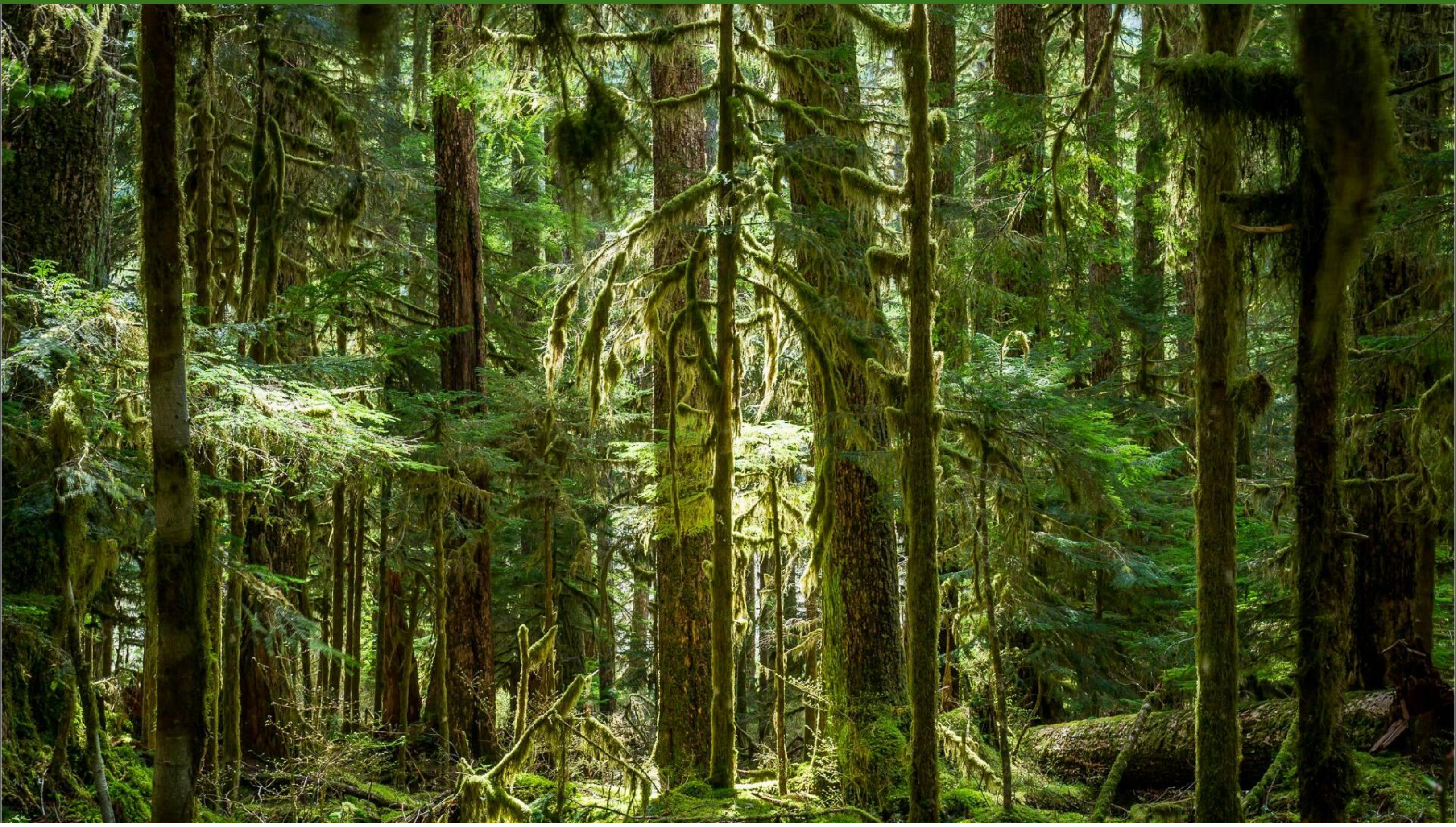

Version 1

BCarbon Forest Carbon Protocol

Issued: November 2022

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Version 1
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1.0 OVERVIEW

This document lays out the technical specifications for quantifying the accumulation of forest carbon content with adequate accuracy and reliability to support the certification of forest carbon credits by BCarbon. This protocol defines a 7-step process, addressing site selection and stratification, measurement guidelines, quantification of the accrued carbon content, specifications on forest management plans, and project documentation. Standard procedures are provided defining the technical specifications for each step in the process.

