CITY FOREST CREDITS

Tree Preservation Protocol – 100 Years

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Introduction

This City Forest Carbon Protocol sets forth the requirements for Tree Preservation projects in urban areas in the U.S. to quantify carbon dioxide sequestration from woody biomass. That woody biomass is referred to herein by the broader term "urban forest."

This protocol provides eligibility rules, methods for quantifying biomass and CO_2 storage, and reporting, monitoring, issuance of credits, reversal, and verification requirements. We have been guided in our drafting by one of the foundational documents for carbon protocols, the World Resources Institute/World Business Council for Sustainable Development Greenhouse Gas Protocol for Project Accounting, which describes greenhouse gas ("GHG") project accounting principles. We refer to this document as the WRI GHG Protocol.

Our goal is in this protocol is to provide for accounting of net GHG reductions is a consistent, transparent, and accurate manner, consistent with the principles and policies set forth in the WRI GHG Protocol document. This process will form the basis for GHG reductions that are real, additional, permanent, verifiable, and enforceable, which can then result in the issuance by the registry of City Forest Credits of carbon credits, called City Forest Carbon+ Credits™.

Urban forests in the U.S. are estimated to store over 643 million tonnes of CO_2.[1] The co-benefits of urban forests include air quality improvements, energy savings from reduction of the urban heat island effect, slope stability, bird and wildlife

[1] Nowak, David J., et al. "Carbon storage and sequestration by trees in urban and community areas of the United States." *Environmental Pollution* 178 (2013): 229-236, 231.

habitat, sound and visual buffering, public health improvements, safety, livability, social cohesiveness, economic improvements, and more.[2] Urban trees clearly influence air temperatures and energy and affect local climate, carbon cycles, and climate change.[3]

Recently updated research documents the magnitude of the contributions of urban forests to climate mitigation. Annually, these trees produce a total of $18.3 billion in value related to air pollution removal ($5.4 billion), reduced building energy use ($5.4 billion), carbon sequestration ($4.8 billion) and avoided pollutant emissions ($2.7 billion).[4]

Moreover, almost 80% of the population worldwide lives in urban areas, and urbanization is a significant demographic trend of the 21st century. The array of benefits delivered by urban trees directly links to human health and life in cities and towns.

Documents and Standards for Protocol Development

No single authoritative body regulates carbon protocols or determines final standards. The Stockholm Environment Institute's Carbon Offset Research and Education resource lists the various institutions and programs that have set out formulations of basic principles that every carbon offset protocol should contain.[5]

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[2] See Alliance for Community Trees, Benefits of Urban Forests: a Research List at http://www.actrees.org/files/Research/benefits_of_trees.pdf

[3] Nowak, 229.

[4] Nowak, David J. et al, "U.S. Urban Forest Statistics, Values, and Projections," *Journal of Forestry* 116(2) (2018): 164-177

[5] See CORE at http://www.co2offsetresearch.org/policy/ComparisonTableAdditionality.html

CORE lists twenty-five different programs or institutions that have either developed standards for protocols or issued standards and rules for their own programs. These institutions range from international bodies such as the Kyoto Protocol, the World Resources Institute, and the International Organization for Standardization, to U.S. carbon programs such as the Regional Greenhouse Gas Initiative and Midwest Greenhouse Gas Reduction Accord, to registries such as the American Carbon Registry, the Climate Action Reserve, and the Verified Carbon Standard.

The standards issued by these bodies vary, and the specific rules formulated to give content to these different standards vary even more. For example, the Clean Development Mechanism under the UN Framework stemming from the Kyoto Protocol lists 115 different approved baseline and monitoring methodologies for large scale offset projects.

To complicate matters, the environmental and carbon community have tolerated a de facto different standard between compliance protocols and voluntary protocols. Compliance protocols exist in cap and trade jurisdictions like California. Because these compliance protocols establish the rules for credits that will offset actual regulated GHG emissions from monitored sources, greater rigor is expected than in voluntary protocols, where purchasers are buying credits voluntarily to reduce their carbon footprint, not to offset regulated emissions.

There is, nonetheless, a general consensus that all carbon offset protocols must contain the following:

- Accounting Rules: offsets must be "real, additional, and permanent." These rules cover eligibility requirements and usually include baselines for additionality, quantification methodologies, and permanence standards.

- Monitoring, Reporting, Verification Rules: monitoring, reporting, and verification rules ensure that credits are real and verifiable.

Certification, enforceability, and tracking of credits and reversals are performed by specific programs or registries, guided by language in the protocol where relevant.

Over the last fifteen years, several documents setting forth standard and principles for protocols have emerged as consensus leaders for programs attempting to develop their own offset protocols for specific project types. We will follow and refer most often to:

- WRI GHG Protocol;
- Clean Development Mechanism, Kyoto Protocol, now part of the UN Framework Convention on Climate Change ("CDM").

We have been guided by the WRI GHG Protocol and have modelled this urban Tree Preservation Protocol after the "avoided conversion" protocols that have been developed for forest land. Further discussion of protocol principles and requirements will be posted soon discussing both the Tree Planting and the Tree Preservation Protocols.

Recognition of Distinct Urban Forest Issues in Protocol Development

The task for the City Forest Drafting Group was to take the principles and standards set forth in these foundational documents and adapt them to urban forestry. Urban and community forestry and its potential carbon projects are different than virtually all other types of carbon projects:

- Urban forests are essentially public goods, producing benefits far beyond the specific piece of land upon which individual trees are planted.

- New tree planting in urban areas is almost universally done by non-profit entities, cities or towns, quasi-governmental bodies like utilities, and private property owners.

- Except for a relatively small number of wood utilization projects, urban trees are not merchantable, are not harvested, and generate no revenue or profit.

- With the exception of very recent plantings begun in California using funds from its Greenhouse Gas Reduction Fund, no one currently plants urban trees with carbon as a decisive reason for doing the planting.

- Because urban tree planting and maintenance are expensive relative to carbon revenues, urban forestry has not attracted established for-profit carbon developers.

- Because urban forest projects will take place in urban areas, they will be highly visible to the public and easily visited by carbon buyers. This contrasts with most carbon projects that are designed to generate tradeable credits purchased in volume by distant and "blind" buyers.

During the drafting process, we remained mindful at all times that the above unique factors of urban forestry distill down to three central attributes:

- Urban trees deliver a broad array of documented environmental and human health benefits,

- Urban trees are essentially a public good delivering their array of environmental benefits to the people and communities living in cities and towns – almost 80% of the population, and

- There are little to no harvests, revenues, or profits for those who preserve and grow the urban forest.

