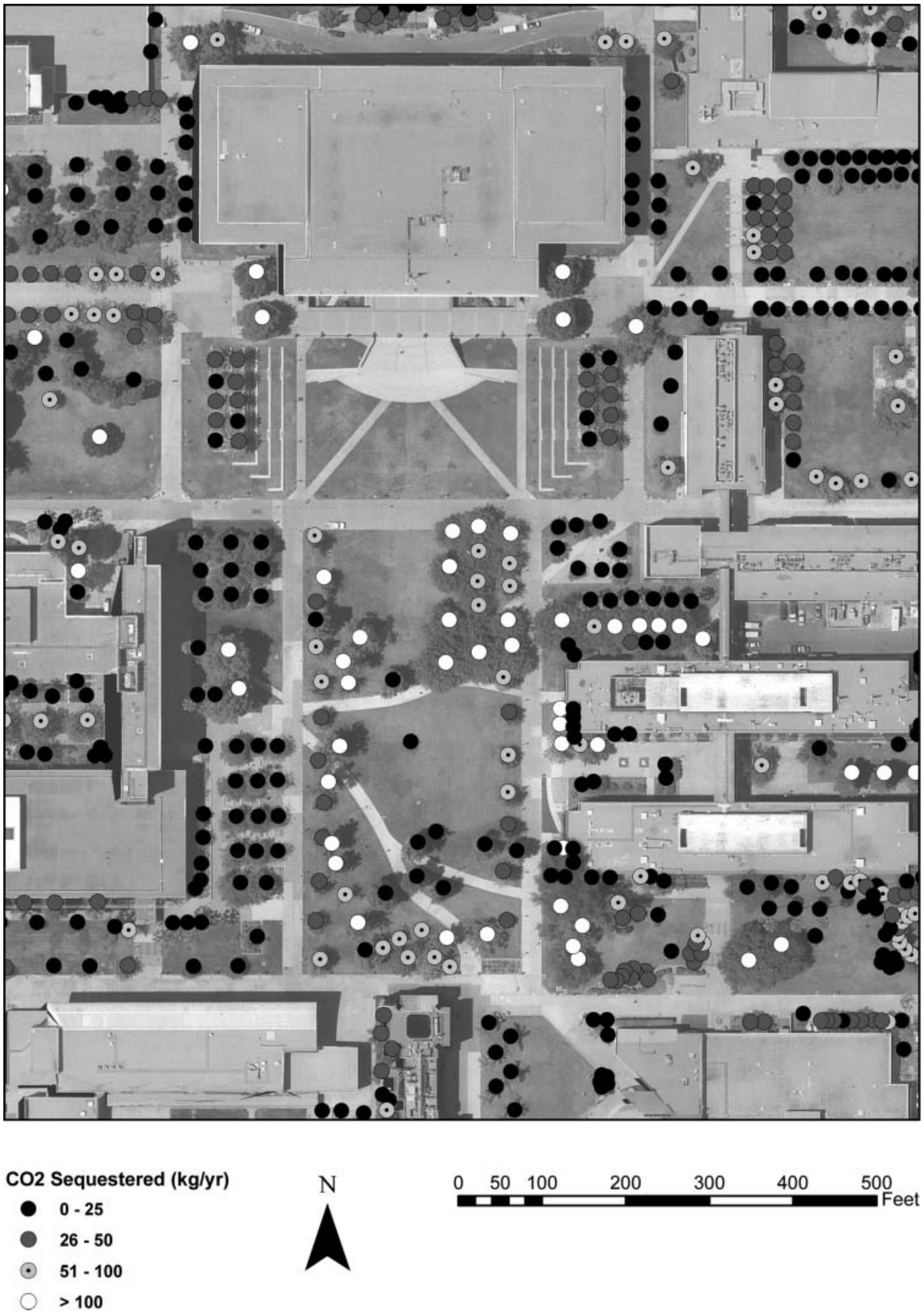

Figure 5. Map of annual CO_2 sequestration rates on campus.

on campus exceed this maximum and are thus assumed to have stopped growing. This is likely to lead to an underestimate of carbon uptake.

In order to set an upper boundary on sequestration rates, the calculations were repeated assuming all trees grow like *Eucalyptus ficifolia* (the fastest growing in the model). This calculation yielded a total carbon dioxide uptake of 320 tonnes per year, a factor of two greater than the estimate given above. Most of this difference results from the projected uptake rate for large trees—particularly those with a diameter greater than two feet—that may have stopped growing if they have reached maturity, or may be consuming carbon dioxide at rates as high as or higher than 300 kg/year if they are still growing. Without the availability of data on mature trees such as these, there will remain considerably uncertainty in the computed value.

It is instructive to compare our results with those of an inventory of 4,051 trees conducted at Eastern Illinois University (EIU 2011) where biomass was estimated in much the same manner, using regression equations based on dbh and species. Carbon content and CO_2 sequestration were derived from these biomass estimates. At EIU, the total dry weight biomass of the trees was calculated to be 2,310 tonnes (570 kg/tree) with a carbon content of 1,591 tonnes and total lifetime CO_2 sequestration of 5,828 tonnes (3.67 times the carbon content). This compares to our dry weight biomass total of 1,725 tonnes (442 kg/tree), carbon content of 862 tonnes, and total CO_2 sequestration of 3,170 tonnes. Biomass estimates (per tree) are thus about 22 percent smaller for our campus. This is not surprising as our campus is much younger and has many new plantings so trees are likely to be less mature. This, coupled with the difference in climate and species on the two campuses, suggests that the results are compatible. However, the carbon (and CO_2) contents are disproportionately different (393 kg/tree at EIU compared to 221 kg/tree at CSUN). Communication with the authors at EIU indicate that they employed the same factor of 50 percent for the carbon content of wood as utilized in the study presented here and based on data for forty-one North American species, which gave a range for these of 46–55 percent (Lamlon and Savidge 2003). Thus the reason for the larger difference in carbon content may be a result of differences in the way that EIU treated wet weight to dry weight conversions or aboveground biomass to total biomass.

Trees indirectly reduce CO_2 emissions through their shading effects (McPherson *et al.* 1999, 2001), and when planted within forty feet or so of buildings can provide a significant reduction in summer cooling costs, particularly for south-facing rooms. The use of well-positioned deciduous trees allows sunlight to reach buildings during winter when additional light and heat may be desirable but shade them during summer (Heisler 1986). The CCTC software can be employed to estimate energy savings from the shading effects of trees, and from this the savings in carbon dioxide emissions computed based on the fuel mix of the local utility provider.

Carbon offset programs may benefit from faster growing trees, but a decision about which trees to plant should be based on a number of criteria including the nature and purpose of the tree (to provide shade, beautify, provide habitat, attract pollinators, etc.), whether or not it is native, the space available, maintenance requirements, water availability, and cost (CUFR 2010). Over the past decade, the paradigm has shifted from a focus on beautification to one that encompasses all the environmental and social benefits of trees (McPherson 2006). Although carbon sequestration should be included in this list as a factor in decision making, there are also problematic issues associated with the planting of fast growing trees for carbon offsets including the possibility of monoculture plantations and the introduction of invasive species (Suzuki 2011).

Learning Experience

Although the tree inventory project (Venkateswaran 2009) was initially directed at quantifying the carbon footprint of the campus, the project addressed the university's sustainability and educational objectives by providing a hands-on learning environment for students. For many students it fostered an interest in sustainability, as they learned about carbon emissions and sequestration, and the project exposed them to the basics of arboriculture and biogeography. As in other field-based GIS projects, students were appreciative of the opportunity to learn new techniques (Carlson 2007). Because the project was not designed as a learning tool in geography, the learning was for the most part unmeasured. If planned in advance, learning outcomes could have been assessed through the implementation of pre- and post-questionnaires and testing materials to measure changes in student knowledge, interest, and understanding of concepts. In particular, it would be instructive to measure whether a student's ability to design and undertake field studies was improved by this experience. One of the most inspiring aspects of the project was that it started off as part of the GHG accounting process and evolved into one that had multiple benefits. The number of students who heard about the project and wanted to get involved resulted in more volunteers than the project could accommodate. Students and alumni read about the project on our Web page and contacted the department to take part. More than half of the students who took part declared that this was the most memorable part of their undergraduate experience.

Although the project described here was carried out by a team of student interns, depending on campus area, tree density, etc. it could be feasible for a similar one to be carried out by an undergraduate geography class during the course of a semester. It can be logistically difficult to incorporate field-based exercises into classes because of the transportation to sites that it generally requires. However, field exercises are essential in the geosciences, and this project provides another effective field experience on campus (Hudak 2003). One could structure a class around the project and incorporate the topics of climate change, carbon sequestration, habitat, biodiversity, water, climate, and arboriculture within the class while giving students experience in working on a group project, using GIS, and gaining field measurement experience. It could be carried out by a class of 12–18 students over the course of a semester, or could provide a good summer school project.

Other Tree Inventories and Analysis Tools

CSUN is not unique in its implementation of a tree inventory, and over the past few years other universities have conducted similar projects. Examples are Utah State University (USU 2011), Indiana University–Purdue University–Indianapolis (IUPUI 2011), the University of Missouri, St Louis (UMSL 2011), the University of Washington (UW 2011), the University of Texas at Austin (UTA 2011). In addition many municipalities have produced tree inventories including the city of Ottawa (Ottawa 2011a), Chico (Gregory and Fairbanks 2010), Boston (Boston 2011) and Washington, D.C. (Washington 2011). Most inventories were conducted for tree management and maintenance purposes, and some have been useful in identifying highly destructive pests such as wood-boring beetles (Ottawa 2011b). Inventories are also useful for analyses of species and size diversity, tracking tree health, and for public information purposes. In some cases researchers have analyzed the benefits of trees using iTree (2011)—a software tool from the U.S. Forest Service, which provides the same kinds of analyses available through the CCTC tool, including carbon storage and sequestration and energy savings. iTree can also be used to compute water storage benefits when tree canopy data is available. In this study, the CCTC tool was chosen over iTree because it allows for computation on a tree-by-tree basis within the tree inventory database whereas iTree produces an overall summary of benefits. Incorporating data for each tree individually in the GIS geodatabase allows for easier implementation of what-if analyses and database update.

CITYgreen (2011) is another software tool for the analysis of the benefits of trees and is available (for purchase) as an extension to ArcGIS. It requires the user to digitize tree canopies from an aerial image, and provides the same output data as iTree including stormwater runoff analysis. It also incorporates the same carbon storage and sequestration model developed by the U.S. Forest Service and included in iTree and CCTC. The choice of CCTC over CITYgreen was made for the same reasons as the choice over iTree, for greater control of data on a tree by tree basis.

Many of the tree inventories listed above either did not report carbon storage/sequestration data or report it only as a summary for the entire campus. By including the computation in the tree record data (as also done by EIU), the data have added flexibility, allowing students to pursue further what-if research questions on different tree mixes (such as investigating the carbon sequestration associated with purely native trees), and allow for automatic update of the carbon calculations when trees are planted or removed.

Facilities Management

The tree inventory, including the GIS geodatabase, atlas, and maps, was transferred to the facilities management unit of the university for use and maintenance. It has been employed in facilities planning and construction to reduce the need for exploratory site visits, and will be used by grounds staff to track tree maintenance. Although the facilities staff have access to GIS software, they have not previously used it. Students have customized the GIS interface for their use, including adding custom functions for staff to easily perform common functions, like *Add a tree*, *Remove a tree*, *Schedule maintenance*. Fields were also added to the tree database to allow staff to store additional information, like planting date, tree removal date, reason for tree removal, and a maintenance flag to indicate a need for and the type of maintenance required. Students were hired to provide GIS training to the staff and, in a separate project, to develop a GIS of other resources on campus (including fire hydrants, piping, light poles, bicycle racks, and academic spaces). The facilities staff will be responsible for all future updates to the database, which will be shared with other units on campus through a server. Thus the project served to create a bridge between facilities management and the academic side of the institution that will lead to partnership opportunities in the future.

Table 1. Project benefits for students, the university, and the community.

Student/Learning Benefits	University and Community Benefits
Student training in making and recording field measurements	A tree guide for the community to use in identifying tree species on campus, and in learning about campus trees.
Student understanding of the use of GIS software to record locations and "join" to spreadsheet data	An online resource that can be used to identify trees by species, type, size, carbon sequestration, or to find memorial trees.
Student understanding of custom programming inside a spreadsheet application	An online resource for facilities planning to use in planning for new construction.
Increased student understanding of tree types and tree identification methods	A (geo)database of trees to be used and maintained by physical plant management in scheduling tree maintenance, conducting arborist assessments, recording planting and trimming dates, and reporting plantings and tree removals.
Student understanding of the way in which trees sequester carbon dioxide and the process by which this can be estimated	A database of carbon storage and sequestration data that can be included in the annual campus GHG inventory. (Accurate information will require annual measurement of the tree diameters. Alternatively, an estimate can be made by employing an average growth rate to all trees using the CUFR model.)
Student experience in working on a team	The establishment of a good partnership between the facilities unit and the academic unit of the campus.

Summary

The student learning, community, and university benefits of the study are summarized in Table 1. These benefits included student training in field measurements, an online resource for facilities planning, and a tree guide for the community, among others. This study began by looking at campus trees as a carbon sink. Although the trees on campus are beneficial in many other ways, as a sink for carbon dioxide they only offset a relatively small proportion of total emissions, amounting to approximately 154 tonnes per year, or less than one percent of campus emissions. This total is roughly equivalent to eight times the U.S. per capita emissions rate and thus offsets the GHG emissions of eight typical U.S. residents.