2.0 SCOPE OF THE FOREST CARBON PROTOCOL

2.1 ***Objectives:*** This protocol defines methods for quantifying the increase in forest carbon content over time across a given landscape with the necessary statistical reliability to support the issuance of carbon credits.

2.2 ***Definitions:*** One BCarbon credit is equal to one ton of $CO_{2,\ eq}$ stored in the forest ecosystem for 10 years as determined using the procedures laid out in this protocol.

The term “forest” in this protocol refers to lands with >10% tree cover. A “stratum” is defined as a group of trees in a project area that are sufficiently alike in composition, age, arrangement, and condition to be readily distinguishable from the forest in adjoining areas.[1]

“Forest carbon” refers to carbon biomass stored in trees. Initial acceptable stores of forest carbon include those with a USDA Forest Vegetation Simulator (FVS) alpha code or a USFS Forest Inventory and Analysis (FIA) tree species code.[2] Interested parties may propose additional species for inclusion in the list of acceptable stores of forest carbon on a case-by-case basis.

For the purposes of this protocol, forest carbon includes the following forest carbon pools:[3]

- *Above-ground live biomass:* Live trees with a diameter at breast height (d.b.h.) of at least 2.5 cm (1 inch), including carbon content of stems, branches, and foliage.
- *Above-ground dead biomass:* Standing dead trees with a d.b.h. of at least 2.5 cm, including carbon mass of stems and branches.

The following forest carbon pools are optional to include:

- *Below-ground live biomass*: Living carbon content of coarse tree roots (between 0.2 and 0.5 cm).
- *Below-ground dead biomass*: Dead carbon content of coarse tree roots (between 0.2 and 0.5 cm).

Applicants may petition BCarbon to include these carbon pools in their project. Requests will be reviewed on a case-by-case basis:

- *Down dead wood:* Woody material that includes logging residue and other coarse dead wood on the ground, as well as stumps and coarse roots of stumps.

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[1] USFS Glossary and List of Terms
[2] FIA Tree Species Codes
[3] Smith et al. 2007 “Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States

- *Shrubs and herbs:* Live vegetation that includes the roots, stems, branches, and foliage of seedlings (trees less than 2.5 cm d.b.h.), shrubs, and bushes.
- *Forest floor/litter: Organic* material on the floor of the forest that includes fine woody debris, tree litter, humus, and fine roots in the organic forest floor layer above the mineral soil.

The following forest carbon pool is excluded from the protocol:

- *Soil:* Soil organic carbon without coarse roots but including fine roots and all other organic carbon not included in other pools to a depth of 1 meter.

2.3 ***Applicability:*** This protocol may be applied to any forest management practice that increases forest carbon in a manner that preserves ecosystem health.

2.4 ***Scope:*** The specifications presented here are directed to a project or activity for forest carbon accrual pertaining to a specified forest area and length of time, or true-up period (maximum of 5 years between measurements). BCarbon forest carbon contracts are for 10 years and consist of two true-up periods. The protocol identifies a stepwise process that includes measurement of the forest carbon content at the beginning and end of the true-up period to quantify the net increase in carbon content over time while accommodating the issuance of interim carbon credits in the meantime. Under the BCarbon program, the carbon accrued in each true-up period as well as issued as interim credits is to be preserved in the forest ecosystem for a minimum period of 10 years following certification.