These three key attributes lead to the conclusion that urban forest projects are highly desirable, bringing multiple benefits to 80% of the population in a public good that is unlikely to be gamed or exploited.

Our task then was to draft urban forest protocols that encouraged participation in urban forest projects through highly-credible protocols that addressed not just catch-phrase principles of carbon protocols, but the policies underlying those principles. Where the needs of urban forest practicality required a variance from accepted principles of carbon protocols, we strived to develop solutions to those variances to maintain a high level of stringency.

1. Eligibility Requirements

1.1 Project Operators and Projects

A Project requires at least one Project Operator, an individual or an entity, who undertakes a Project, registers it with the registry of City Forest Credits (the "Registry"), and is ultimately responsible for the project and its reporting.

A Project may include multiple parcels or properties. But the dates of the Preservation Commitments under Section 4.1 of the parcels or properties within a Project may not exceed the span of one year.

1.2 Project Implementation Agreement

A Project Operator must sign a Project Implementation Agreement (PIA) with the Registry setting forth the Project Operator's obligation to comply with this Protocol.

1.3 Project Location

Project Areas must be located in parcels within or along the boundary of at least one of the following:

A. The Urban Area boundary ("Urban Area"), defined by the most recent publication of the United States Census Bureau (https://www.census.gov/geo/maps-data/maps/2010ua.html);

B. The boundary of any incorporated city or town created under the law of its state;

C. The boundary of any unincorporated city, town, or unincorporated urban area created or designated under the law of its state;

D. The boundary of land owned, designated, and used by a municipal or quasi-municipal entity such as a utility for source water or water shed protection;

E. A transportation, power transmission, or utility right of way, provided the right of way begins, ends, or passes through some portion of A through D above.

In recognition of the urban-rural gradient and the strong public policy interest in preserving open space and forest land within and along that gradient, the Project Area may lie outside the boundary of one of A through E above. But any Project Area outside the boundary of A through E above must lie within or across parcels whose forest or open space is being preserved, and that constitute a sequence, chain, or progression of contiguously connected parcels. In addition, some part of the property line of one of those contiguously connected parcels must be coterminous with the boundary of one of A through E above.

1.4 Defining the Project Area

The Project Operator must specify the Project Area and provide an electronic map of the Project Area with geospatial location in any file type that can be imported and read by Google Earth Pro.

The Project Area must

A. Be within one of the areas specified in Section 1.3 on Project Location. The Project Area may consist of contiguous or non-contiguous parcels, subject to the requirements of Section 1.3. Project Area boundaries do not have to follow land parcel boundaries; and

B. Meet the requirements of Section 4.3; and

C. Have at least 80% tree canopy in locations that receive at least 20 inches of precipitation per year or 60% tree canopy in locations that receive less than 20 inches of precipitation per year

Precipitation may be determined by maps produced by a government agency, or from the average of the most recent ten years of data from the nearest government precipitation measurement station for which data is publicly available.

Forests naturally have spaces between trees and gaps, and locations of these gaps may change over time. The Project Operator may choose to map gaps in the forest and exclude those non-treed areas from the Project Area. If the Project Operator does not exclude gaps from the Project Area, determination of the carbon stock and sequestration on the Project Area must account for tree canopy gaps using a method that is consistent with the methods for quantifying Project Stock in Section 10.1.A.

1.5 Ownership or Eligibility to Receive Potential Credits

The Project Operator must demonstrate ownership of potential credits or eligibility to receive potential credits by meeting at least one of the following:

A. Own the land and potential credits upon which the Project trees are located; or

B. Own an easement or equivalent property interest for a public right of way within which Project trees are located and accept ownership of those Project trees by assuming responsibility for maintenance and liability for them; or

C. Have a written and signed agreement from the landowner, granting ownership to the Project Operator of any credits for carbon storage, other greenhouse gas benefits, and other co-benefits delivered by Project trees on that landowner's land. If the Project Area is on private property, the agreements in this sub-section must be recorded in the public records in the county where the property is located. The recordation requirement can be satisfied if the agreements specified in this sub-section are contained in a recorded easement, covenant, or deed restriction on the property.

2. Project Duration

As set forth in Section 6, the Registry will issue credits based on at least a 100-year Preservation Commitment (see Section 4.1 for definition of Preservation Commitment). Project Operators must monitor and report under Section 7 throughout their Preservation Commitment. Projects may earn credits after 100 years as provided in Section 9.

3. Project Documentation and Record-keeping

Project Operators shall submit all documents required by this Protocol and the Registry, including an Application, a Project Implementation Agreement, a Project Design Document, documents demonstrating the Preservation Commitment under Section 4.1, and quantification documents.

Project Operators shall keep all documents and forms related to the project for the Project Duration. If the Project seeks credits after the Project Duration, it must retain all documents for as long as it seeks issuance of credits. This information may be requested by the Registry at any time.

The Registry requires data transparency for all Projects. For this reason, all project data reported to the Registry will be publicly available on the Registry's website or by request.

4. Demonstrating Preservation and Threat of Loss

To earn credits for Tree Preservation projects (Trees Preserved from Removal), a Project Operator must meet the requirements of Sections 4.1, 4.2, and 4.3:

4.1 That the trees in the Project Area have been preserved as follows (the actions in A and B below are referred to as the "Preservation Commitment"):

A. If the Project Area is privately owned, that the trees are preserved from removal by a recorded easement, covenant, or deed restriction (referred to hereafter as "Recorded Encumbrance") with a term of at least 100 years. Or,

B. If the Project Area is publicly owned, that the trees are preserved from removal by either:

i. A Recorded Encumbrance with a term of at least 100 years; or

ii. A zoning designation and development regulation, adopted by the governmental body with authority over that land, which preserves the trees in the Project Area from removal for at least 100 years ("Governmental Preservation of Trees on Public Land").

And,

4.2 That prior to the Preservation Commitment in Subsection 4.1 above, the project trees were not preserved from removal through a Recorded Encumbrance, Governmental Preservation of Trees on Public Land, or other prohibitions on their removal, and

4.3 That prior to the Preservation Commitment in Subsection 4.1 above, the Project Area meets A below and at least one of B, C, or D:

A. Was in a land use designation that allows for at least one non-forest use (non-forest uses include industrial, commercial, transportation, residential, agricultural, or resource other than forest, as well as non-forest park, recreation, or open space uses), and is not in an overlay zone that prohibits all development (the words "overlay zone" are intended to include prohibitions on development such as critical areas or wetlands designations, but if a Project Operator believes an overlay zone allows development, the Project Operator may submit the facts to the Registry and seek a determination that it has met the requirements of Section 4.3.A) ; **and at least one of conditions B, C, or D**:

B. Was surrounded on at least 50% of its perimeter by non-forest, developed, or improved uses, including residential, commercial, or industrial. If the Project Area is surrounded by forested land, the 50% perimeter can apply to the surrounding forested land. If the Project Area consists of several parcels not contiguous, the 50% perimeter requirement can be calculated based on the sum of the perimeters of all the parcels; **or**

C. Had been sold or conveyed or had an assessed value within three years of preservation under Subsection 4.1 for greater than $10,000 average price per acre for the bare land; **or**

D. Would have a fair market value after conversion to a non-forested "highest and best use" greater than the fair market value after preservation in subsection 4.1, as stated in a "highest and best use" study from a state certified general real estate appraiser in good standing.