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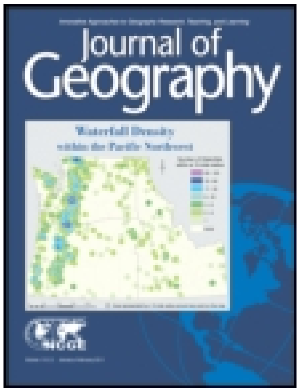

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A Sustainability Initiative to Quantify Carbon Sequestration by Campus Trees

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Global Warming

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Introduction
Global Warming
How is Today's Warming Different from the Past?
Is Current Warming Natural?
How Much More Will Earth Warm?
How Will Global Warming Change Earth?
References and Related Resources

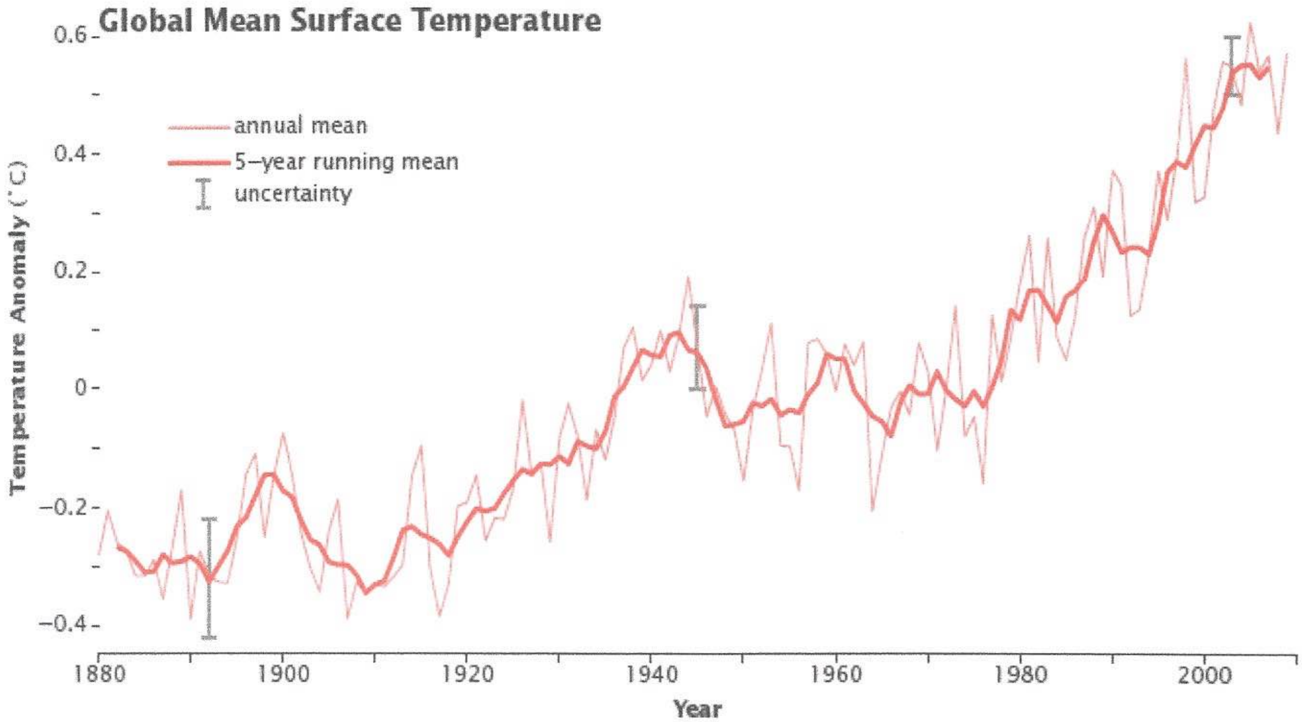
Atmosphere | Heat | Land | Water

Throughout its long history, Earth has warmed and cooled time and again. Climate has changed when the planet received more or less sunlight due to subtle shifts in its orbit, as the atmosphere or surface changed, or when the Sun's energy varied. But in the past century, another force has started to influence Earth's climate: humanity

How does this warming compare to previous changes in Earth's climate? How can we be certain that human-released greenhouse gases are causing the warming? How much more will the Earth warm? How will Earth respond? Answering these questions is perhaps the most significant scientific challenge of our time.

What is Global Warming?

Global warming is the unusually rapid increase in Earth's average surface temperature over the past century primarily due to the greenhouse gases released as people burn fossil fuels. The global average surface temperature rose 0.6 to 0.9 degrees Celsius (1.1 to 1.6° F) between 1906 and 2005, and the *rate* of temperature increase has nearly doubled in the last 50 years. Temperatures are certain to go up further.



Despite ups and downs from year to year, global average surface temperature is rising. By the beginning of the 21st century, Earth's temperature was roughly 0.5 degrees Celsius above the long-term (1951–1980) average. (NASA figure adapted from Goddard Institute for Space Studies Surface Temperature Analysis.)

Earth's natural greenhouse effect

Earth's temperature begins with the Sun. Roughly 30 percent of incoming sunlight is reflected back into space by bright surfaces like clouds and ice. Of the remaining 70 percent, most is absorbed by the land and ocean, and the rest is absorbed by the atmosphere. The absorbed solar energy heats our planet.

As the rocks, the air, and the seas warm, they radiate "heat" energy (thermal infrared radiation). From the surface, this energy travels into the atmosphere where much of it is absorbed by water vapor and long-lived greenhouse gases such as carbon dioxide and methane.

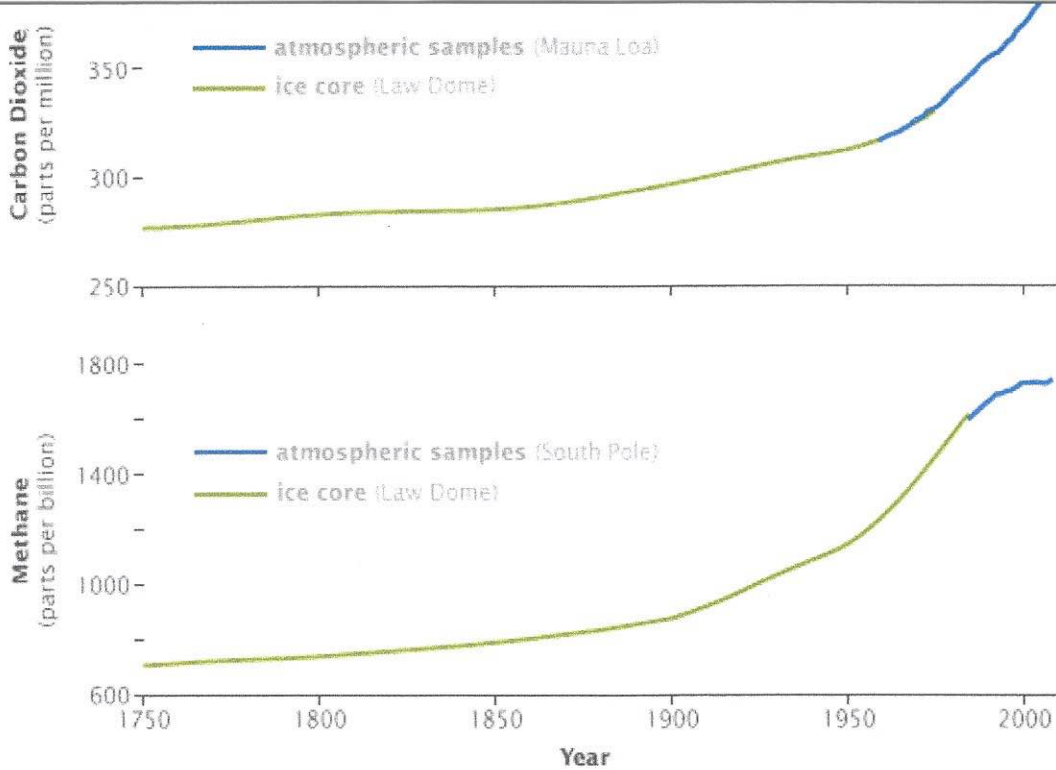
When they absorb the energy radiating from Earth's surface, microscopic water or greenhouse gas molecules turn into tiny heaters— like the bricks in a fireplace, they radiate heat even after the fire goes out. They radiate in all directions. The energy that radiates back toward Earth heats both the lower atmosphere and the surface, enhancing the heating they get from direct sunlight.

This absorption and radiation of heat by the atmosphere—the natural greenhouse effect—is beneficial for life on Earth. If there were no greenhouse effect, the Earth's average surface temperature would be a very chilly -18°C (0°F) instead of the comfortable 15°C (59°F) that it is today.

See Climate and Earth's Energy Budget to read more about how sunlight fuels Earth's climate.

The enhanced greenhouse effect

What has scientists concerned now is that over the past 250 years, humans have been artificially raising the concentration of greenhouse gases in the atmosphere at an ever-increasing rate, mostly by burning fossil fuels, but also from cutting down carbon-absorbing forests. Since the Industrial Revolution began in about 1750, **carbon dioxide levels have increased nearly 38 percent as of 2009 and methane levels have increased 148 percent.**



Increases in concentrations of carbon dioxide (top) and methane (bottom) coincided with the start of the Industrial Revolution in about 1750. Measurements from Antarctic ice cores (green lines) combined with direct atmospheric measurements (blue lines) show the increase of both gases over time. (NASA graphs by Robert Simmon, based on data from the NOAA Paleoclimatology and Earth System Research Laboratory.)

The atmosphere today contains more greenhouse gas molecules, so more of the infrared energy emitted by the surface ends up being absorbed by the atmosphere. Since some of the extra energy from a warmer atmosphere radiates back down to the surface, Earth's surface temperature rises. By increasing the concentration of greenhouse gases, we are making Earth's atmosphere a more efficient greenhouse.

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SOIL, AGRICULTURE, AND AGRICULTURAL BIOTECHNOLOGY

Soil Carbon Storage

By: Todd A. Ontl (*Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA*) & Lisa A. Schulte (*Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA*) © 2012 Nature Education

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Soil carbon storage is a vital ecosystem service, resulting from interactions of ecological processes. Human activities affecting these processes can lead to carbon loss or improved storage.

Aa Aa Aa

Organic matter is a key component of soil that affects its physical, chemical, and biological properties, contributing greatly to its proper functioning on which human societies depend. Benefits of soil organic matter (SOM) include improvement of soil quality through increased retention of water and nutrients, resulting in greater productivity of plants in natural environments and agricultural settings. SOM improves soil structure and reduces erosion, leading to improved water quality in groundwater and surface waters, and ultimately to increased food security and decreased negative impacts to ecosystems. Since the beginnings of recorded history, societies have understood that human activities can deplete soil productivity and the ability to produce food (McNeill and Winiwarter 2004). Only in recent history has the understanding of soil productivity been tied to SOM levels, with the depletion of SOM stocks often leading to large-scale impacts on whole ecosystems as well as the entire planet. For example, destruction of rainforests that hold a significant amount of the carbon stored in terrestrial ecosystems contributes significantly to rising atmospheric carbon dioxide (CO_2) levels linked to climate change, while reductions in SOM levels from soil disturbance from mining can impact infiltration of rainfall and the storage of soil moisture important for flood mitigation. Soil disturbance also leads to increased erosion and nutrient leaching from soils, which have led to eutrophication and resultant algal blooms within inland aquatic and coastal ecosystems, ultimately resulting in dead zones in the ocean (Fig. 1). Restoration of organic matter levels in soil requires an understanding of the ecological processes important for SOM storage. Proper restoration techniques can help restore terrestrial ecosystem functions.

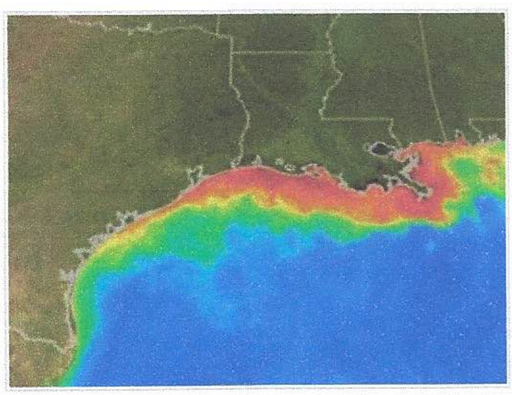

Figure 1: Summer algal conditions along the US Gulf Coast.

Red indicates high concentrations of algae due to nutrients flowing into the Gulf of Mexico, primarily from the Mississippi River basin.

Fundamentals of Soil Organic Carbon

Soil organic matter is composed of soil microbes including bacteria and fungi, decaying material from once-living organisms such as plant and animal tissues, fecal material, and products formed from their decomposition. SOM is a heterogeneous mixture of materials that range in stage of decomposition from fresh plant residues to highly decomposed material known as humus. SOM is made of organic compounds that are highly enriched in carbon. Soil organic carbon (SOC) levels are directly related to the amount of organic matter contained in soil and SOC is often how organic matter is measured in soils.

SOC levels result from the interactions of several ecosystem processes, of which photosynthesis, respiration, and decomposition are key. Photosynthesis is the fixation of atmospheric CO_2 into plant biomass. SOC input rates are primarily determined by the root biomass of a plant, but also include litter deposited from plant shoots. Soil C results both directly from growth and death of plant roots, as well as indirectly from the transfer of carbon-enriched compounds from roots to soil microbes. For example, many plants form symbiotic associations between their roots and specialized fungi in the soil known as mycorrhizae; the roots provide the fungi energy in the form of carbon while the fungi provide the plant with often-limiting nutrients such as phosphorus. Decomposition of biomass by soil microbes results in carbon loss as CO_2 from the soil due to microbial respiration, while a small proportion of the original carbon is retained in the soil through the formation of humus, a product that often gives carbon-rich soils their characteristic dark color (Fig. 2). These various forms of SOC differ in their recalcitrance, or resistance to decomposition. Humus is highly recalcitrant, and this resistance to decomposition leads to a long residence time in soil. Plant debris is less recalcitrant, resulting in a much shorter residence time in soil. Other ecosystem processes that can lead to carbon loss include soil erosion and leaching of dissolved carbon into groundwater. When carbon inputs and outputs are in balance with one another, there is no net change in SOC levels. When carbon inputs from photosynthesis exceed C losses, SOC levels increase over time.