2.5 ***Limitations:*** This protocol is directed to forest carbon pools only and does not encompass the evaluation of soil organic carbon accrual. Parties interested in incorporating below-ground carbon into their project are referred to the BCarbon Soil Carbon Protocol and BCarbon Soil + Forest Carbon Guidance. Quantitative analysis of the potential net increase in greenhouse gas (GHG) emissions associated with the project is not required.

2.6 ***Recommended Methods:*** This document provides Standard Procedures A through E regarding acceptable methods for stratification of individual and group projects into strata (Standard Procedure A), procedures for forest carbon measurements (Standard Procedure B), methods for forecasting carbon accrual (Standard Procedure C), statistical analysis of data to determine the net accrual of forest carbon over the project period (Standard Procedure D), specifications for acceptable forest management plans (Standard Procedure E), and guidelines on project documentation (Standard Procedure F).

The Standard Procedures provided identify acceptable methods for sampling, measuring, monitoring, and statistical analysis. Use alternative methods is subject to the advance review and approval by BCarbon.

3.0 PROCESS FOR QUANTIFICATION OF FOREST CARBON ACCRUAL

This protocol prescribes a 7-step process based on measurement of the initial forest carbon content at the start of the true-up period, a second round of measurements at the end of the true-up period, and statistical analysis of the net carbon content accrued over that time. Figure 1 provides an illustration of these process steps. Performance criteria for each step of this process are provided below.