5. Project Commencement

Projects must submit applications to the Registry within one year of the date of the Preservation Commitment under subsection 4.1 above. Projects whose Preservation Commitment dates from prior to November 1, 2017 are not eligible.

If a Project includes multiple parcels or properties, the starting date for the one-year period within which a Project application must be submitted is the date of the last Preservation Commitment on any parcel or property within that Project.

Projects commence upon approval of the application by the Registry.

6. Issuance of Credits for Tree Preservation Projects

The Registry will issue City Forest Carbon+ Credits™, representing a tonne of carbon dioxide equivalent (CO_2e) per credit plus other ecosystem benefits. To request credits, Project Operators shall submit to the Registry a completed Project Design Document, including quantification data.

As set forth in Section 11, the Project Operator's compliance with both eligibility and quantification requirements shall be reviewed and verified by a 3rd-party verifier. The Registry shall issue credits only after receiving a Verification Report and only in the amount and schedule set forth in the Verification Report (see Section 12) and per the Project Implementation Agreement.

The Registry shall continue to issue credits on the schedule contained in the Verification Report until modification of that issuance of credits is necessary due to a request by the Project Operator for credits for quantified and verified additional growth under Section 10.3, noncompliance under Section 7 on Monitoring and Reporting, or a reversal under Section 8.

If the Project Area is less than 20 acres, the Project may quantify CO_2e eligible for crediting, seek verification, and request issuance of credits at any time after the Preservation Commitment is in place protecting project biomass and after the Project Commencement date, subject to the provisions below.

If the Project Area is greater than 20 acres and not more than 200 acres, the Project may quantify CO_2e eligible for crediting, seek verification, and request issuance of credits at any time after the Preservation Commitment is in place protecting project biomass and after Project Commencement. To reflect the likely staging of development over time if the project area were to have been developed, initial credits are issued attributable to the equivalent of 20 acres of the Project. At each subsequent annual anniversary of the original issuance of credits, the project may request issuance of credits attributable to the equivalent of 20 more acres of the Project, until all attributed credits have been issued, using the most recent verified amount of offsets attributed to the Project.

For example, if the Project Area is 60 acres, the Project Operator would quantify the CO_2e eligible for crediting on all 60 acres, and then the Project is eligible to be issued one-third of the total number of credits attributed to the project each year for three years (one-third being the equivalent of 20 acres), and with all credits for the project thus issued by the end of the third year.

If the Project Area is greater than 200 acres, the Project may quantify CO_2e eligible for crediting, seek verification, and request issuance of credits at any time after the Preservation Commitment is in place protecting project biomass and after Project Commencement. To reflect the likely staging of development over time if the project area were to have been developed, initial credits are issued attributable to the equivalent of 10% of the total credits attributed to the Project. The Project can quantify all CO_2e eligible for crediting for the Project Area and request issuance of 10% of the credits each year, until all credits have been issued.

Additional growth under Section 10.3 must be quantified and verified before any credits can be issued for that additional growth.

In all Tree Preservation projects, the Registry will issue 90% of credits earned and requested and will hold 10% in the Registry's Reversal Pool. At the end of the Project Duration, if application of Registry accounting methods shows that the project has generated more credits than the Project has been issued, then, (if the Project requests) the Registry will issue to the Project those excess credits. Amounts of credits to be issued under the provisions of this section are gross amounts and include amounts to be issued to both the Project Operator and amounts to be transferred to the Registry's Reversal Pool.

7. Monitoring and Reporting

Throughout the Project Duration, the Project Operator must report on tree conditions across the Project Area to the Registry. These reports must be submitted no less frequently than on the triennial anniversary of the date of the first Verification Report.

These reports must be in writing, may be based on professional judgment, and the Project Operator must attest to the accuracy of the reports. The reports must estimate the percentage of the Project Area that appears to be gaining stored carbon, the percent of the Project Area that appears to have constant stored carbon stocks, and the percent of the Project Area that appears to be losing stored carbon stock. If any area appears to be losing carbon stock, the report shall state the estimated amount of loss. The report shall also estimate the number of acres of significant soil disturbance that has occurred since the previous report. Plowing and removal of topsoil both constitute significant soil disturbance. For the purposes of these reports, areas of soil exposed by trees tipping over are not counted as areas of significant soil disturbance.

If a Project Operator fails to submit a report when due under this section, the Registry shall notify the Project Operator of such failure. The Project Operator shall then have 60 days to submit reports under this section.

If a Project Operator fails to monitor or to report after receiving notice and an opportunity to cure its failure under the preceding paragraph, the Registry can investigate and take actions including assessing carbon stock and invoking the reversal provisions of Section 8 and cancelling of the Project and all credits issued.

8. Reversals in Tree Preservation Projects

Reversals can occur if there is a loss of stored carbon serving as the basis for credits for GHG emission mitigation after credits have been received by projects but before the expiration of the Preservation Commitment. (References in this section to "carbon" shall mean carbon serving as the basis for credits for GHG emission mitigation). A "Reversal" is loss of stored carbon such that the remaining stored carbon within the Project Area is less than the amount of stored carbon for which Registry credits have been issued. If the Project Operator or the Registry become aware of a potential Reversal, the Project Operator must estimate the amount of remaining carbon and report this estimate within 60 days of becoming aware of the loss.

The Registry shall determine, at its own discretion, whether a reversal was the result of intentional action or gross negligence by the Project Operator or property owner. If a Reversal was not the result of intentional action or gross negligence, the Registry will replace offsets invalidated by the Reversal with credits from the Registry's Reversal or Insurance Pool.