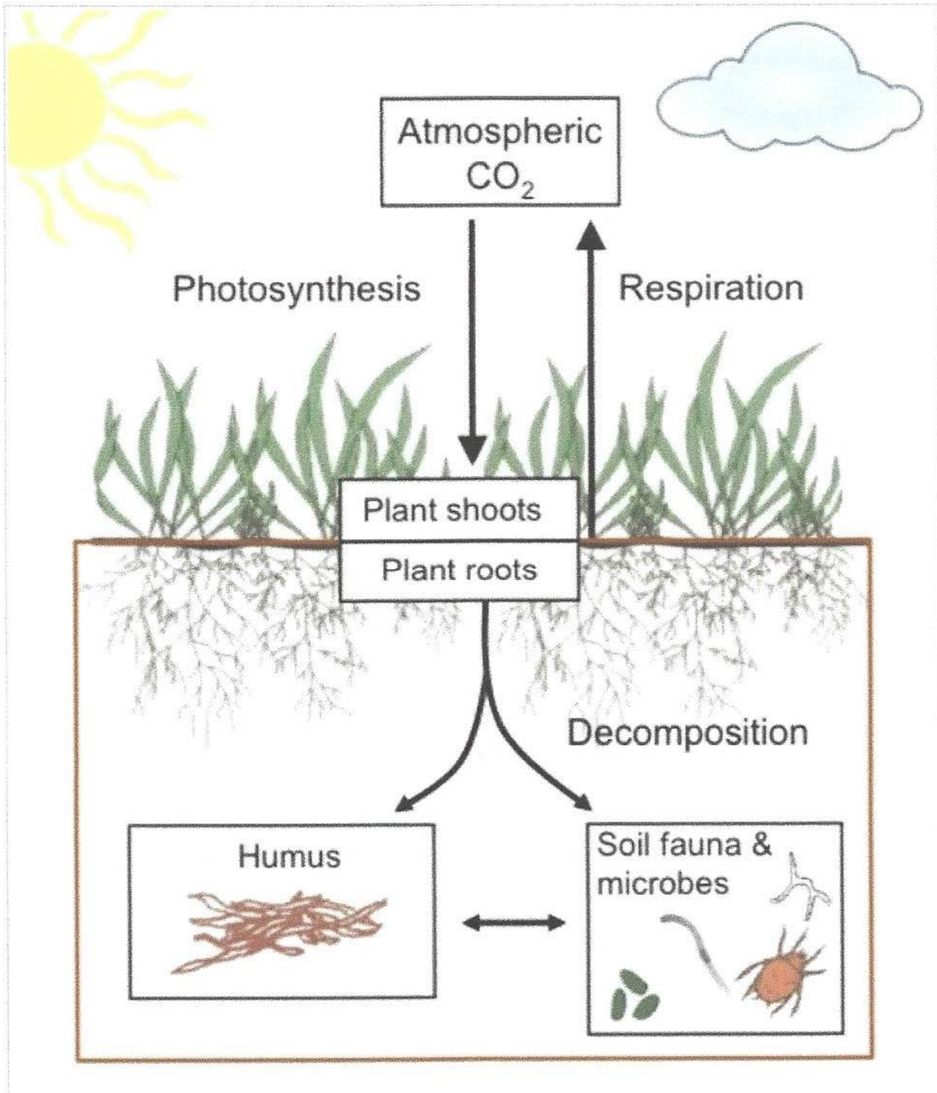

Figure 2: Carbon balance within the soil (brown box) is controlled by carbon inputs from photosynthesis and carbon losses by respiration.
Decomposition of roots and root products by soil fauna and microbes produces humus, a long-lived store of SOC.

Photosynthesis, decomposition, and respiration rates are determined partly by climatic factors, most importantly soil temperature and moisture levels. For example, in the cold wet climates of the northern latitudes, rates of photosynthesis exceed decomposition resulting in high levels of SOC (Fig. 3). Arid regions have low levels of SOC mostly due to low primary production, while the tropics often have intermediate SOC levels due to high rates of both primary productivity and decomposition from warm temperatures and abundant rainfall. Temperate ecosystems can have high primary productivity during summer when temperature and moisture levels are highest, with cool temperatures during the rest of the year slowing decomposition rates such that organic matter slowly builds up over time (Fig. 4). While climatic conditions largely generate global patterns of soil carbon, other factors that vary on smaller spatial scales interact with climate to determine SOC levels. For example, soil texture — the relative proportions of sand, silt, and clay particles that make up a particular soil — or the mineralogy of those soil particles can have a significant impact on soil carbon stocks. Additionally, the processes of erosion and deposition act to redistribute soil carbon according to the topography of the landscape, with low-lying areas such as floodplains often having increased SOC relative to upslope positions.

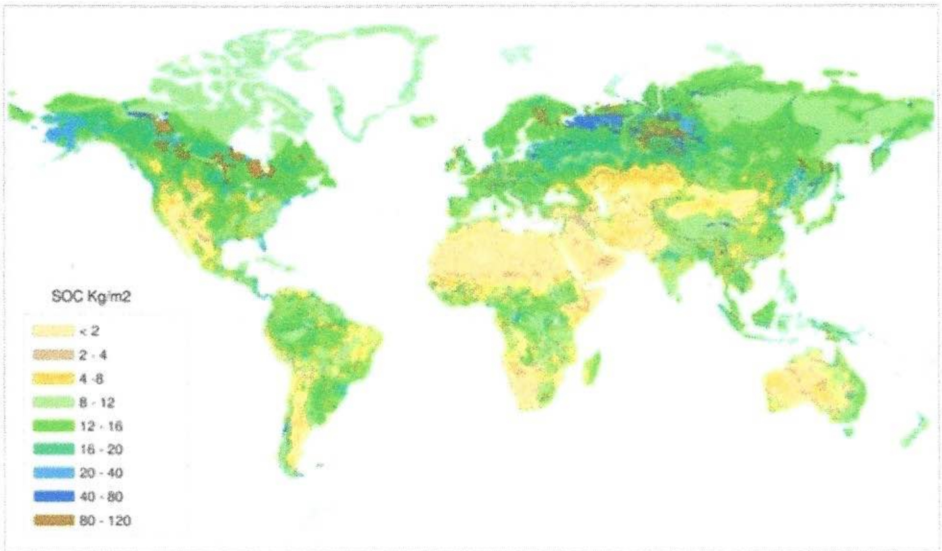

Figure 3: World map showing the quantity of SOC to 1 m depth.

Figure 4: Dark colored topsoil showing high levels of SOC due to abundant plant roots and their associated soil fauna and microbes in a cultivated soil in central Iowa.

Soil Carbon and the Global Carbon Cycle

The amount of C in soil represents a substantial portion of the carbon found in terrestrial ecosystems of the planet. Total C in terrestrial ecosystems is approximately 3170 gigatons (GT; 1 GT = 1 petagram = 1 billion metric tons). Of this amount, nearly 80% (2500 GT) is found in soil (Lal 2008). Soil carbon can be either organic (1550 GT) or inorganic carbon (950 GT). The latter consists of elemental carbon and carbonate materials such as calcite, dolomite, and gypsum (Lal 2004). The amount of carbon found in living plants and animals is comparatively small relative to that found in soil (560 GT). The soil carbon pool is approximately 3.1 times larger than the atmospheric pool of 800 GT (Oelkers & Cole 2008). Only the ocean has a larger carbon pool, at about 38,400 GT of C, mostly in inorganic forms (Houghton 2007).

Soil Carbon and Climate Change

There is a growing body of evidence supporting the hypothesis that the earth's climate is rapidly changing in response to continued inputs of CO_2 and other greenhouse gases (GHGs) to the atmosphere resulting from human activities (IPCC 2007). While a suite of GHGs exist (e.g., N_2O, CH_4), CO_2 has the largest effect on global climate as a result of enormous increases from the preindustrial era to today. Atmospheric CO_2 concentrations have risen from approximately 280 parts per million (ppm) prior to 1850, to 381.2 ppm in 2006 (WMO 2006), with a current annual increase of 0.88 ppm (3.5 GT C/yr) (IPCC 2007). Approximately two-thirds of the total increase in atmospheric CO_2 is a result of the burning of fossil fuels, with the remainder coming from SOC loss due to land use change (Lal 2004), such as the clearing of forests and the cultivation of land for food production (Fig. 5).

Figure 5: Deforestation around Rio Branco, Brazil.
Light colored areas are where rainforest vegetation has been cleared and burned (see smoke plume) for farming and cattle ranching.

While the carbon released to the atmosphere through deforestation includes carbon emitted from the decomposition of aboveground plant biomass, carbon levels in the soil are also rapidly depleted from the decomposition of SOM. The decomposition of SOM is due to the activity of the microbial decomposer community in the absence of continual rates of carbon input from the growth of forest vegetation, as well as increased soil temperatures that result from warming of the ground once the forest canopy has been removed. Although this soil carbon loss has contributed to increased CO_2 levels in the atmosphere, it also is an opportunity to store some of this carbon in soil from reforestation.

Despite the much larger size of the oceanic carbon pool relative to the soil carbon pool, the rate of exchange between the atmosphere and the soil is estimated to be higher than that between the atmosphere and the ocean. Current estimates are that carbon inputs from photosynthesis by terrestrial vegetation fixes more carbon than carbon loss through soil respiration, resulting in a soil storage rate of about 3 GT C/yr. Oceanic carbon flux rates suggest oceans store about 2 GT carbon/yr despite occupying a vastly larger proportion of the earth's surface. Although there is interest in increasing oceanic carbon storage rates through large-scale nutrient additions, there is skepticism towards this approach due to the unknown consequences on global nutrient cycles and marine ecosystems (Cullen & Boyd 2008). The goal of increased storage of carbon in soil has received much wider acceptance due to a better understanding of the processes involved in SOC storage, more direct control of these processes through human activities, and the other known ecosystem benefits to be obtained by increasing SOC, including benefits to water quality and increased food security.

Soil Carbon Sequestration

Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. This process is primarily mediated by plants through photosynthesis, with carbon stored in the form of SOC. In arid and semi-arid climates, soil carbon sequestration can also occur from the conversion of CO_2 from air found in soil into inorganic forms such as secondary carbonates; however, the rate of inorganic carbon formation is comparatively low (Lal 2008).

Since the industrial revolution, the conversion of natural ecosystems to agricultural use has resulted in the depletion of SOC levels, releasing 50 to 100 GT of carbon from soil into the atmosphere (Lal 2009). This is the combined result of reductions in the amount of plant roots and residues returned to the soil, increased decomposition from soil tillage, and increased soil erosion (Lemus & Lal 2005). Depletion of SOC stocks has created a soil carbon deficit that represents an opportunity to store carbon in soil through a variety of land management approaches. However, various factors impact potential soil carbon change in the future, including climatic controls, historic land use patterns, current land management strategies, and topographic heterogeneity.

Continued increases in atmospheric CO_2 and global temperatures may have a variety of different consequences for soil carbon inputs via controls on photosynthetic rates and carbon losses through respiration and decomposition. Experimental work has shown that plants growing in elevated CO_2 concentrations fix more carbon through photosynthesis, producing greater biomass (Drake *et al.* 1997). However, carbon loss may also increase due to increased plant respiration from greater root biomass (Hungate *et al.* 1997), or from accelerated decomposition of SOM through increased microbial activity (Zak *et al.* 2000). Likewise, increased temperatures may impact the carbon balance by limiting the availability of water, and thus reducing rates of photosynthesis. Alternatively, when water is not limiting, increased temperatures might increase plant productivity, which will also impact the carbon balance (Maracchi *et al.* 2005). Increased temperatures may also lead to higher rates of SOM decomposition, which may in turn produce more CO_2, resulting in positive feedbacks on climate change (Pataki *et al.* 2003).

At the scale of a watershed or crop field, the carbon sequestration capacity of the soil may be influenced by local controls on ecosystem processes. Processes such as rainfall infiltration, soil erosion and deposition of sediment, and soil temperature can vary on local scales due to landscape heterogeneity — all of which affect carbon input and carbon loss rates (Fig. 6), resulting in differences in SOC contents along topographic gradients (Thompson and Kolka 2005). For example, slope position impacts soil moisture and nutrient levels, with subsequent impacts on the root growth of plants that may have consequences for soil carbon (Ehrenfeld *et al.* 1992). The combined effects of changes in carbon inputs and losses from land use, land management, and landscape-level effects on carbon input and loss rates result in variation in the carbon sequestration capacity across landscapes.