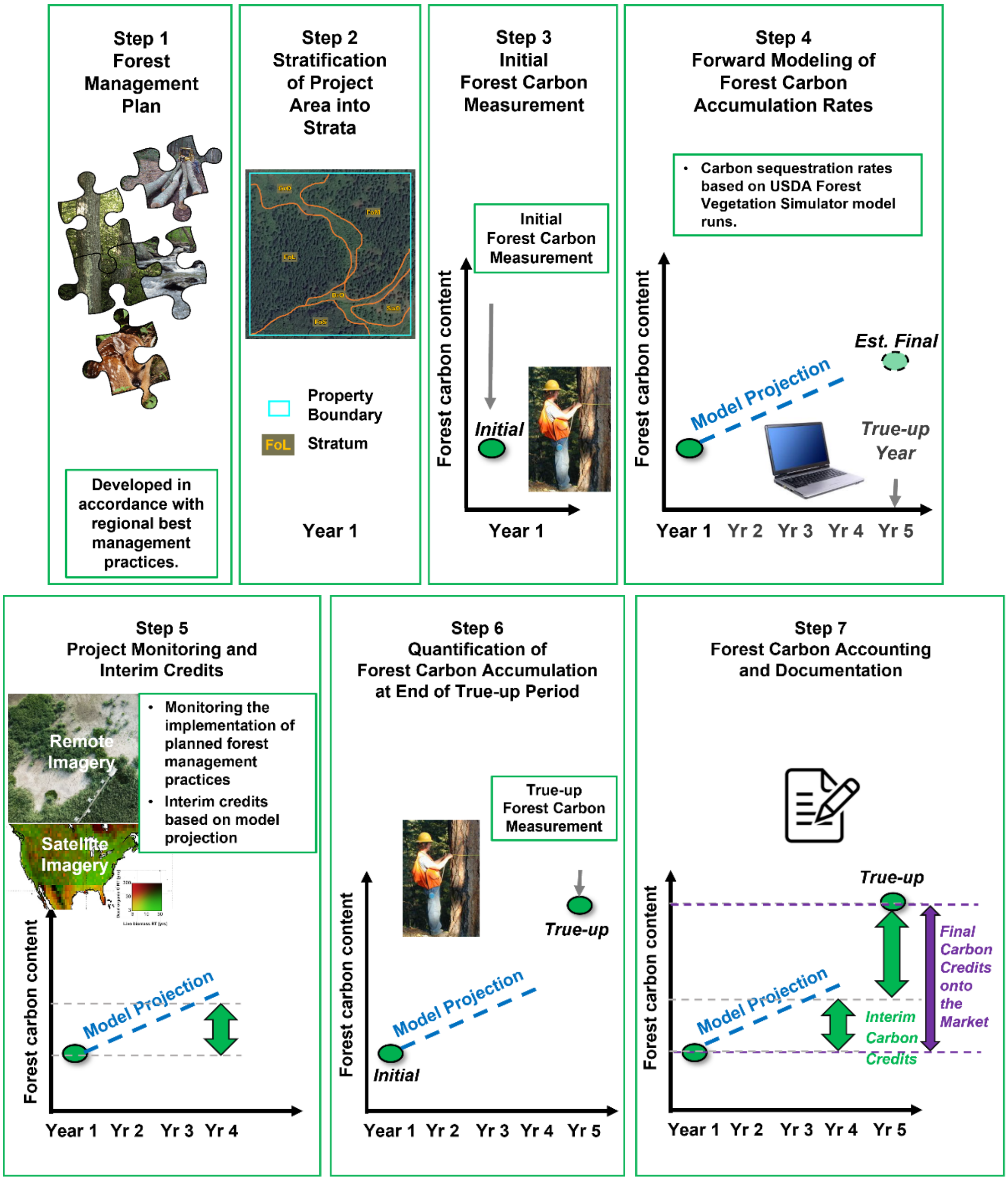


Figure 1: Illustration of 7-Step Process

Step 1: Documentation of Forest Management Plan

BCarbon requires forest carbon projects certified under our system to have a forest management plan in place that protects forest ecosystem integrity. The following are a few examples of acceptable plans:

1. Forest management plans in accordance with the protocols created by the Sustainable Forestry Initiative, the Forest Stewardship Council, the American Tree Farm System, and other analogous natural forest management organizations.
2. Forest management plans approved by individual state forestry agencies in accordance with local best management practices.
3. Forest management plans developed by university academic departments.
4. Forest management plans approved by the Bureau of Indian Affairs.
5. Forest management plans developed by a Society of American Foresters Certified Forester, Association of Consulting Foresters, and/or state-licensed/registered foresters.
6. Forest management plans created in conjunction with the Natural Resource Conservation Service.
7. Forest management plans created by a Professional Wetland Scientists, Professional Wetland Delineators, and/or other certified ecological restoration professionals.

Step 1
Forest Management Plan

Developed in accordance with regional best management practices.

Step 2: Stratification of Project Area into Strata

Overview and Objectives: Measurements to determine changes in forest carbon content pose a classic "signal and noise" problem. In this case, the high degree of variability in the natural carbon content of the forest ecosystem (the "noise") can make it difficult to distinguish the small increase in carbon content (the "signal") that is achieved by the project. Consequently, several measures are necessary to improve the ability to quantify the net increase in forest carbon content with adequate reliability. First among these is "stratification" of the project area, whereby the site is divided into strata in which forest ecosystem characteristics are sufficiently alike to minimize the natural variability (the "noise") of the initial forest carbon content measured in that stratum. Proper stratification may reduce the number of measurements necessary to characterize initial carbon content with high accuracy and improve the reliability of the measurement of the change in carbon content over time.

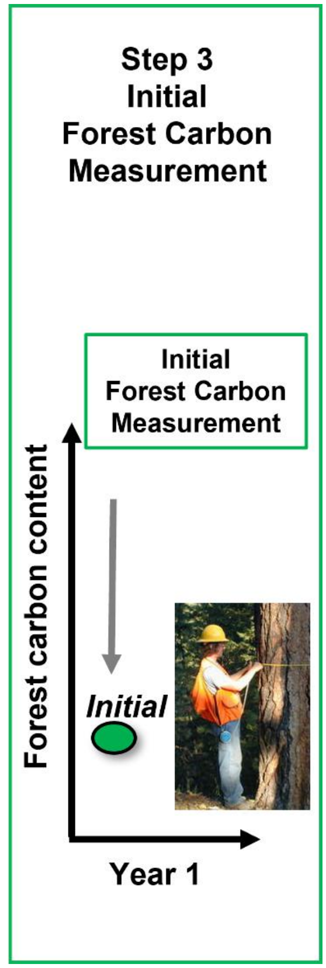
Definition of Project Area and True-up Period: Each forest carbon project shall be defined based on an identified forested area and a specified timeframe for the carbon accrual period (beginning and end seasons whether growing or dormant), hereafter referred to as the "true-up period", which must occur within five years of the initial measurement.