If the Registry determines that the Reversal was the result of an intentional action or gross negligence by the Project Operator, the Registry shall estimate the number of remaining creditable tonnes CO_2e using the quantification methods contained in this Protocol. The Registry shall notify the Project Operator of this count. If the Registry determines that more credits have been issued to the Project (counting both credits issued to the Project Operator and credits transferred to the Registry's offset insurance account), the Registry shall notify the Project Operator of this shortfall. The Project Operator shall be responsible for replacing the number of credits that have been issued but that are no longer supported by carbon storage within the Project Area. Within 60 days of being notified of the number of credits that it is obligated to replace, the Project Operator shall submit to the Registry a sufficient number of City Forest Carbon+ Credits to cover the shortfall. If the Project Operator is unable to obtain sufficient City Forest Carbon+ Credits, the Project Operator may pay the Registry $20 per tonne CO_2e of shortfall to satisfy the Project Operator's reversal obligation.

Quantifications of carbon stocks determined by the Registry shall be considered to be verified amounts under this section.

If the Project Operator disputes the Registry's reversal calculation, the Project Operator may, at its own expense, measure the remaining carbon stocks within the Project Area that may be more accurate than estimates made by the Registry. The Registry shall consider carbon stock counts submitted to it by the Project Operator, and if the Registry finds that the Project Operator's count is likely to be more accurate than the Registry's estimate, the Registry shall use the Project Operator's count of carbon stocks to determine the Project Operator's liability for replacing credits that are no longer supported by carbon storage within the Project Area.

If a Project has had its carbon stock go below the carbon stock necessary to support credits issued by the Registry, no further credits will be issued to the Project until the carbon stocks are above the amounts needed to support issued credits, including credits allocated to the Registry's Reversal account.

If a Project Operator fails to compensate for a reversal, that Operator may be barred, at the sole discretion of the Registry, from submitting applications to the Registry.

9. Continuation of Tree Preservation Projects after 100-Year Project Duration

After a 100-year Preservation Commitment, Tree Preservation projects may continue their activities, submit Project Reports under Appendix A, and seek issuance of credits for growth under Section 10.3. Projects must comply with all applicable requirements of this Protocol.

10. Quantification for Credits

The Registry will issue City Forest Carbon+ Credits™ to a Project only after quantification by a Project Operator, verification by a 3rd-party verifier contracted by the Registry, and a request for issuance of credits by a Project Operator. Project Operators must follow the following Quantification methods.

There are five steps in the quantification of credits generated by a Project. These steps are described in full in this section, beginning with sub-section 10.1. In summary, the five steps are:

1. Estimate the biomass stock present, and adjust for uncertainty in the estimate to calculate the "Accounting Stock" (Section 10.1)

2. Calculate the fraction of the Accounting Stock that likely would be emitted as a result of development, to calculate "Avoided Biomass Emissions" (Section 10.2)

3. The Project Operator may elect to also account for growth of trees within the project area, or may choose not to count growth (Section 10.3)

4. Calculate "Avoided Soil Carbon Emissions" (Section 10.4)

5. Apply the deductions for displaced development (leakage) to Avoided Biomass Emissions and Avoided Soil Carbon Emissions as set forth in Section 10.5.

10.1 Quantifying Stored Carbon Stock Present within the Project Area

Acceptable ways of quantifying the stored carbon stock present within the Project Area include:

A. The afforestation table, Appendix B, from the US Forest Service General Technical Report (GTR) NE-343 appropriate to the geographic area and species, "total nonsoil" carbon stock for stands of the age of the forest on the Project Area. If this method is used, the Project Area must be assessed and divided into stands as by the species grouping in the relevant geographic area in GTR NE-343 and by stand age. Stand age may be determined by publically available historical materials documenting afforestation of the Project Area or presence of substantially complete tree cover on the Project Area. Stand age may be determined by coring a random or well distributed systematic selection of trees. Other methods to determine stand age may be used, subject to approval by the Registry. If the Project Area is classified as one stand, at least 30 co-dominant trees well distributed across the Project Area will be used to calculate stand age. If the Project Area is divided into more than one stand, at least 20 co-dominant trees per stand will be used to determine stand age. For each stand, stand age shall be the median age of the sampled trees.

   If using this quantification method in Section 10.1.A, the Project must measure the percent canopy cover. The Project may use i-Tree Canopy or LiDAR, or it may use another method approved by the Registry. The Project may prove canopy cover by using the i-Tree Canopy tool and submitting to the Registry the i-Tree Canopy report for the Project Area, plus the i-Tree Canopy export file containing the coordinates of all evaluated points and the evaluation of each point. If using sampling like i-Tree rather than a wall-to-wall map, enough points must be sampled so that the standard error of the percent canopy cover is less than 10%. The carbon stock attributed to the Project equals:

Project Stock = Stock * Percent

Where "Project Stock" is the number of tonnes of stored carbon stock used for subsequent calculations of credits attributed to the project, "Stock" is the live tree or total non-soil carbon stock per acre estimated using tables from GTR NE-343 times the number of acres in the Project Area, and "Percent" is the percent canopy cover.

Because the tables in GTR NE-343 cover a wide range of conditions, some stands will have less carbon stock than the amount estimated by using the tables. If a project estimates carbon stock using these tables, the "Accounting Stock" shall be 80% of the "Project Stock" estimated in the equation above in this subsection. The application of this 80% factor to the calculation of carbon stock using the GTR tables is an additional deduction imposed to make the GTR-based calculation conservative.

B. An inventory of live trees at least 5" in diameter at 4.5' above the ground (where the height above the ground is measured on the uphill side of the tree) present on the Project Area using i-Tree methods and tools (available from http://www.itreetools.org/). When using this method, the Accounting Stock attributed to the project is the carbon stock calculated by i-Tree, minus one standard error of that estimate. For example, if the mean estimated carbon stock is 100 tonnes, and the standard error is 10 tonnes, then the number of Accounting Stock attributed to the project is 90 tonnes.

C. A forest inventory using accepted forestry methods and biomass equations that are valid for the species, growth conditions, and tree sizes to which the equations are being applied and that are published in a peer reviewed publication, by a government agency, or by a not-for-profit organization. The project may choose to include smaller trees, standing dead trees, and/or down dead wood. When using this method, the Accounting Stock attributed to the Project is the mean estimated carbon stock, minus one standard error of that estimate.