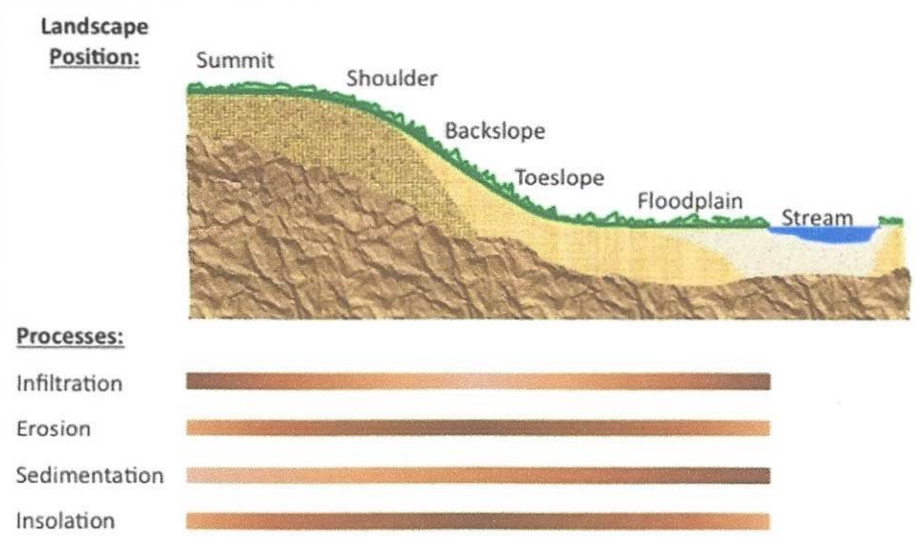

Figure 6: Landscape heterogeneity due to landscape position along a hill slope and possible effects on biophysical processes that effect carbon inputs and losses.
Darker areas on bars indicate higher rates.

Carbon sequestration potential may be determined by an understanding of both the historic SOC stocks under natural vegetation prior to conversion to other uses and the influences of those land uses on carbon loss. Land uses and management that reduce carbon inputs or increase losses compared to natural vegetation result in reductions in SOC over time, creating a soil carbon deficit relative to the levels of carbon that previously existed in the soil. This deficit represents an opportunity to store carbon from conversions in land use and management when those changes result in either increased inputs or decreased losses of carbon. For example, reforestation or grassland restoration on a former crop field can reduce the carbon deficit caused from years of agricultural production and sequester carbon through higher root productivity compared to crops. Likewise, the creation of wetlands and ponds can sequester large amounts of carbon because decomposition is greatly reduced in waterlogged soils from lack of oxygen; this can actually result in carbon gains that exceed the deficits resulting from past land use. Other management practices such as irrigation of pasture or rangelands may also increase carbon levels beyond historic SOC stocks if carbon inputs under new management greatly exceed levels under natural conditions. The effect of land management on SOC levels, especially the impacts of management in agricultural settings, is the subject of much current research (Table 1). These changes in soil carbon, however, typically take many decades to occur, making actual measurements of changes in SOC stocks difficult.

Management practice	**Effect**
Reduced tillage/ no tillage	Reduced C loss
Erosion control (contour plowing, terracing)	Reduced C loss
Addition of organic amendments (compost, manure, crop residues)	Increased C input
Use of cover crops	Reduced C loss/increased C input

Table 1: Possible management practices for increasing SOC levels through reduced carbon losses and increased carbon inputs in agricultural systems.

Conclusion

SOC is a vital component of soil with important effects on the functioning of terrestrial ecosystems. Storage of SOC results from interactions among the dynamic ecological processes of photosynthesis, decomposition, and soil respiration. Human activities over the course of the last 150 years have led to changes in these processes and consequently to the depletion of SOC and the exacerbation of global climate change. But these human activities also now provide an opportunity for sequestering carbon back into soil. Future warming and elevated CO_2, patterns of past land use, and land management strategies, along with the physical heterogeneity of landscapes are expected to produce complex patterns of SOC capacity in soil.

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Original article

Increased home size and hardscape decreases urban forest cover in Los Angeles County's single-family residential neighborhoods

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A B S T R A C T

Single-family residential neighborhoods make up large areas within cities and are undergoing change as residences are renovated and redeveloped. We investigated the effects of such residential redevelopment on land cover (trees/shrubs, grass, building, and hardscape) in the 20 largest cities in the Los Angeles Basin from 2000 to 2009. We identified spatially stratified samples of single-family home lots for which additional square footage was recorded and for which additional construction was not recorded by the tax assessor. We then digitized land cover on high-resolution color imagery for two points in time to measure land cover change. Redevelopment of single-family homes in Los Angeles County resulted in a significant decrease in tree/shrub and grass cover and a significant increase in building and hardscape area. Over 10 years, urban green cover (trees/shrubs and grass) declined 14–55% of green cover in 2000 on lots with additional recorded development and 2–22% of green cover in 2000 for single-family lots for which new permits were not recorded. Extrapolating the results to all single-family home lots in these cities indicate a 1.2 percentage point annual decrease in tree/shrub cover (5.6% of existing tree/shrub cover) and a 0.1 percentage point annual decrease in grass cover (2.3% of existing grass cover). The results suggest that protection of existing green cover in neighborhoods is necessary to meet urban forest goals, a factor that is overlooked in existing programs that focus solely on tree planting. Also, changing social views on the preferred size of single-family homes is driving loss of tree cover and increasing impervious surfaces, with potentially significant ramifications for the functioning of urban ecosystems.

1. Introduction

For nearly a hundred years since the establishment of North American residential suburban neighborhoods, and accelerating since World War II, single-family neighborhoods have exhibited a characteristic ratio of building to landscape, with properties reliably including a healthy proportion of tree, shrub, and grass cover (Ward, 2011; Gillespie et al., 2012). Suburban tracts being laid out through the middle decades of the twentieth century in North America reflected a cultural value of appreciation for greenery and shade, included places for children and pets to play outdoors, and provided hedges affording privacy. With the aging of the housing stock, emerging preferences for larger homes, and market forces rewarding speculative development, many homes in single-family neighborhoods are being expanded and redeveloped. This redevelopment results in larger homes (National Association of Home Builders (NAHB) 2006, 2010), with a trend toward increased hardscape, play spaces being brought indoors or moved off-site, increased indoor storage, and an overall drastic change to the relatively homogeneous landscape of neighborhoods that had been developed with similar massing and building–landscape ratios.

Besides fulfilling an aesthetic objective, the landscape design of the first wave of single-family residential tract development inherently brought with it a range of what would now be recognized as ecological services (e.g., shade, stormwater management, habitat for birds and other wildlife). These ecologically beneficial consequences occurred organically—not as the result of conscious environmental policy, but rather as an outgrowth of the cultural aesthetic and economics of the times. That these benefits were not planned does not diminish their value. In fact, the ecosystem services of such neighborhoods are an integral, although unrecognized, part of the land use baseline which forms the context in which current urban land use decisions are made (Tratalos et al.,

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2007). That is, the landscape aesthetics of the single-family neighborhood provide significant environmental benefits that can be underappreciated in current discussions over the future of cities, especially those promoting density as a sustainable urban form (Jabareen, 2006; Hassan and Lee, 2015). Furthermore, the redevelopment of these neighborhoods threatens to eliminate their environmental benefits in a way that is not readily appreciated because the zoning classification does not change. Public agencies spend significant funds on parklands and open space, with the expectation that such lands will continue to support resident and migratory species of birds and other wildlife. In truth, if the areas in between urban parklands are allowed to be filled in, paved, and denuded through redevelopment of neighborhoods, those values will be diminished (Fernández-Juricic, 2000).

In this study, we investigated trends in green cover, defined as trees, shrubs (bushes), and grass (lawn), in single-family neighborhoods relative to patterns of redevelopment of those lots on an individual basis. The study focused on the 20 largest cities in the Los Angeles Basin (that is, on the coastal side of the major mountain ranges in Los Angeles County) as an example of a landscape with mature single-family neighborhoods. The time period investigated is 2000–2009, which was a decade of rapid appreciation in the local housing market that fueled the aggressive expansion and replacement of residences. Our approach, which compared changes detected using parcel-level aerial imagery with official records of building size, additionally provided an indication of whether expansion of single-family homes is being permitted and recorded in a way that allows it to be properly taxed. With this approach, we asked three research questions:

- How has green cover changed on parcels for which the permitted building footprint increased compared with those for which no change was recorded?
- How has the rate of building modification and associated changes in green cover varied across the 20 most populous cities in the Los Angeles Basin?
- How much has green cover changed across the Los Angeles Basin as a result of the redevelopment of single-family neighborhoods?

2. Background

The size of the average single-family home has increased dramatically in North America over the past 50 years, with the size of new or expanded structures in some neighborhoods reaching proportions that have been described as "mansions" (e.g., Szold, 2005) and in some cases referred to as "McMansions" because they are developed on a speculative basis in a manner out of scale with their surroundings.

Residential areas, especially single-family neighborhoods, play an important role in urban ecosystems because they cover a large fraction of the land area in cities. For example, single-family neighborhoods consume more than half of the land area in urbanized Los Angeles County. According to the NAHB (NAHB, 2006, 2010), the average size of single-family homes in the U.S. has steadily increased from 983 ft^2 in 1950 to 2349 ft^2 in 2004. In addition, the number of bedrooms and bathrooms, as well as the number of parking spaces, has increased. For example, just 1% of single-family homes had four bedrooms and only 2% had three bathrooms in 1950; these rates had increased to 37% with four bedrooms and 24% with three bathrooms by 2005. Meanwhile, the size of the average household dropped from 3.67 persons in 1940 to 2.62 persons in 2002 (Wilson and Boehland, 2005), meaning that these newer, larger homes are resulting in a lower density of urban residents (see Ward, 2011 for similar statistics in Canada).

The environmental benefits of trees and other forms of green cover are many and varied and play a crucial role in improving residents' quality of life and in maintaining urban environmental amenities (Akbari et al., 1997, 2001; Dwyer et al., 1992; Dwyer and Miller, 1999; Longcore et al., 2004; Simpson and McPherson, 1996). Abundant green cover helps to maintain or boost property values and brings environmental benefits such as reduction in energy use, improvement in air quality, reduction in noise, control of stormwater runoff, provision of habitat for wildlife, and enhancement of aesthetic values. Together, the tree, shrub, and grass cover of the city can be conceptualized as an "urban forest," which meets the definition of a forest by exceeding 10% cover of trees (Rowntree, 1984).

Trees provide shade and decrease energy consumption by helping to keep buildings cool in summer (Dwyer et al., 1992; Simpson and McPherson, 1996). Trees intercept sunlight before it heats buildings and reduce wind speed by as much as 50%. Approximately $10 billion is spent annually to cool residential dwellings in the U.S. so the potential impact of these savings is considerable (Akbari et al., 1990). Akbari et al. (2001) reported that the City of Los Angeles, for example, could save $270 million annually from an expanded tree cover. Vegetation cover may also help to reduce the urban heat island and thereby reduce nighttime residential energy consumption.

Trees also improve air quality because gaseous pollutants such as CO_2, O_3, and NO_2 are absorbed by leaves and O_2 is released to the air (McPherson et al., 2005a; Nowak et al., 2006). It has been estimated that the addition of 100 million mature trees in cities in the U.S. would remove 8.16 million tons of CO_2 from the atmosphere and save approximately $2 billion per year (Akbari et al., 1998; Dwyer et al., 1992). In addition, increasing tree cover decreases O_3 concentrations (Taha, 1996; Nowak et al., 2000) and improved air quality enhances human health and can reduce expenditures for health care (Dwyer et al., 1992; Dwyer and Miller, 1999; Gauderman et al., 2004, 2005). Lovasi et al. (2008) suggest that trees play an important role in preventing childhood asthma and one cost-effective way to reduce air pollution is to increase the extent and quality of urban forest (Escobedo et al., 2008). Heavy vehicular traffic usually leads to elevated levels of noise and air pollution; both adversely affect human health. Strategically placed trees, such as near roadways, substantially reduce the perception of traffic-related noise (Dzhambov and Dimitrova, 2014).

Urban green cover also plays an important role in reducing stormwater runoff because green cover intercepts rainfall and some of this intercepted precipitation is evaporated back to the atmosphere (Brooks et al., 2012). Xiao and McPherson (2002), for example, have shown that Santa Monica, California's municipal urban forest intercepts 1.6% of the total rainfall per year. Trees and other forms of green cover also promote infiltration and groundwater recharge (McPherson et al., 2005a) and thereby help to control stormwater runoff (McPherson et al., 2005a, 2005b). Sanders (1986) estimated that existing trees reduced runoff by 7% in Dayton, Ohio and that this would increase to 12% with planned growth of tree cover. Reducing runoff volume mitigates potential flood hazard and pollutant loadings to nearby rivers and lakes (Millward and Sabir, 2011).

Urban neighborhoods support birds and other wildlife of various types (Livingston et al., 2003; Aronson et al., 2014), but the increasing urban footprints and accompanying population growth threaten habitats for a variety of wild species (Matteson and Langellotto, 2010; McKinney, 2008).

Finally, trees enhance the aesthetics of single-family neighborhoods, help sustain and improve residential property values, and provide a series of recreational opportunities (Conway and Urbani, 2007). Anderson and Cordell (1988) reported that in Athens, Georgia between 1978 and 1980 each large front-yard tree resulted in an average 0.88% increase in home sale prices, and the same authors later argued that increased property values can, in turn, increase a city's property tax revenues. Sander et al. (2010) also show a positive relationship between tree cover and property sale value such that a 10% increase in tree cover within 100 m of a home increased property sale prices by 0.48% and within 250 m of the home increased sale prices by 0.29%. Conway et al. (2010) conclude in a study of Los Angeles that proximity to greenspace has a significant impact on home prices and greening cities may be a way to elevate depressed housing markets. In contrast, Saphores and Li (2012) did not find a large price benefit of trees on single-family residential parcels, but did find such an effect for the surrounding 200 m, suggesting that people want trees, but perhaps do not want to pay to take care of them.