Strata of Comparable Forest Carbon Composition: The project area must be stratified to define strata in which the key parameters related to carbon accrual rates are relatively uniform. At minimum, stratification should account for tree species, age class, stocking levels, and current forest management practices. The properties of these parameters across the project area shall be determined based upon published information, physical inspection of the forest, landowner knowledge, and other reliable information sources. Guidelines for definition of strata are provided in Standard Procedure A.

Criteria for Group Projects: Owners of geographically co-located properties may combine their forest properties into a "group project" under this protocol if they share comparable forest characteristics and are subject to consistent forest management practices. Group projects require advance review and approval by BCarbon based on demonstration that the proposed combined areas share consistent properties of key stratifying parameters and will be subject to the same measurement and monitoring protocols, as well as consistent forest management practices. Performance criteria for group projects are provided in Standard Procedure A. It is important to note that, under Steps 2 and 5 below, group projects will require measurements conducted at plots distributed across the full group project area to obtain a representative measure of forest carbon content.

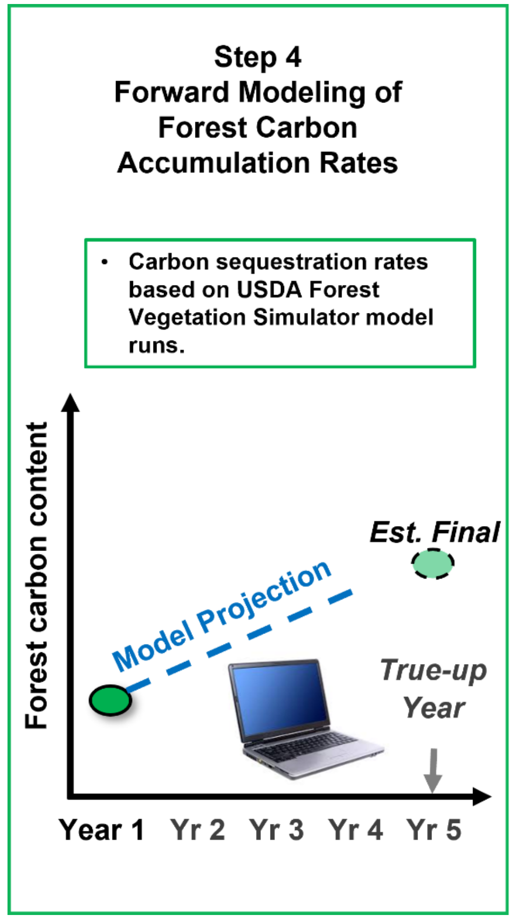
Step 3: Initial Forest Carbon Measurement

The initial forest carbon content of the project area shall be quantified by means of direct measurements to determine the forest carbon content in each stratum, applying the performance criteria outlined in Standard Procedure B. The number of plots analyzed shall be adequate to quantify the current carbon content and later determine the net gain in forest carbon content over the true-up period to an acceptable degree of statistical accuracy. The statistical methods to be applied for this purpose are specified in Standard Procedure D. Specifications for measuring carbon in the forest ecosystem are provided in Standard Procedure B.



Step 4: Forward Modeling of Forest Carbon Accrual Rates

Forecasting of forest carbon accrual over the true-up period is a recommended but not mandatory step of this protocol. Advance estimation of carbon accrual rates may provide the benefits of i) confirming that an adequate number and locations of permanent plots have been assessed to quantify the initial and final forest carbon content with the necessary statistical confidence, and ii) accommodating issuance of interim forest carbon credits during the true-up period.