10.2 Areas Expected to Remain in Trees after Potential Development

When an area is developed, some trees may be retained. This subsection adjusts the "Accounting Stock" calculated in the preceding subsection to adjust for the fact that even with development, some of the trees within the Project Area may remain, and the carbon in these remaining trees is not emitted during development. To account for these trees that might remain after development, the Project Operator must do the following accounting:

A. In industrial, commercial, mixed use, and other primarily non-residential zones, 90% of the Accounting Stock on the Project Area is the "Avoided Biomass Emissions"; or

B. In residential zones the smaller of:

i. 90% of the Accounting Stock, or

ii. 2 acres per allowed dwelling unit plus 10% of the remaining Project Area, calculated as:

Avoided Biomass Emissions = Accounting Stock * ((2 * Dwellings) + ((Project Area – (2 * Dwellings)) * 0.1))"

Where "Accounting Stock is defined in Section 10.1, "Dwellings" is the number of dwelling units allowed by zoning to be built within the Project Area, and "Project Area" is the area (in acres) specified by the Project Operator per Section 1.4.

10.3 Re-measurement and Verification of Carbon Stock Necessary to Claim Additional Credits for Growth

If the project wishes to claim credits for ongoing tree growth occurring within the Project Area after the Project Commencement, only the quantified and verified increase in stored carbon from the prior issuance of credits may be requested. Increases may be quantified using any method approved by the Registry in Section 10.1, including deductions for calculation of the "Accounting Stock." The fraction of the "Accounting Stock" of new biomass sequestration in new growth that counts as "Avoided Biomass Emissions" is the same as the fraction that is the number of "Avoided Biomass Emissions" present at the project start date divided by the "Accounting Stock" present at the project start date.

10.4 Quantification of Soil Carbon

The Project may claim avoidance of emissions from soil carbon caused by conversion of soils to impervious surfaces in the Project Area. Avoided soil carbon emissions shall be no more than:

A. On commercial, industrial, and mixed use and other non-residential zones, if the applicable zoning and development rules specify a maximum fraction of parcel area that may be in impervious surface, up to the allowed impervious area may be claimed as avoided conversion to impervious surface. If the applicable zoning and development rules do not limit impervious area, 90% of the Project Area and in commercial, industrial, or mixed use zone may be attributed to being eligible for conversion to impervious surface.

B. On residential zones, if the applicable zoning and development rules specify a maximum fraction of parcel area that may be in impervious surface, up to the allowed impervious area may be claimed as avoided conversion to impervious surface. If the applicable zoning and development rules do not limit impervious area, 50% of the Project Area that is in a residential zone may be attributed to being eligible for conversion to impervious surface.

C. For development uses of the project area that retain live vegetation on the ground, such as creation of recreational grass playfields, there are no soil carbon emissions attributed to development. If potential development of the Project Area would include some vegetative cover, and some non-vegetated surface uses (such as parking lots, restrooms associated with playfields, or artificial turf playfields) divide the Project Area into areas with vegetation and without vegetation, and analyze each area separately.

If there is existing impervious surface within the Project Area, that existing impervious area must be subtracted from the potential area of impervious surface under developed use, to calculate net area of avoided impervious surface for calculating avoided soil carbon emissions.

Per acre of avoided impervious surface, the project may claim 120 metric tonnes carbon dioxide equivalent of Avoided Soil Carbon Emissions per acre of net avoided impervious surface. This emission rate is based on research studies showing that when soil is removed from a site and piled with minimal revegetation, 65% of the soil carbon stock is lost, and soil carbon mapping showing that almost all US forest soils have more than 185 metric tonnes carbon dioxide equivalent per acre in the top meter of soil. The calculation is:

Avoided Soil Carbon Emissions = Avoided Impervious Surface * 120

Where "Avoided Impervious Surface" is the number of acres within the Project Area that are developable according to the requirements of Section 4.3.A, in units of acres, after the adjustments specified in Sections 10.4.A and 10.4.B.

10.5 Calculation of Deduction for Displaced Development

Preventing development of some lands is likely to displace development to other lands. Displacing development to other lands may or may not cause emissions from trees and soil. If development is displaced to locations with no trees but with minimally disturbed soils, there would be no biomass emission attributed to the displacement but there would be soil carbon emissions resulting from the displacement. If development is displaced to previously developed sites, there could be negligible emissions from biomass and soil from sites where development is displaced to.

All projects are assigned a deduction based on average emissions from displacement of development throughout the US. The calculation of the displaced development deduction is described in Appendix B.

A. Of the total number of tonnes of Avoided Biomass Emissions from within the Project Area, 18.3% are assumed to be emitted from development displaced from the Project Area. Therefore, the number of creditable tonnes of Avoided Biomass Emissions is calculated by reducing the number of tonnes of Avoided Biomass Emissions calculated in Section 10.2 by 18.3%. In the sequence of calculations, this reduction is done immediately prior to calculation of Reversal Pool obligations. The calculation is:

Credits from Avoided Biomass Emissions = Avoided Biomass Emissions * (1 - 0.183)

B. Of the total number of tonnes of Avoided Soil Carbon Emissions from within the Project Area, 30.3% are assumed to be emitted from development displaced from the Project Area. Therefore, the number of creditable tonnes of Avoided Soil Carbon Emissions is calculated by reducing the number of tonnes of Avoided Soil Carbon Emissions attributed to within the project area by 30.3%. In the sequence of calculations, this reduction is done immediately prior to calculation of Reversal Pool obligations. The calculation is:

Credits from Avoided Soil Emissions = Avoided Soil Carbon Emissions * (1 – 0.303)

Credits attributed to the Project are the sum of Avoided Biomass Emissions plus Avoided Soil Carbon Emissions, after adjusting for displacement of development as provided for in this section, plus credits for tree growth if growth is quantified.

Reversal Pool

Of the credits attributed to the project, verified by the Registry, and issued to the project, 90% shall be issued to the Project Operator and 10% shall be transferred to the Registry Reversal Pool.

11. Verification

The Registry will retain a 3rd-party verifier to verify compliance with this Tree Preservation Protocol per the requirements set forth herein and per International Standards Organization 14064-3. Specifically, the Registry adopts and utilizes the following standards from ISO 14064-3:

- Upon receiving a completed Project Design Document with updated data on eligibility, quantification of carbon, and a request for credits, the Registry will retain a 3rd-party verifier to verify the project's compliance with this Protocol. The Registry will maintain its status as a non-profit organization, and will be independent of specific project activities.
- Verification by a 3rd-party verifier is described in more detail below. Urban forest projects, unlike many other types of carbon offset projects, will be conducted in urban areas, by definition. The trees in urban forest projects will be visible to virtually any resident of that urban area, and to anyone who cares to examine project trees.
- The Registry will maintain independence from the activities of projects and will treat all projects equally with regard to verification.

- The Registry requires a reasonable level of assurance in the accuracy the asserted GHG removals.
- The verification items identified in Table 11.2 and the following sections are all material elements, and any asserted GHG removals must be free of material errors, misstatements, or omissions regarding those elements.
- The Registry will record, store, and track all quantification and verification data and either display it for public review or make it available for public review upon request.
- The Registry will develop a risk assessment standard to provide a cross-check on data collection and review.
- The Registry will adopt a process for follow-up and maintenance for consistency and continuity.