The mixed result on home sale prices from Saphores and Li (2012) highlights that trees do have costs for homeowners (Roy et al., 2012), including the perceived need to trim trees (although much urban tree trimming is unnecessary and violates arboricultural guidelines), potential damage to infrastructure, production of allergens, and production of volatile organic compounds.

The benefits of green cover, especially trees, within cities have been well documented and recognized. As a consequence, plans and efforts have been launched in recent decades to increase green cover in a variety of urban settings. The United Nations Environment Programme (2011), for example, launched the Billion Trees Campaign to encourage national, state, county, and city governments as well as nonprofit organizations and individual residents to plant indigenous trees in both rural and urban areas. Likewise, the U.S. Conference of Mayors launched a Community Trees Task Force to protect and increase urban green cover and increase public awareness of its value (U.S. Conference of Mayors, 2008). The Task Force surveyed local officials in 135 cities with at least 30,000 residents in 36 states and documented the methods used to manage, sustain, and expand green infrastructure as well as to share information about urban forest status. Los Angeles and New York, the two largest cities in the U.S., launched projects in 2006 to plant an additional one million trees (City of Los Angeles, 2006; City of New York, 2006), with different approaches and eventual outcomes (Pincetl, 2010).

These new programs can add to green cover only if existing green cover is retained. Increases in home sizes in single-family neighborhoods result in removal of existing vegetation, including trees, and expansion of the area covered by impermeable surfaces. The extent of these threats to urban green cover during a period of growth in the residential real estate market is the subject of our investigation.

3. Methods

3.1. Study area

Los Angeles County, California is the most populous county in the U.S. and, if it were a state, it would constitute the eighth most populous state (ahead of Ohio). The County's population grew from 4,151,687 in 1950 to 9,858,989 in 2011 (U.S. Census Bureau, 2000; California Department of Finance, 2011) and dramatically increased in urban footprint. As a result of the increase, Los Angeles County ranked first among all counties in terms of the funds ($9.4 billion) spent on home remodeling per year from 2005 to 2009. Cook County, Illinois ($4.6 billion), Orange County, California ($4 billion), San Diego County, California ($3.4 billion), and Maricopa County, Arizona ($3 billion) rounded out the top five counties in terms of remodeling expenses during this same period.

More than 90% of the population in Los Angeles County resides in the County's 88 incorporated cities and most of the remaining residents live in urbanized areas that are located near one or more of these cities. The land mass varies in elevation from sea level to 3000 m. Most of the urban population resides in relatively flat, low-lying areas that constitute the analysis units chosen for this study (Fig. 1).

The City of Los Angeles is the largest city in Los Angeles County (and in California) and the second largest city in the U.S. For purposes of this study, the City of Los Angeles was analyzed in units defined by the 15 council districts used for city governance (see Fig. 1 and Table 1 for additional details). We used the district boundaries from June 2009.

3.2. Data sources

The two main data sources were property information and aerial imagery. Property information (2000–2001 and 2009–2010), which was generated June 18, 2009, is maintained and distributed as a GIS dataset (boundary shapefile and a tabular data) by the Los Angeles County Office of the Assessor and includes sales information, property values, property built year, property boundaries, building descriptions, land uses, and other variables. The property information dataset was created for use in this study by joining the tabular data to the boundary shapefile using the Assessor Index Number (AIN).

One-foot (2000) and four-inch (2008) pixel resolution color ortho-imagery was obtained from the Los Angeles Region – Imagery Acquisition Consortium (LAR-IAC). The color ortho-imagery consists of 3 bands (red, green, blue) without an infrared band so we did not pursue an image classification approach to extract vegetation features that an infrared band would have allowed.

Both of the two main datasets were projected to the North America Datum (NAD) 1983 State Plane California V FIPS coordinate system. We also used the city boundary layer from the Los Angeles County GIS Data Portal. We chose the 2009 data to describe the 2008 imagery to account for delays in recording permitted redevelopment and renovation by the Office of the Assessor.

3.3. Sample design

The 20 largest cities in the Los Angeles Basin by population in 2010 were chosen to maximize coverage of the region and to provide a dataset with which we could compare differences between municipalities. Combining the 15 council districts of the City of Los Angeles with the 19 remaining cities yielded 34 analysis units ranging in population from 81,604 (City of Baldwin Park) to 494,709 residents (City of Long Beach) (see Table 1 for additional details).

More than 2.3 million parcels are found in Los Angeles County and among these more than 1 million parcels were occupied by single-family homes in both 2000 and 2009. For this study, we examined the 639,080 parcels in the 20 largest cities in both 2000 and 2009 that were classified as single-family homes using the land use code specified by the Los Angeles County Office of the Assessor (Table 1).

Single-family home parcels in each city and council district were extracted using the addresses recorded by the Assessor's office as well as city and council district boundaries. In some instances, however, the addresses were mismatched with geographic boundaries. The Spatial Join tool (in ArcGIS 10.3) was used with the intersecting match option, in which the features in the join features were matched if they intersected a target feature, to count the number of single-family home parcels in 19 cities and 15 council districts.

We split the existing single-family homes into a treatment group and a control group. The treatment group includes those homes for which the Los Angeles County Office of the Assessor recorded a change in building area from 2000 to 2009. The control group contained a sample of developed single-family residential lots for

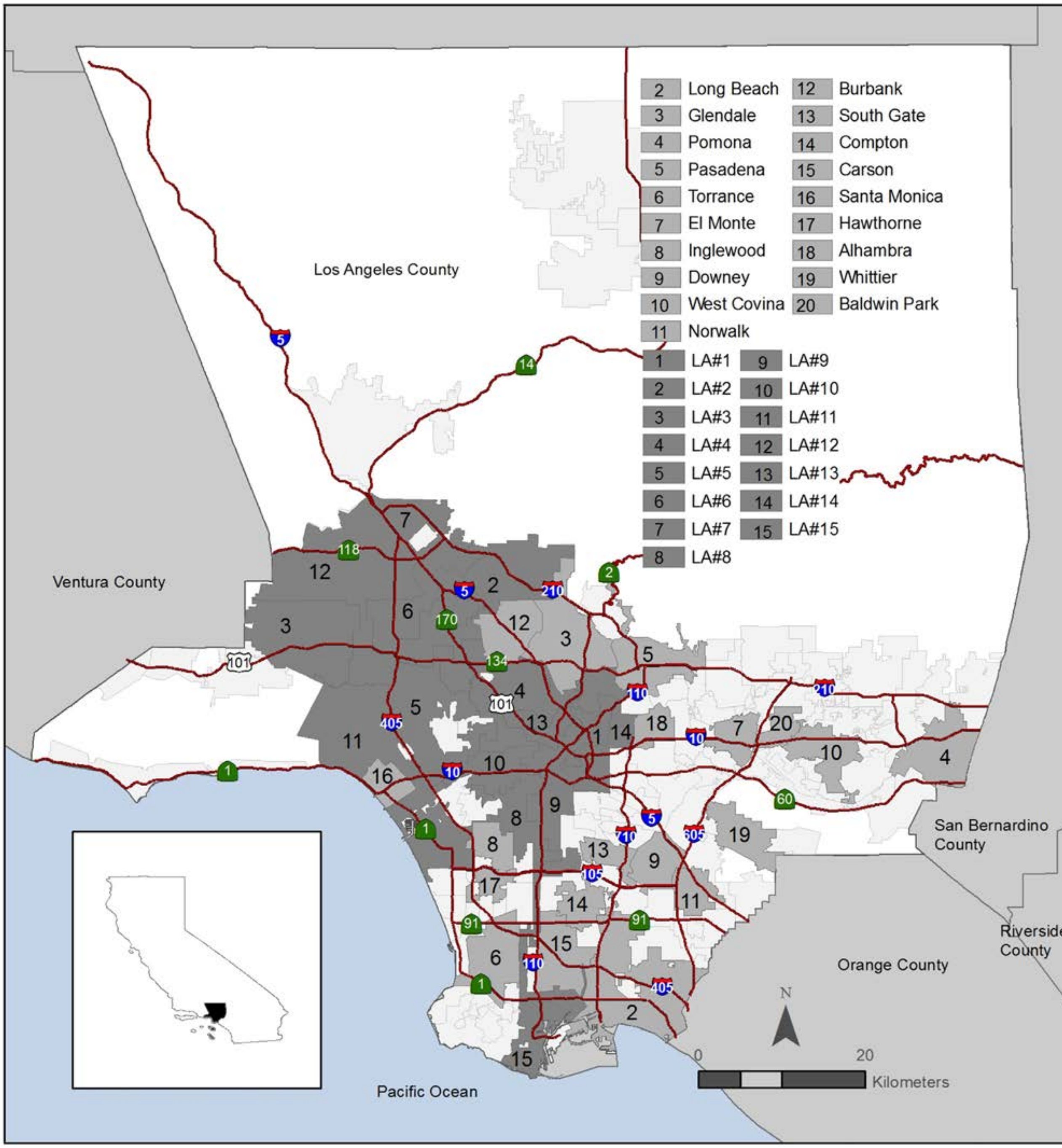

Fig. 1. Los Angeles County, California, with outlines of all 88 cities, the 20 largest cities are indicated (gray), with the dark gray area showing the City of Los Angeles divided into 15 council districts.

which no such change was recorded. For the treatment group, changes in square footage included new single-family homes on vacant lots and the occasional removal of a home. This approach eliminated the need to specify what constituted a "large" new house on a "small" lot and a "large-scale" addition and renovation to an existing home; we measured the effects of all changes in recorded building square footage. For lots where a change in building square footage had been recorded, the larger of a 1% or 30-home stratified random sample was selected in each of the 34 analysis units; for lots at which no change had been recorded, 20 homes were randomly sampled in each of the 34 units of analysis (Table 1).

3.4. Digitizing and change analysis

Five land cover types (buildings, hardscape, swimming pools, grass, and trees/shrubs) were digitized for each of the sampled home lots on the color ortho-imagery for 2000 and 2008. Shrubs were included with trees and further reference to tree cover includes shrub cover as well. Additionally, shaded (unknown) areas were identified (Fig. 2). Land cover types were digitized using the Editor tool in ArcGIS 10.3, with a single investigator (S. J. Lee) interpreting all aerial imagery (see e.g., Fig. 2). To minimize user errors, the point, end, vertex, and edge snapping tools were implemented while creating new features and segments by tracing existing features.

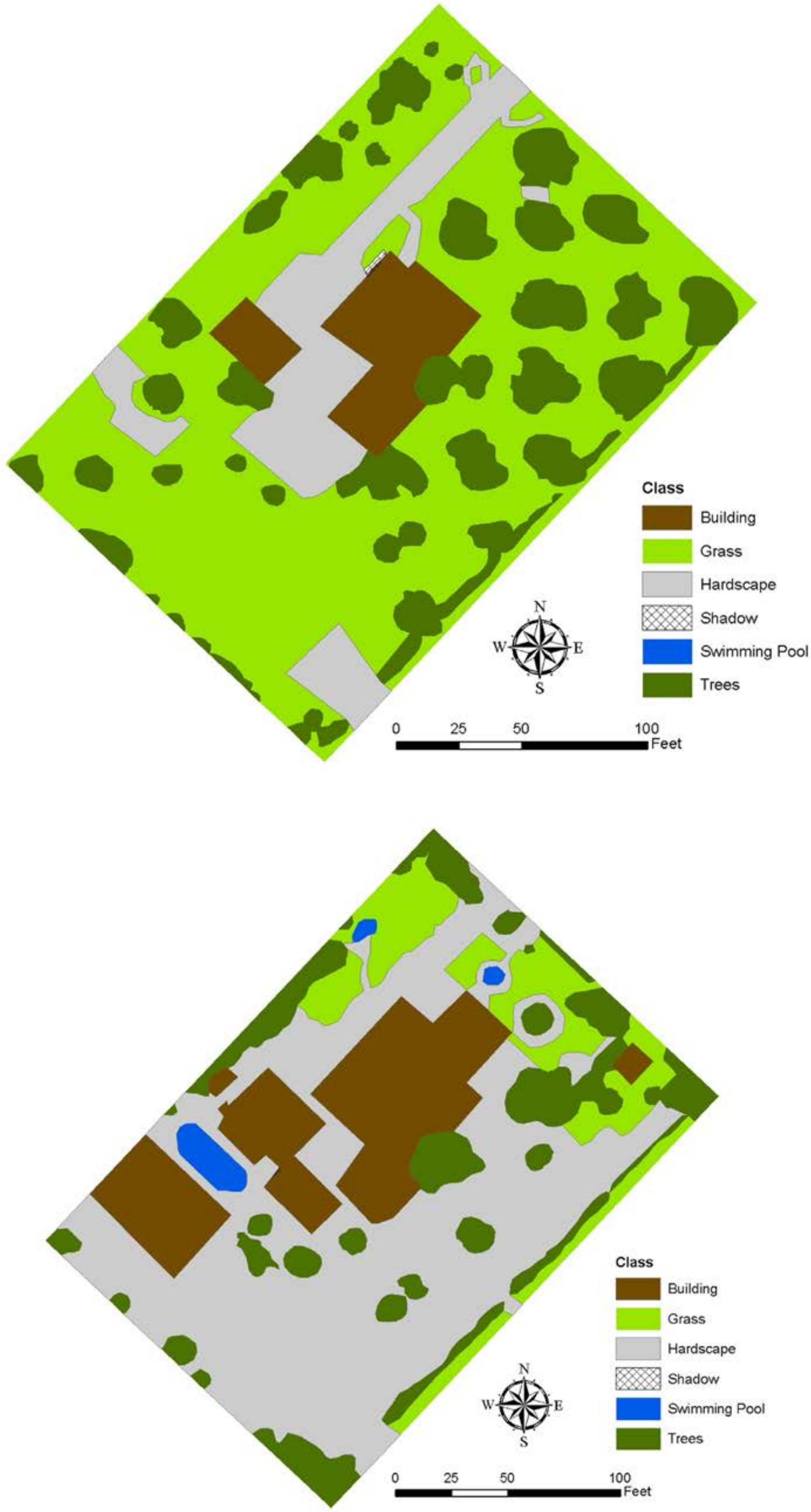

Fig. 2. Samples of digitized single-family residence lots using six classes: 1) building, 2) grass, 3) hardscape, 4) shadow, 5) swimming pool, and 6) trees (including shrubs) in 2000 (upper) and 2009 (lower).