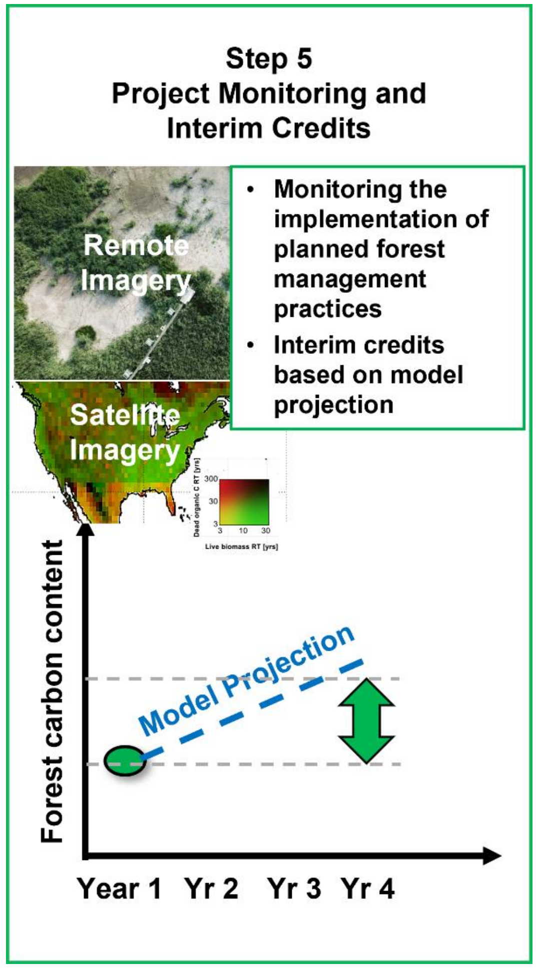
This protocol provides specifications for modeling of the rate of carbon accrual in forest ecosystems. The applicability of the selected methodology to the project conditions and the appropriateness of the input parameters must be documented based on site-specific measurements and observations, as well as professional judgment. Care must be taken to avoid overestimation of carbon accrual during the project period.

Specifications for forecasting carbon accrual rates are provided in Standard Procedure C.

Step 5: Project Monitoring and Eligibility for Interim Carbon Credits

Project Monitoring and Record-Keeping: Each year of the true-up period, the user must certify in writing that appropriate forest management practices remain in effect in the full project area to increase forest carbon at levels that meet or exceed the initial forest carbon content.

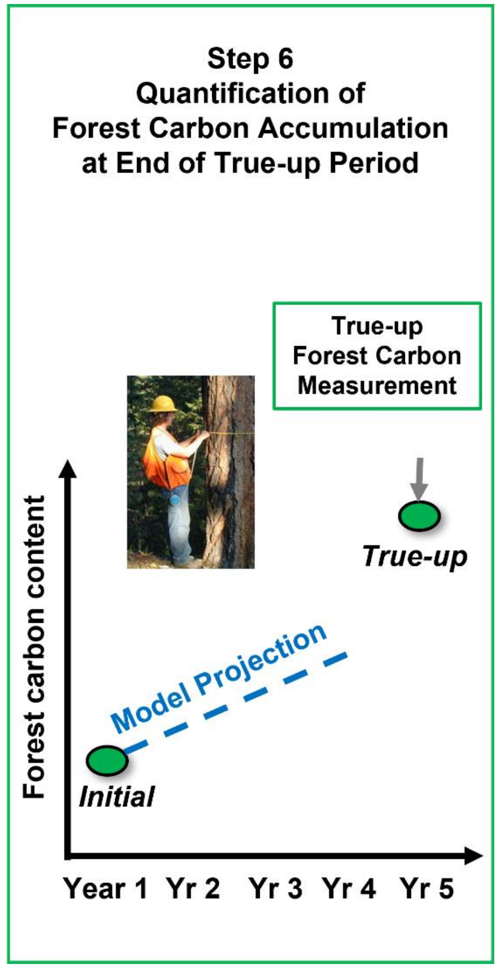
Eligibility for Issuance of Interim Carbon Credits: Subject to demonstration that appropriate forest management practices remain in effect to increase forest carbon, the incremental increase in forest carbon estimated to have been achieved prior to the true-up end date can be used to support issuance of interim carbon credits. Alternatively, direct measurements can be conducted at any time during the project in accordance with Step 3 and used to quantify the net increase in forest carbon with the necessary statistical confidence. Issuance of interim carbon credits will require review and approval by BCarbon, subject to the criteria set forth in Standard Procedure C.