11.1 Verification of Eligibility Requirements

Table 11.1 displays the verification for eligibility requirements.

Table 11.1

Item	Elements to Verify	Protocol Section	How
1.	PO Identity	1.1	State/local records
2.	PIA	1.2	Signed/received
3.	Location	1.3	Maps/location data
4.	Project Area	1.4	Maps/location data
5.	Right to Receive Credits	1.5	Recorded Encumbrance or Governmental Preservation
6.	Commencement	5	Date of Preservation Commitment

Item	Elements to Verify	Protocol Section	How
7.	Project Documentation	4	Check
8.	Project Duration	3	Recorded Encumbrance or Governmental Preservation
9.	Preservation Commitment	4	Same
10.	No Pre-existing Preservation	4	Project Design Document and Supporting Documentation
11.	Threat of Tree Loss	4	Project Design Document and Supporting Documentation; for all of above: Signed PIA

11.2 Verification of Project Operator's Quantification of Carbon

Table 11.2 displays the verification requirements for quantification.

Table 11.2

Item	Elements to Verify	Protocol Section
1.	Quantifying Stored Carbon Stock, Calculating Accounting Stock	10.1
2.	Calculating Avoided Biomass Emissions	10.2
3.	Additional Growth	10.3
4.	Calculating Avoided Soil Carbon Emissions	10.4

5.	Calculating Leakage or Displaced Development Adjustments	10.5

12. Verification Report

The 3rd-party verifier retained by the Registry shall submit its Project verification report in compliance with the requirements of Section 11 of this Protocol and of ISO 14064-3.

The Verification Report shall contain at a minimum reporting on

- Verification process, data reviewed, standards applied
- The Verifier's verification of compliance with Protocol requirements and of the Project Operator's GHG reduction assertion in its Completed Project Design Document
- Project Area and, if applicable parcels or properties
- Total Credits Attributed to that Project and allocation of credits by sub-area or property if requested by the Project Operator in the Completed Project Design Document
- Deductions for the program-wide Reversal Pool of credits
- Schedules for Issuance of Credits

Appendices:

A. Process Guide for Application, Project Design, Initial Verification, and Credit Issuance

The following sets out a non-binding guide to the process workflow of a preservation project. This is offered for informational purposes only.

1. Pre-application discussion between Project Operator and Registry (also referred to herein as CFC). Review checklist of requirements re
   a. Eligibility
   b. Quantification
   c. Process guidance
2. Application submitted to Registry
   a. Review and approval by Registry, conditional on receipt of application fee
   b. Registry may require revisions to Application
   c. Application fee paid; application formally approved (indicating Registry's general but non-binding assessment that the Project appears appropriate for CFC's Protocol)
   d. If application not approved, application fee is returned to Project Operator
   e. Note: Application requires basic information on Project Trees/Forest being protected. Application has optional sections, which, if completed, can be incorporated into the Project Design Document (PDD). Applicant

should not complete the quantification portion of the PDD prior to application approval except where specifically discussed ahead of time with the Registry.

3. Project Operator conducts quantification per Protocol, and submits "Completed PDD"
    a. Note: Project Operator checks in with Registry throughout Quantification to ensure acceptable process, documentation, and assertions
4. Registry secures 3rd-party "Verification Report" of Completed PDD
    a. Project Operator works with verifier to resolve any issues, make revisions, resubmit PDD to Registry for approval, and finalize verification
5. Within 14 business days of receiving final Verification Report, Registry Issues Carbon+ Credits to the Project Operator, in the amount and schedule specified by the Verification Report

B. Derivation of displaced development factors

When a project takes land out of the pool of land available for development, that action reduces the supply of land available for development or re-development. Some, but not all of the development that would have occurred on project lands is shifted to other lands.

Deductions for displaced development have two components. One component is estimating the fraction of development that is displaced. The second component is estimating emissions for each unit of development displaced.

The amount of displacement has been modelled econometrically by estimating the effect of a change in supply on price, and then estimating the effect of that change in price on demand, and calculating how much total demand changes.

Calculating the fraction of development displaced requires measurements of the relationships of (a) change in price with change in supply, and (b) change in price with change in demand. Both of these relationships have been estimated empirically.

Reducing the supply increases the price of the remaining available lands, which motivates more landowners to put their land on the market and make it available for sale. Economists call this relationship the price elasticity of supply. Wheaton, Chervachidze and Nechayev (2014) estimated the long run price elasticity of supply of housing in 68 metropolitan areas in the US.

Including outlier cases with unusual situations, the median elasticity found for the 68 metropolitan areas is 0.8715. This means that for a small fractional increase in price, the supply would increase by 0.8715. For example for a 1% increase in price, 0.87% more properties comes onto the market.

At the same time, when price increases, demand decreases. Gyourko and Voith (1999) calculate that the price elasticity of demand for residential land is -1, which means when price increases 1% then demand decreases 1%.

The equilibrium with these two shifts can be calculated. This calculation of displacement uses the equation for quantifying displacement given in Murray, McCarl and Lee (2004). We assume that the amount of land conserved is small relative to the total supply of land in an urban area. This is a conservative assumption because as the fraction of total land conserved increases, less land is available for development elsewhere, and less displacement occurs, so not adjusting for the fraction of total supply conserved has very little effect to a small overestimate of displacement. Using the elasticity of supply of 0.8715 and the elasticity of demand of -1, and the equation for calculating the net displacement as an interaction of supply and demand elasticities, 46.6% of the reduced development is made up elsewhere.

On average, lands to which development is displaced have less than 100% forest canopy. Nowak and Greenfield (2018) calculate the average tree canopy cover of US urban areas at 39.4%. We assume that the biomass carbon stock per acre, acres per dwelling unit, and acres of land per square foot of built commercial space are the same. This may be a conservative assumption, because as supply of land is decreased, the density of development increases, with more residences and more square feet of commercial buildings per acre of land. Multiplying the 46.6% of development that occurs elsewhere because of conservation of project lands, times 39.4% tree cover on the lands receiving the displacement means that 18.3% of the conserved tree carbon is lost from displacement of development.

Similarly, there is displacement of impervious surface, which reduces the soil carbon benefit of conserving lands.

The soil displacement factor uses the same displacement rate of 46.6% that is used to calculate the deduction for displacement of biomass emissions.