Table 1
Population and housing statistics for the 20 most populous cities in Los Angeles Basin, 2010 (Population compiled from California Department of Finance (2011) and housing data from Los Angeles County Office of the Assessor (2010)). Lots with buildings in 2000–2001 and 2009–2010.

Cities/Council Districts	Population (2010)	No. of single-family homes	Fraction of modified homes (%)	No. of modified homes	No. of modified homes sampled	No. of other homes sampled
Los Angeles	4,094,764	346,006	9	30,756	463	300
LA#2	290,380	31,354	11	3420	34	20
LA#7	287,670	22,642	10	2205	30	20
LA #3	284,200	32,719	8	2737	30	20
LA#12	281,480	31,815	7	2369	30	20
LA#11	274,090	33,616	12	3911	39	20
LA#4	274,020	17,038	8	1289	30	20
LA#5	271,410	25,770	12	3033	30	20
LA#15	268,920	26,898	8	2103	30	20
LA#6	261,750	23,723	11	2493	30	20
LA#9	261,250	13,156	8	1003	30	20
LA#13	252,280	9365	8	759	30	20
LA#8	251,290	31,083	8	2485	30	20
LA#10	250,790	14,936	8	1127	30	20
LA#14	247,180	23,704	6	1432	30	20
LA#1	246,680	8187	5	390	30	20
Long Beach	494,709	51,497	11	5733	57	20
Glendale	207,902	18,133	6	1101	30	20
Pomona	163,683	18,307	5	993	30	20
Pasadena	151,576	16,923	9	1597	30	20
Torrance	149,717	25,275	8	2099	30	20
El Monte	126,464	7992	8	665	30	20
Inglewood	119,053	9798	8	792	30	20
Downey	113,715	14,134	10	1477	30	20
West Covina	112,890	14,628	7	962	30	20
Norwalk	109,817	18,694	10	1789	30	20
Burbank	108,469	14,190	13	1797	30	20
South Gate	101,914	9631	10	1000	30	20
Compton	99,769	14,226	6	898	30	20
Carson	98,047	16,052	10	1568	30	20
Santa Monica	92,703	6055	13	763	30	20
Hawthorne	90,145	6030	7	435	30	20
Alhambra	89,501	8996	8	740	30	20
Whittier	87,128	13,299	9	1138	30	20
Baldwin Park	81,604	9214	10	910	30	20
Totals	6,602,196	639,080	9	57,213	1060	680

Once land cover features on the stratified random samples were digitized, we merged land cover features by land cover in each sample to yield the total area of each land cover category. The merged data were then spatially joined by each city or council district for the statistical analysis. The digitized land cover features at each of the two dates were then compared using the field calculator within the attribute table.

3.5. Statistical analysis

We calculated summary statistics for land cover types in each of the sampled categories in the 19 cities and 15 council districts. We then calculated the total cover for each time period for all single-family neighborhoods in each of the units by weighting the averages by the area within each unit that either had or did not have a change in home area reported by the Assessor. This extrapolation was also used to calculate the total area of land cover changes in units and across the entire study area for the 639,080 parcels with single-family homes in our study. All calculations were for single-family residential parcels only and do not include streets and roads. Calculations were performed by extracting data with the Select by Attribute and Field Calculator tools in ArcGIS 10.3. and exporting to the JMP Pro 12.0 statistical software (SAS, Cary, North Carolina) for calculation of descriptive statistics and other analyses.

4. Results

4.1. Distribution of lot size and building footprints for single-family homes

The average lot size for single-family homes varied substantially (Fig. 3). The fraction of building area relative to lot size (i.e., floor-area ratio; FAR) that is recorded by the Los Angeles County Office of the Assessor on all single-family home lots (639,080) increased from 22.0% in 2000 to 22.8% in 2009. This proportion increased in all 20 cities from 2000 to 2009, ranging from 0.3% (Pomona) to 2.1% (Santa Monica). Floor-area ratio increased more than 1% in Santa Monica (2.1%), LA#11 (1.7%), LA#5 (1.3%), Long Beach (1.2%), Burbank (1.2%), and Downey (1.1%). Compton (0.4%), Glendale (0.4%), West Covina (0.4%), LA#1 (0.4%), and Pomona (0.3%) showed less than 0.5% increase in the fraction of building area from 2000 to 2009.

4.2. Land cover change from 2000 to 2009

From the stratified random samples (n = 1740, Table 1), the following results were extracted. Taking the cities and City of Los Angeles council districts as the units of analysis, the average proportion of each lot covered by building and hardscape increased both for lots where permitted expansion was documented by the Assessor's office and for lots where increased square footage was not documented (Fig. 4).

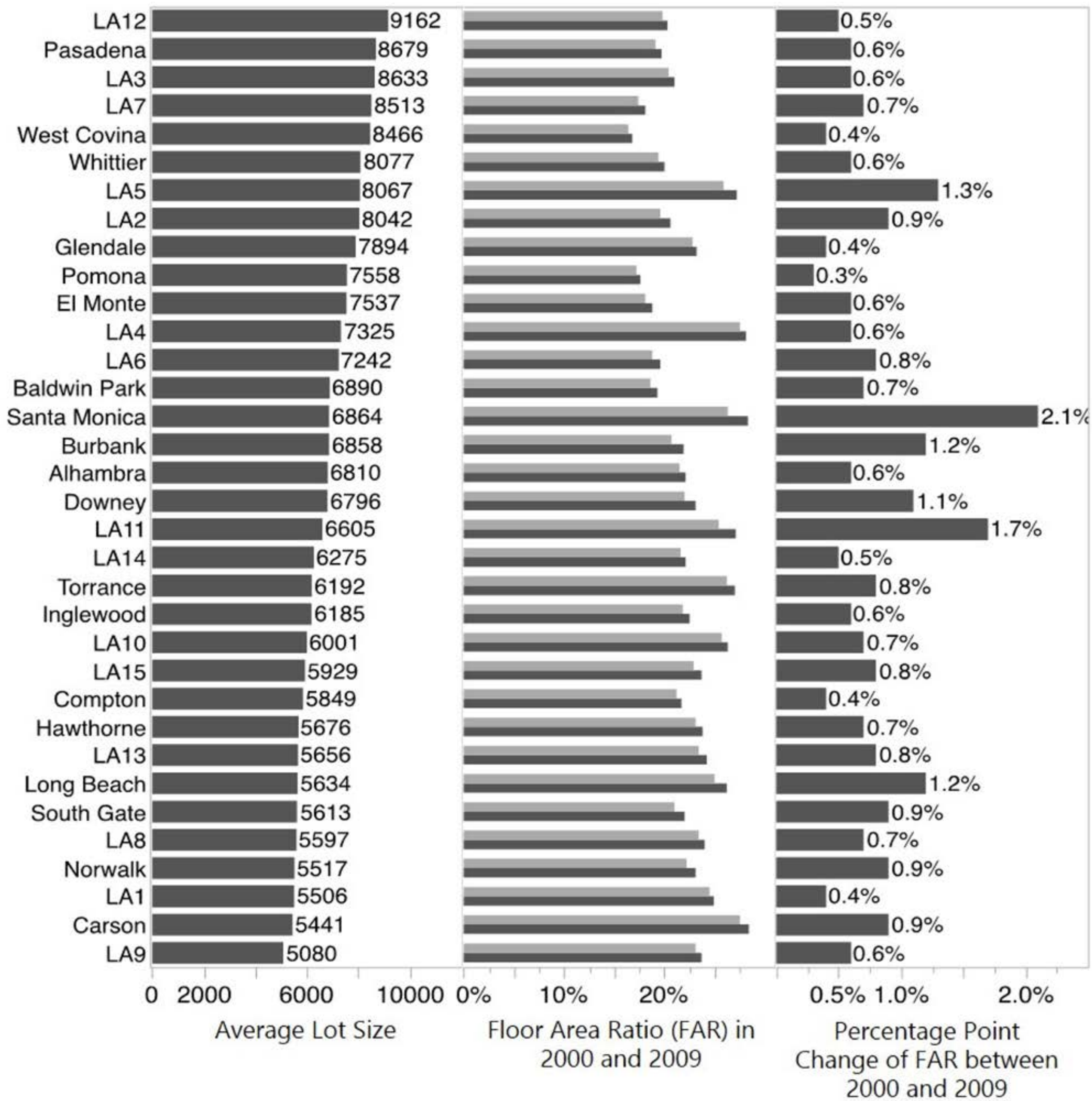

Fig. 3. Average lot size, floor area ratio in 2000 (light gray) and 2009 (dark gray), and average percentage point change of floor area ratio between 2000 and 2009 for all single-family home lots (n = 639,080) in the 20 most populous cities in the Los Angeles Basin.

An additional 9.1% of lots was covered by buildings (13% for recorded development and 2.8% for no recorded increase). Hardscape increased 8.7% (10.2% for recorded development and 6.5% for no recorded increase). The average increase in impervious surfaces was 17.8% ± 5.9% s.d. (n = 34). For sites with recorded development, average increase in buildings and hardscape was 23.2% ± 8.4% s.d. and for no recorded development average increase in buildings and hardscape was 9.3% ± 5.7% s.d.

Similarly, tree cover decreased an average of 13.6% (16.9% for recorded development and 8.4% for no recorded increase). Grass cover declined 4.1% (6.2% for recorded development and 0.8% for no recorded increase). Overall, average green cover declined 17.7% ± 6.0% s.d. (n = 34). For sites with recorded development, average decline in green cover was 23.1% ± 8.5% s.d. and for no recorded development average decline in green cover was 9.2% ± 5.8% s.d.

The changes in pervious (trees and grass) and impervious (building and hardscape) surfaces were a mirror image (Fig. 5). This pattern was consistent across jurisdictions with widely variable lot sizes. This pattern strongly suggests that loss of grass cover was not the result of conversion to shrubs or trees, but rather by the replacement of grass by impermeable surfaces.

The green cover changes in single-family neighborhoods across the jurisdictions (Fig. 6) are all negative and show a highly variable spatial pattern across the Los Angeles Basin between 2000 (Fig. 7) and 2009 (Fig. 8). The decrease in green cover in single-family neighborhoods ranges from 14% to 55% (Fig. 6). In 2000, single-family neighborhoods in the study area ranged from 42% green cover in Hawthorne to 70% green cover in Baldwin Park, with

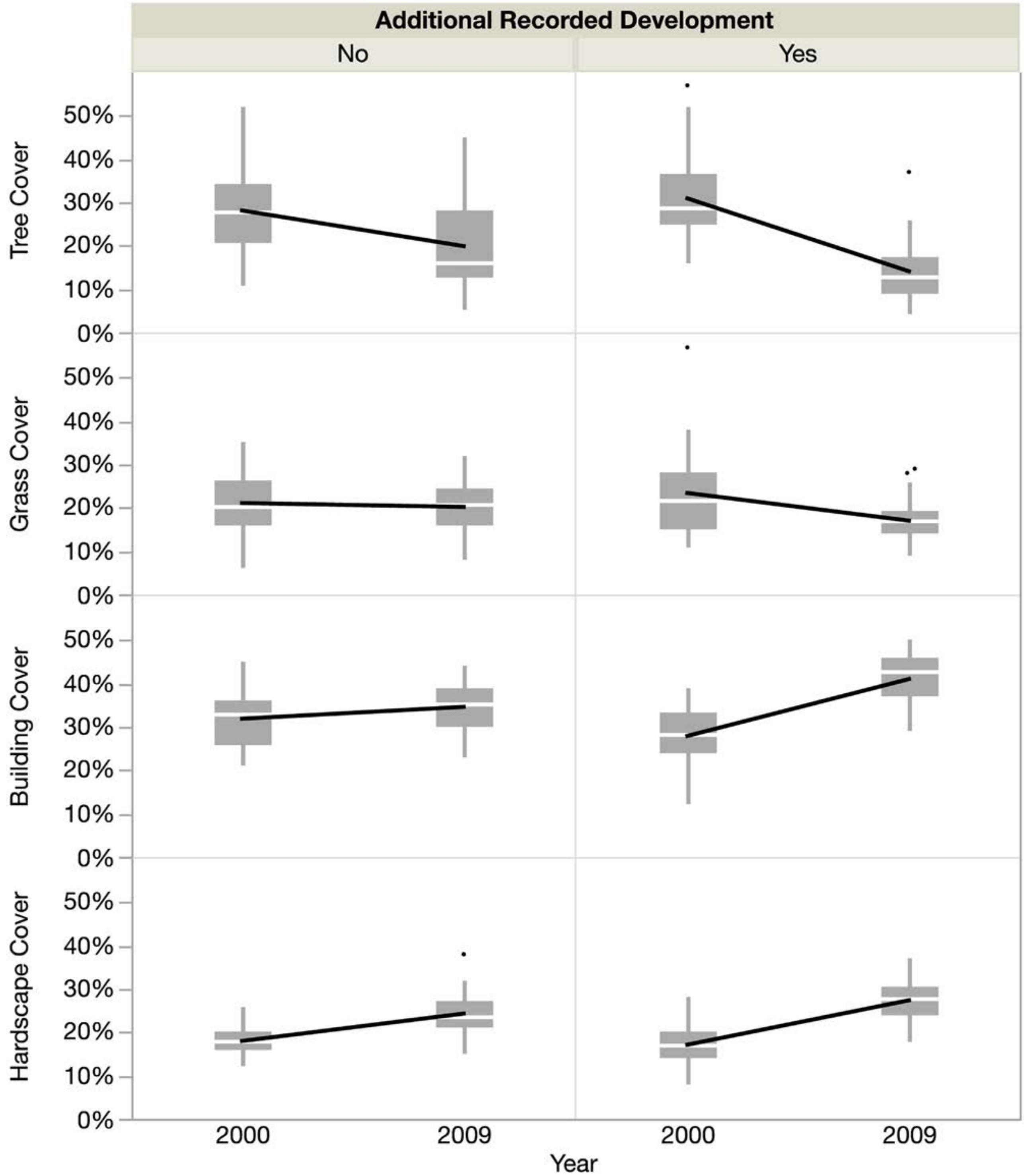

Fig. 4. Change in lot cover for trees/shrubs, grass, buildings, and hardscape between 2000 and 2009 for single-family residences in 15 Los Angeles City Council Districts and 19 cities that either did or did not have additional development recorded for the property by the Assessor. Whisker plots show median value, first and third quantile, and outliers. Solid black lines connect means.

an average of 52%. By 2009, the green cover in Baldwin Park's single-family neighborhoods had declined 39 percentage points (from 70% to 31% green cover, a loss of 55% of the existing green cover in 2000), indicating the most dramatic loss of cover within a city or council district.