We have been unable to find measurements of the percent impervious surface in newly developed and re-developed land parcels in US urban areas. Natural

Resources Conservation Service (1986) gives the following percent impervious surface by development type:

Use	**Percent Impervious Surface**
Commercial	85
Industrial	72
Residential, 1/8 acre or less per dwelling unit	65
Residential, 1/4 acre per dwelling unit	38
Residential, 1/3 acre per dwelling unit	30
Residential, 1/2 acre per dwelling unit	25
Residential, 1 acre per dwelling unit	20
Residential, 2 acre per dwelling unit	12

Based on discussions with entities considering use of this protocol, it appears that most land that would be conserved is in residential zones. Most of the land zoning would require more than 1/8 acre pre dwelling unit. As a conservative but plausible average, we take the impervious cover percentage of the most dense residential category, 65%, and assume that a substantial fraction of the residential development is somewhat lower density with a lower fraction impervious surface, and a moderate fraction is commercial development with a higher fraction impervious cover.

Multiplying 65% impervious surface times 46.6% of the development avoided by the project occurring elsewhere equals 30.3% of the soil carbon is lost due to displaced development.

References

Gyourko, Joseph and Richard Voith. 1999. The Price Elasticity of the Demand for Residential Land: Estimation and Implications of Tax Code-Related Subsidies on Urban Form. Lincoln Institute of Land Policy Working Paper WP99JG1.

Murray Brian, Bruce McCarl, and Heng-Chi Lee. 2004. Estimating leakage from forest carbon sequestration programs. *Land Economics.* 80(1): 109-124.

Natural Resources Conservation Service. 1986. *Urban Hydrology for Small Watersheds.* Technical Release 55. Conservation Engineering Division.

Nowak, David J. and Eric J. Greenfield. 2018. Declining urban and community tree cover in the United States. *Urban Forestry and Urban Greening*. 32: 32-55.

Wheaton, William C., Serguei Chervachidze, and Gleb Nechayev. 2014. Error Correction Models of MSA Housing "Supply" Elasticities: Implications for Price Recovery. MIT Center for Real Estate. https://dspace.mit.edu/bitstream/handle/1721.1/84478/Wheaton14-05.pdf?sequence%3D1

C. Quantifying Co-Benefits for City Forest Preservation Projects

Introduction

Ecoservices provided by trees to human beneficiaries are classified according to their spatial scale as global and local (Costanza, 2008). Removal of carbon dioxide (CO_2) from the atmosphere by urban forests is global because the atmosphere is so well-mixed it does not matter where the trees are located. The effects of urban forests on building energy use is a local-scale service because it depends on the proximity of trees to buildings.

To quantify these and other ecoservices City Forest Credits (CFC) has relied on peer-reviewed research for quantification of CO_2 storage, and effects of trees on building energy use, rainfall interception, and air quality. CFC's quantification tools provide estimates of co-benefits after 25 years in Resource Units (i.e., kWh of electricity saved) and $ per year. Values for co-benefits are first-order approximations extracted from the i-Tree Streets datasets for each of the 16 U.S. reference cities/climate zones (https://www.itreetools.org/streets/) (Maco and McPherson, 2003). Modeling approaches and error estimates associated with co-benefits have been documented in numerous publications (see References below) and are summarized here.

Quantification of Carbon Dioxide Storage

For City Forest Preservation Projects, as distinct from Planting Projects, the quantification of CO_2 storage is set forth in Section 10 of the Preservation Protocol. Section 10 describes the methods and source materials, and the Displaced Development (leakage) methodology is set forth in Appendix B to this Preservation Protocol.

Quantification of Co-Benefits

Source Materials

Data on co-benefits are based on the U.S. Forest Service's recently published technical manual and the extensive Urban Tree Database (UTD), which catalogs urban trees with their projected growth tailored to specific geographic regions (McPherson et al. 2016a, b). The products are a culmination of 14 years of work, analyzing more than 14,000 trees across the United States. Whereas prior growth models typically featured only a few species specific to a given city or region, the newly released database features 171 distinct species across 16 U.S. climate zones.

The trees studied also spanned a range of ages with data collected from a consistent set of measurements. Advances in statistical modeling have given the projected growth dimensions a level of accuracy never before seen. Moving beyond just calculating a tree's diameter or age to determine expected growth, the research incorporates 365 sets of tree growth equations to project growth.

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

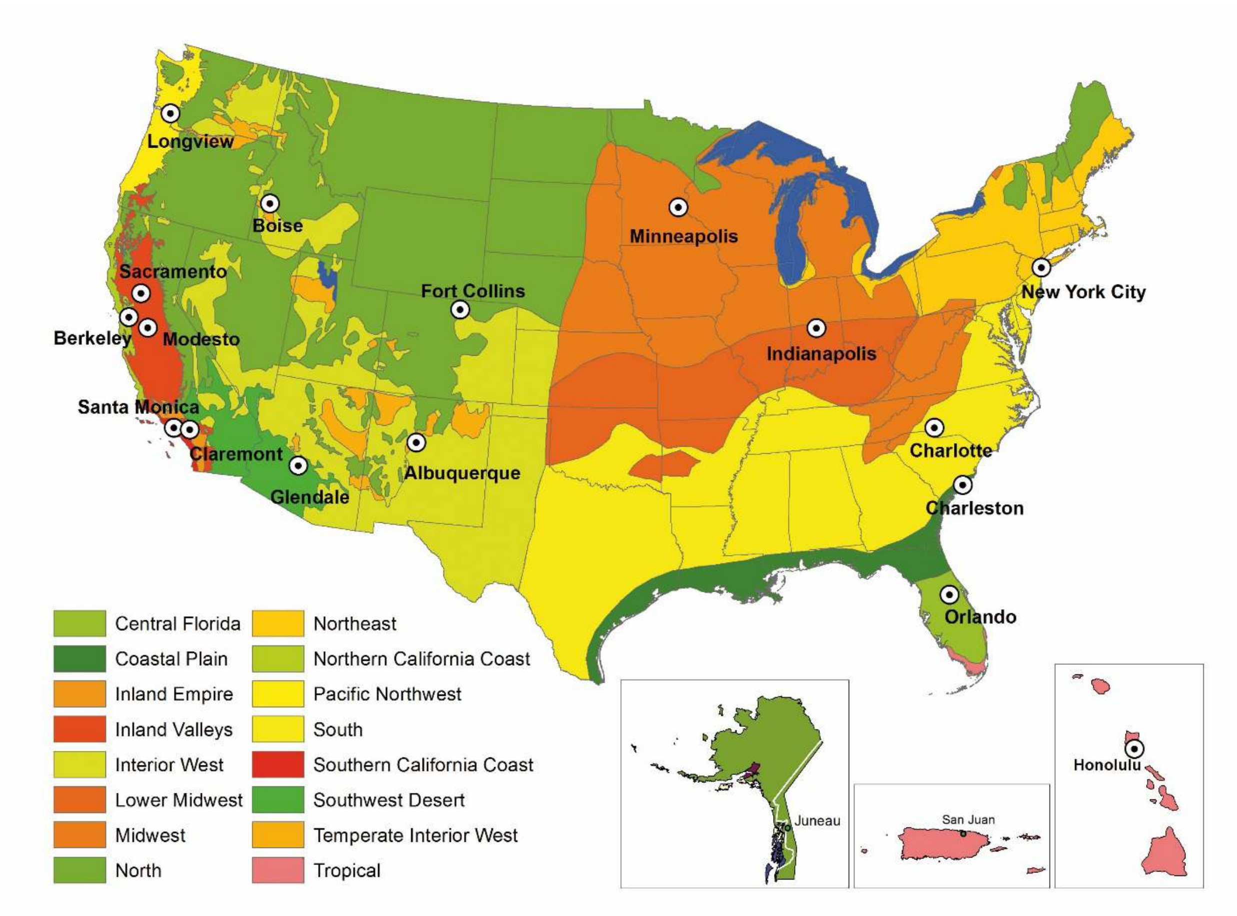

Fig. 1. Climate zones of the United States and Puerto Rico were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree data were collected. Sacramento, California was added as a second reference city (with Modesto) to the Inland Valleys zone. Zones for Alaska, Puerto Rico and Hawaii are shown in the insets (map courtesy of Pacific Southwest Research Station).

Co-Benefit: Energy Savings

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

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

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

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

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

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

Error Estimates and Limitations

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

Co-Benefit: CO_2 Avoided

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

As with Energy Savings, because these effects are highly site-specific we conservatively apply an 80% reduction to the CO_2 Avoided calculation of this benefit of trees for Preservation Projects.

Error Estimates and Limitations

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

Co-Benefit: Rainfall Interception

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

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

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

Error Estimates and Limitations

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

Co-Benefit: Air Quality

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

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

Error Estimates and Limitations

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

Conclusions

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

References

Aguaron, E., & McPherson, E. G. (2012). Comparison of methods for estimating carbon dioxide storage by Sacramento's urban forest. In R. Lal & B. Augustin (Eds.), *Carbon sequestration in urban ecosystems* (pp. 43-71). Dordrecht, Netherlands: Springer.

Anderson, L. M., & Cordell, H. K. (1988). Influence of trees on residential property values in Athens, Georgia: A survey based on actual sales prices. Landscape and Urban Planning, 15, 153-164.

Cairns, M. A., Brown, S., Helmer, E. H., & Baumgardner, G. A. (1997). Root biomass allocation in the world's upland forests. Oecologia 111, 1-11.

Costanza, R. (2008). Ecosystem services: Multiple classification systems are needed. Biological Conservation, 141(2), 350-352. doi: http://dx.doi.org/10.1016/j.biocon.2007.12.020

Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2015). Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. Journal of Applied Ecology, 52(4), 1020-1032. doi: 10.1111/1365-2664.12469

Hildebrandt, E. W., & Sarkovich, M. (1998). Assessing the cost-effectiveness of SMUD's shade tree program. Atmospheric Environment, 32, 85-94.

Husch, B., Beers, T. W., & Kershaw, J. A. (2003). *Forest Mensuration* (4th ed.). New York, NY: John Wiley and Sons.

Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. (2004). Comprehensive database of diameter-based biomass regressions for North American tree species. Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p.

Lefsky, M., & McHale, M. (2008). Volume estimates of trees with complex architecture from terrestrial laser scanning. Journal of Applied Remote Sensing, *2*, 1-19. doi: 02352110.1117/1.2939008

Leith, H. (1975). Modeling the primary productivity of the world. Ecological Studies*,* *14*, 237-263.

Maco, S.E., & McPherson, E.G. (2003). A practical approach to assessing structure, function, and value of stree tree populations in small communities. Journal of Aboriculture. 29(2): 84-97.

McPherson, E. G. (2010). Selecting reference cities for i-Tree Streets. Arboriculture and Urban Forestry, *36*(5), 230-240.

McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. (2016a). Urban tree database and allometric equations. General Technical Report PSW-253. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. 86 p. TreeSearch #52933

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

McPherson, G., Q. Xiao, N. S. van Doorn, J. de Goede, J. Bjorkman, A. Hollander, R. M. Boynton, J.F. Quinn and J. H. Thorne. (2017). The structure, function and value of urban forests in California communities. Urban Forestry & Urban Greening. 28 (2017): 43-53.

McPherson, E. G., & Simpson, J. R. (2003). Potential energy saving in buildings by an urban tree planting programme in California. Urban Forestry & Urban Greening, 3, 73-86.

McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., & Xiao, Q. (2005). Municipal forest benefits and costs in five U.S. cities. Journal of Forestry, 103, 411-416.

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. Environmental Pollution, 193, 119-129.

Peper, P. J., McPherson, E. G., & Mori, S. M. (2001). Equations for predicting diameter, height, crown width and leaf area of San Joaquin Valley street trees. Journal of Arboriculture, 27(6), 306-317.

Schulp, C. J. E., Burkhard, B., Maes, J., Van Vliet, J., & Verburg, P. H. (2014). Uncertainties in ecosystem service maps: A comparison on the European scale. PLoS ONE 9(10), e109643.

Scott, K. I., McPherson, E. G., & Simpson, J. R. (1998). Air pollutant uptake by Sacramento's urban forest. Journal of Arboriculture, 24(4), 224-234.

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

Vos, P. E. J., Maiheu, B., Vankerkom, J., & Janssen, S. (2013). Improving local air quality in cities: To tree or not to tree? Environmental Pollution, 183, 113-122. doi: http://dx.doi.org/10.1016/j.envpol.2012.10.021

Wang, M.Q.; Santini, D.J. (1995). Monetary values of air pollutant emissions in various U.S. regions. Transportation Research Record 1475. Washington DC: Transportation Research Board.

Wenger, K. F. (1984). Forestry Handbook. New York, NY: John Wiley and Sons.

Xiao, Q., E. G. McPherson, S. L. Ustin, and M. E. Grismer. A new approach to modeling tree rainfall interception. Journal of Geophysical Research. 105 (2000): 29,173-29,188.

Xiao, Q., & McPherson, E. G. (2016). Surface water storage capacity of twenty tree species in Davis, California. Journal of Environemntal Quality, 45, 188-198.