Looking specifically at lots where building additions were recorded, the loss of tree and grass cover was not consistent across jurisdictions. For example, developed lots in Baldwin Park lost 55% green cover and those in Compton lost 41%, while the developed lots in Pasadena lost only 14% and Glendale only 15% of the green cover present in 2000. As a whole, the average green cover for sites with reported increases in building area dropped by nearly a third, from 52% in 2000 to 35% in 2009.

Remarkably, only a quarter of lots (24%; 170 of 720) without additional recorded development had more tree canopy at the end of the study period than at the beginning and for lots with addi-

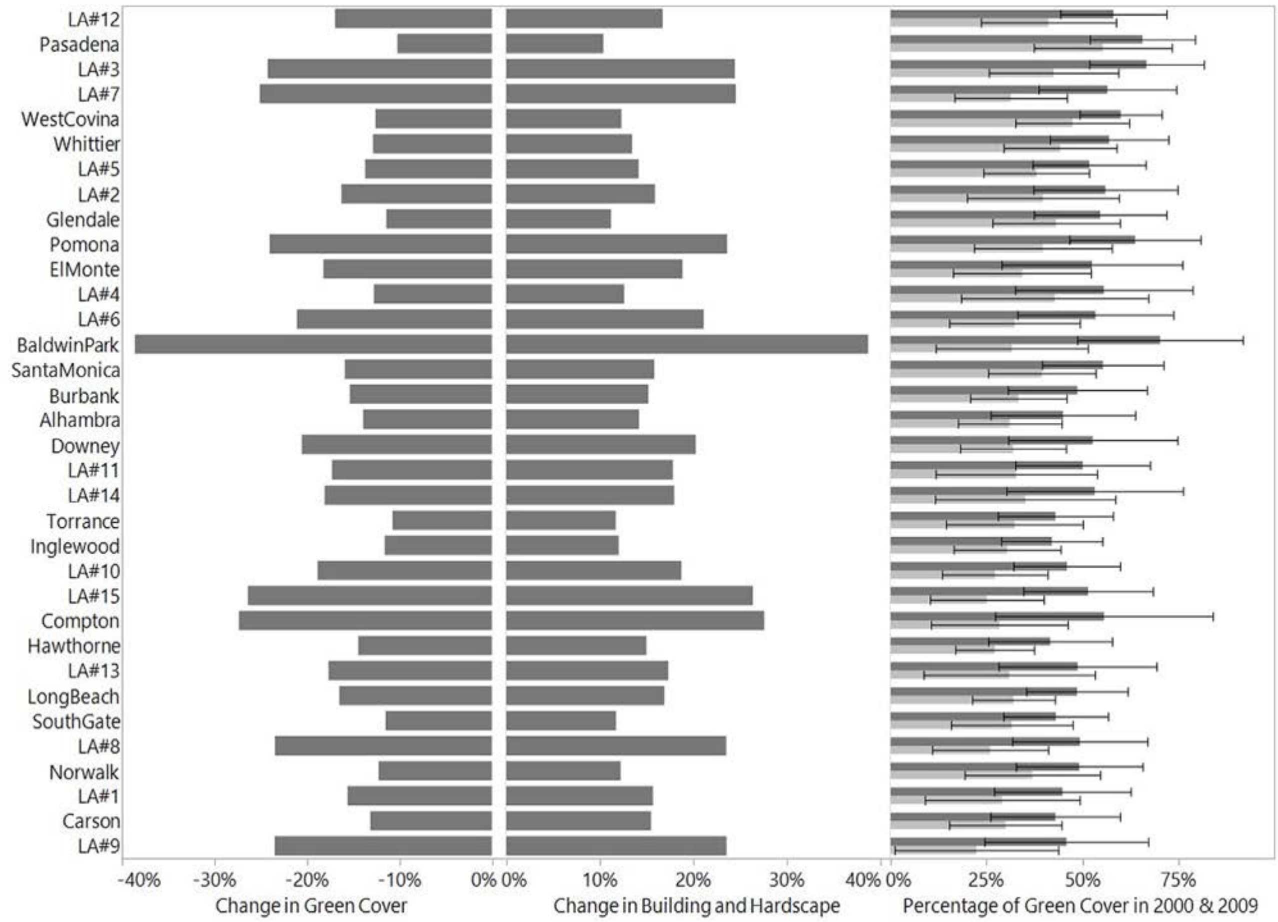

Fig. 5. Bars (ordered by average lot size) show changes in green cover (left) and building and hardscape (center) between 2000 and 2009; and percentage of green cover (right) in 2000 (dark gray) and 2009 (light gray) with standard deviations in the 20 largest cities in Los Angeles County.

tional development that proportion declined to 12% (126 of 1020). The cover of grass increased on 381 of 1020 sampled lots (38%) for which building footprint additions were recorded and on 308 of 720 sampled lots (42%) for which building footprint additions were not recorded. Increases in both trees and grass occurred on only 9 lots for which building footprint additions were recorded (0.8%), and on 25 single-family home lots for which building footprint additions were not recorded (3.5%).

4.3. Cumulative green cover loss

One of the most important consequences of the trends in single-family neighborhood redevelopment is the resulting decrease in green cover in neighborhoods across individual cities and the metropolitan region as a whole. The green cover losses (Fig. 4), not surprisingly, closely tracked the building and hardscape gains. Baldwin Park, Compton, LA#7, LA#15, and Downey were the top five study units in terms of green cover loss on single-family home lots for which building footprint additions were recorded.

Taken as a whole, the results show that the 20 cities studied have lost approximately 6.9 km^2 of tree cover and approximately 1.6 km^2 of grass cover on single-family home lots for which building footprint additions were recorded by the Los Angeles County Office of the Assessor, and 34.8 km^2 of tree cover and approximately 4.0 km^2 of grass cover on single-family home lots for which building footprint additions were not recorded. This result represents a 9.6% decrease in tree cover and a 1.0% decrease in grass cover across all of the 639,080 single-family lots in the 20 cities studied.

4.4. Digitizing errors

The aerial photographs contained only red, green, and blue color bands without an infrared band, which restricts implementing image classification approaches. We found that heads-up digitizing can generate interpretation errors so we tried to minimize errors by comparing total area of land cover with lot size. Digitizing errors as measured by a comparison of the digitized areas with the total lot size were less than $\pm 20\,ft^2$ (<0.2% of lot size), which we believe is acceptable, given the magnitude of the differences in land cover detected.

5. Discussion

Green cover changed substantially on residential lots in single-family residential neighborhoods across Los Angeles County during the decade examined here. These results present a troubling reversal of the long-term trend in urban forest cover in Los Angeles. This reversal was also detected for 2005–2009 (Nowak and Greenfield, 2012) and points to a failure of existing policies to protect and increase tree cover in various jurisdictions. Furthermore, the discovery that homes for which no additional legal building area had been reported to the Assessor nevertheless had both increased building area and lost tree cover has potentially significant ramifications for municipal finance.

Gillespie et al. (2012) reported long-term tree cover increase between the 1920s and 2006 in representative areas of urban Los Angeles. Their results show that since the 1950s tree density

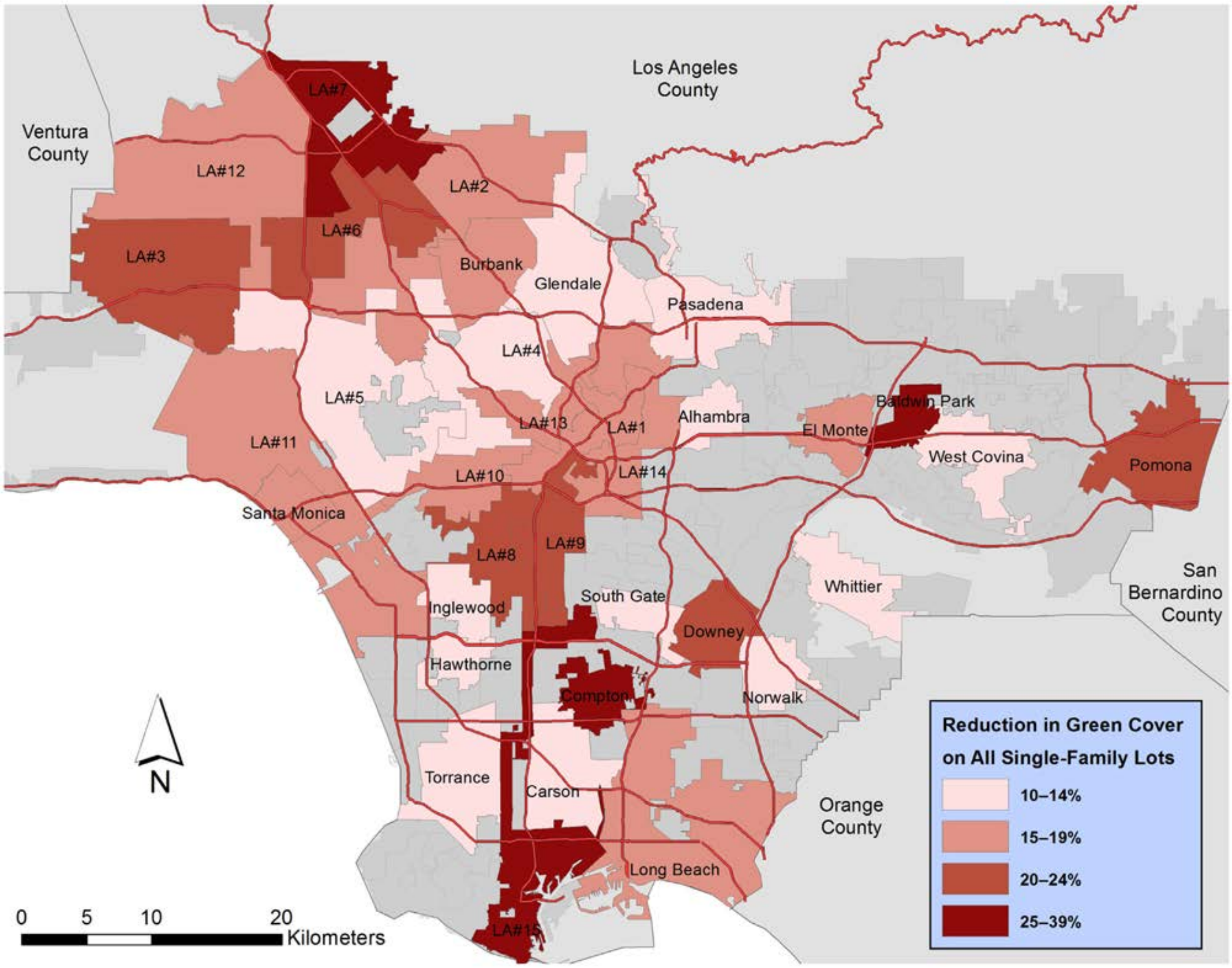

Fig. 6. Percent point reduction in green cover between 2000 and 2009 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

increased much more substantially on private land than on land under public ownership. Although we measured tree canopy area, which is not directly comparable with the tree stems per acre measured by Gillespie et al. (2012), our results indicate a reversal of the long-term increase in urban forest cover dating from the 1920s through 2000 and underscore the vulnerability of the urban forest to the changing attitudes about trees on private property and especially in residential neighborhoods.

The relatively recent and rapid decline in urban tree cover in the Los Angeles Basin undermines the ability of jurisdictions to adapt to increased urban temperatures, manage urban stormwater, and maintain urban nature and quality of life. Two important processes may explain these patterns.

First, as documented in this study, the redevelopment of single-family homes through both additions and replacement construction has resulted in homes filling more of each parcel, with an associated decrease in space for green cover. In addition, property owners are increasing hardscape area significantly. For the neighborhoods across much of the region that were laid out in the post-World War II housing boom with homes that were scaled to their parcel size, this redevelopment results in large houses on small- or medium-sized parcels and a dramatic decline in green cover. Such redevelopment is seen in cities in this study with large areas of wealthy, single-family neighborhoods, such as Santa Monica, and in socioeconomically similar council districts in the City of Los Angeles (e.g., LA#3, LA#11). Our results provide evidence that the aggressive, lot-filling redevelopment of these neighborhoods (i.e., mansionization) is indeed resulting in significant changes in the urban fabric.

Second, we observed a familiar pattern from the urban forestry literature, which is continued low levels of green cover in the poorest areas, where we documented significant declines as well. The disparity between rich and poor neighborhoods in terms of tree cover is so prevalent across the U.S. that recent scholars have observed that “trees grow on money” (Schwarz et al., 2015). Such is the case in Los Angeles County, where poorer cities and council districts show both low green cover and significant declines in green cover (e.g., Compton, LA#9) during the decade we measured. We assume that these declines are associated with either owners or absentee landlords removing trees to avoid the expense of their care or to make way for legal or illegal housing densification. Ironically, both rich and poor neighborhoods alike saw reductions in green cover and increases in hardscape during the study period, but the poorest neighborhoods started with less green cover and the smallest parcel sizes to accommodate additional development. It is our observation that speculative development drives the increased home and hardscape extent in middle and upper income neighborhoods, while economic necessity leading to densification drives the pattern in low income neighborhoods and future research could investigate these overlapping forces in the market.

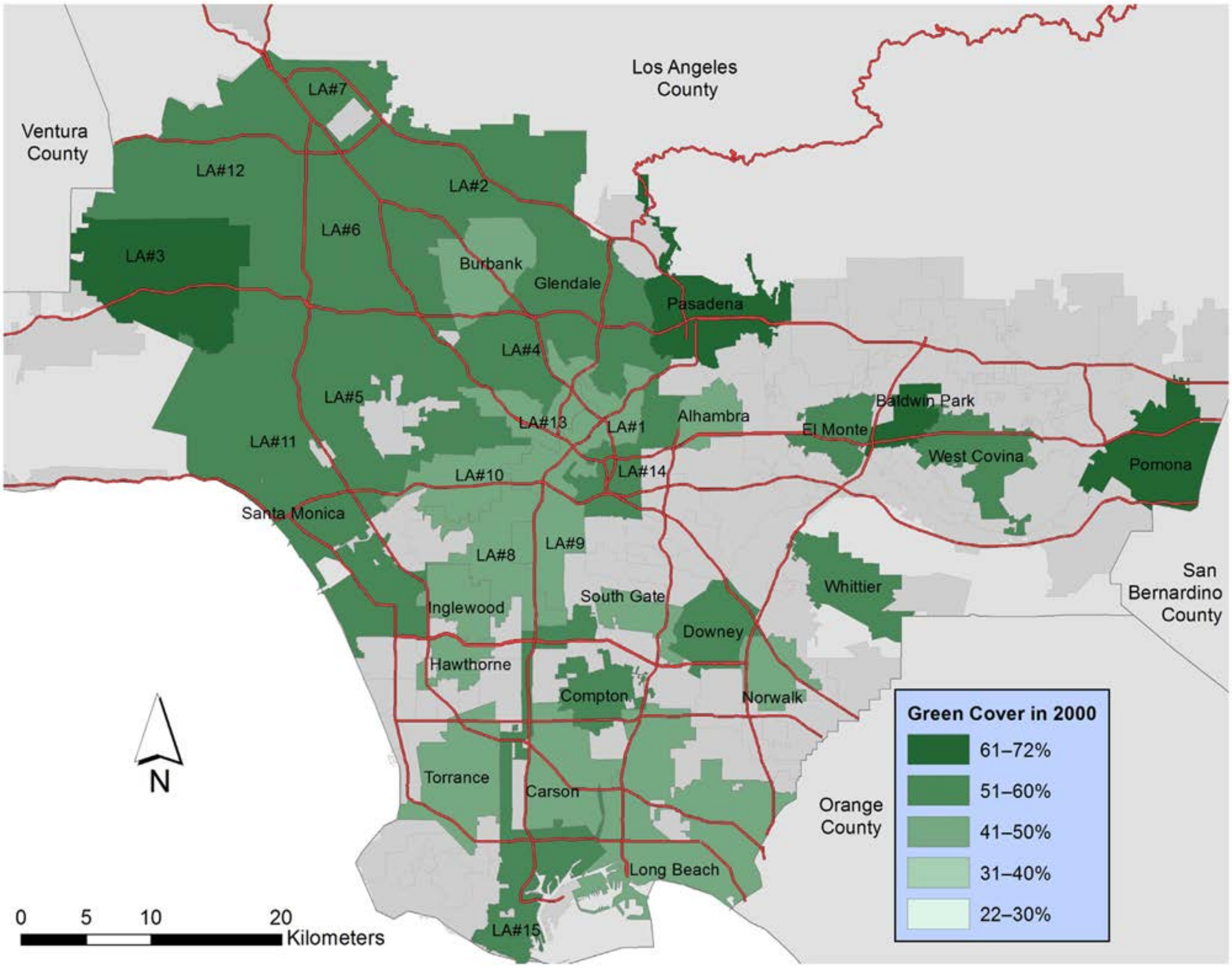

Fig. 7. Percentage green cover in 2000 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

5.1. Efforts to increase tree cover

In 2006, then-Mayor Antonio Villaraigosa established the "Million Trees LA" initiative, which focused on planting new trees on private land rather than public land (McPherson et al., 2011; Pincetl, 2010). McPherson et al. (2008) developed tree-planting scenarios in which the City of Los Angeles planned to encourage residents to plant 290,000 new trees through 2010. Although the benefits of such a program would take many years to manifest, our results from 2009 indicate that if any increases in tree cover on single-family residential properties resulted from the program, they were more than offset by tree removal to accommodate additional hardscape and larger homes.

Monitoring of urban forest cover would have been a valuable tool for this program, which merged with another tree program in 2010 to create a new program known as City Plants. The tree-planting initiative was arguably a failure in policy direction because it did not recognize that tree canopy was already being eroded rapidly for construction and hardscape. Rather than focusing on protecting trees that had been grown and nourished over decades (see Gillespie et al., 2012), it attempted to increase canopy cover by planting new trees. In retrospect, this effort was shoveling sand against the tide.

Many cities in the U.S. implemented large-scale tree planting programs in the mid-2000s because of a growing recognition that urban forest cover can improve human health, socioeconomic conditions, and the environment (Arnberger and Eder, 2012; Clarke et al., 2013; Gillespie et al., 2012; McPherson et al., 2011; Nowak and Greenfield, 2012; Pincetl et al., 2013). Similar to our results, however, Nowak and Greenfield (2012) investigated 20 U.S. cities over the previous decade and reported that tree cover had decreased in 17 of them (including Los Angeles). Tree cover had been reduced by about 0.27% per year and impervious surface had increased by 0.31% per year (Nowak and Greenfield, 2012).

5.2. Legal or illegal residential development

Our results also uncovered a pattern we were not originally investigating—widespread increases in building footprint for parcels where no legal increase in square footage had been reported to the Assessor. We had included samples of parcels where the recorded building footprints had not changed as a control to compare with the effects of increasing building footprints on land cover, expecting that changes in tree cover at such parcels would be the result of natural changes in landscaping over time, impacts from re-landscaping, and other factors. Instead, we discovered that the remotely measured footprints of buildings in many instances had increased without being recorded by the Assessor. The two likely explanations are that 1) the owners of these properties had building permits to increase building area but those increases were not reported to the Assessor or were delayed in being reported, or 2) the owners did not have permits for the additional building

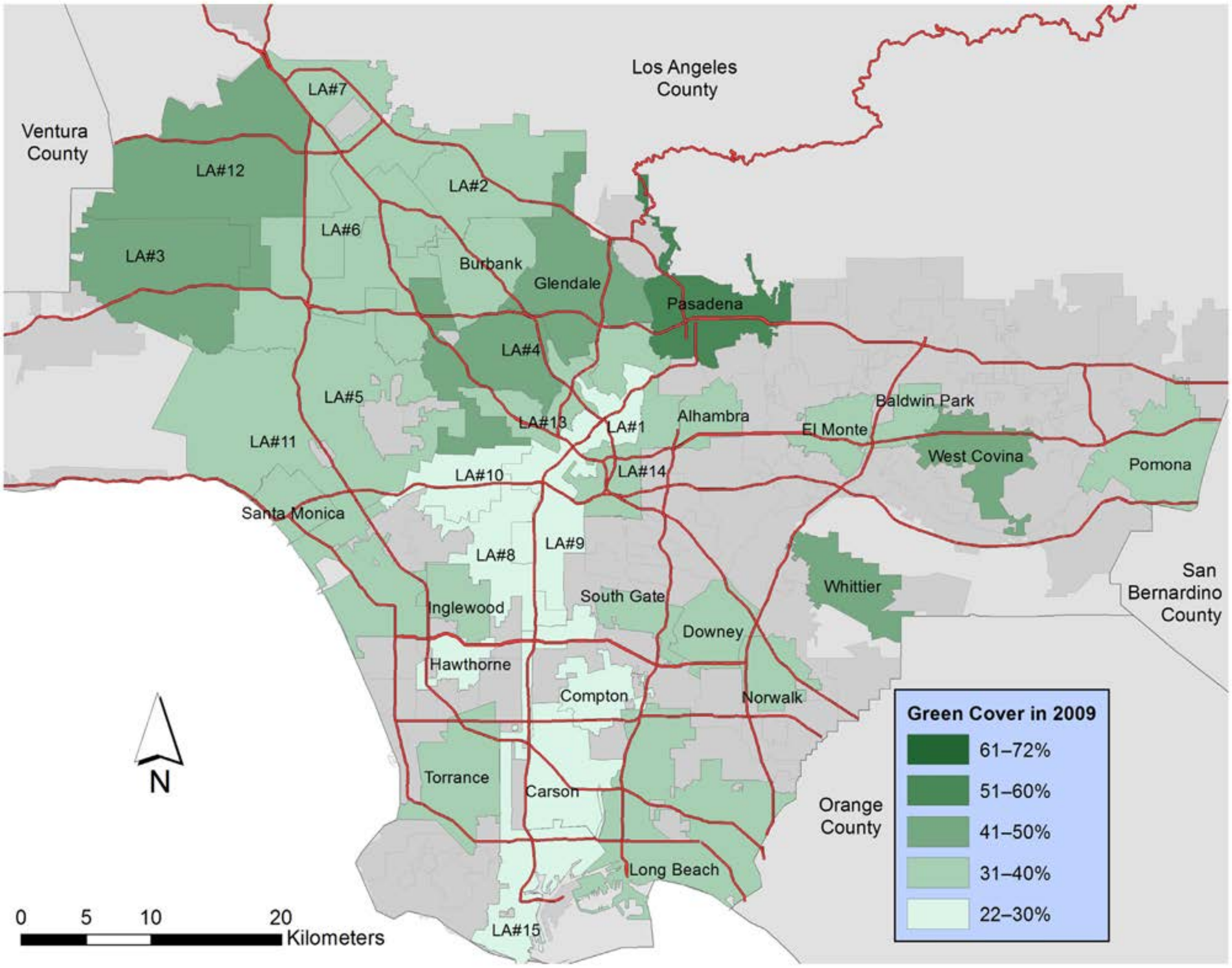

Fig. 8. Percentage of green cover in 2009 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

area. In either scenario, the Assessor had not recorded the full area of the houses in many instances. Furthermore, the level of additional, unrecorded development was significantly greater in the City of Los Angeles compared with all other cities. The two possible explanations for this pattern are that the City of Los Angeles is ineffective at ensuring compliance with its building codes and/or it is much slower at reporting new permitted building to the Assessor. Smaller cities with good reputations for a well-functioning city government (e.g., Burbank, Glendale) have much lower levels of presumably unpermitted development and far lower rates of urban forest removal as a result.

Our discovery of apparently widespread expansion of home size without associated recording by the Assessor has important implications for municipal finance. Because of the tax system in California, upward assessment of property values is significantly constrained. One of the few opportunities for municipalities to increase tax revenues is when properties are redeveloped. The existence of many properties for which redevelopment has occurred but reassessment for tax purposes (tied to the legal square footage) has not is therefore extraordinarily problematic because it represents the annual loss of millions of dollars of uncollected property taxes.

6. Conclusions

Fully one-third of the existing green cover of each single-family residential lot is lost during the average home expansion in the Los Angeles Basin. The rate of redevelopment in our study area was sufficiently high that green cover is declining cumulatively at a substantial annual rate across single-family neighborhoods as a whole. Because low density residential land uses represent a substantial portion of the land area of most cities, actions to address these private land uses will be necessary to protect the ecosystem services and natural amenities provided by trees and green cover.

The pattern of residential redevelopment seen in the decade we measured may have been subsequently slowed by an economic downturn, but the following economic recovery has seen an equally rapid increase in housing prices and associated development. Indeed, for all cities with population growth and appreciating real estate prices over the long run, increases in home size and resulting decrease in green cover are likely, and this factor may be at the root of at least part of the documented national patterns of urban tree cover decline (Nowak and Greenfield, 2012). Furthermore, the trend toward increased densification across all land uses as manifested by efforts to weaken single-family zoning and densify multi-family zoning in cities with high housing pressures (e.g., Los Angeles, Seattle) also seems likely to continue. As we have shown previously (Lee et al., 2010), residential density decreases green cover in Los Angeles cities while laws that protect tree species on private property and limit floor-area ratios are associated with higher green cover, similar to findings in other regions (Troy et al., 2007; Landry and Pu, 2010). Without regulations that specifically protect existing tree and green cover the ability of cities to maintain a healthy and ecologically vibrant urban landscape will be hampered.

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