Step 6: Quantification of Forest Carbon Accrual at the End of the True-up Period

The maximum true-up period length is 5 years. At this end date, measurements shall be conducted and analyzed from the project strata using the same methods as applied in Step 3 above and in the same season (whether growing or dormant) as the prior measurement program, to minimize variability introduced by changes in methodology or seasonality. Measurements shall be evaluated to quantify the forest carbon content in the project area at the end date. The forest carbon content measured at the beginning and end of the true-up period shall then be compared to estimate the net increase in forest carbon content in the project area, using the statistical procedures described in Standard Procedure D.

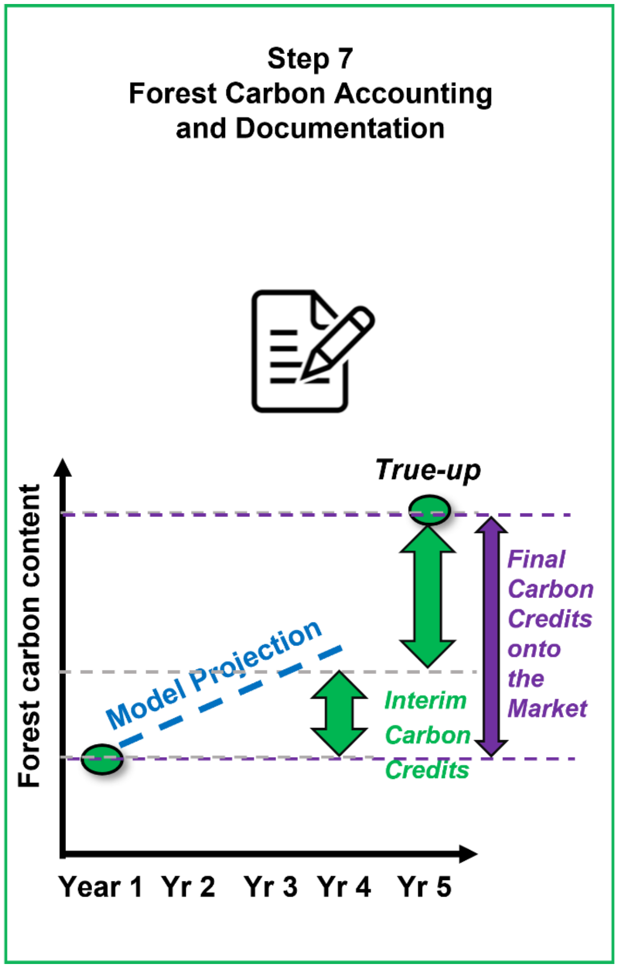
Statistical evaluation is necessary to determine the uncertainty of the estimation of the net increase in forest carbon content and to provide a reliable value for carbon credits. This protocol provides a method to quantify the difference in the initial and final mean carbon content of each stratum by subtracting the initial mean carbon content, estimated within a specified margin of error, from the final mean carbon content, estimated within that same margin of error.



Step 7: Forest Carbon Accounting and Project Documentation

To support certification of forest carbon credits, the user must provide a report to BCarbon that documents the basis for quantification of the net increase in forest carbon in the project area over the true-up period. The report shall address the procedures and results of Steps 1 through 6, including definition of the project area and strata, documentation forest management practices, measurement and monitoring data, and relevant statistical analyses. The net increase in forest carbon content at the end of the true-up period (Step 5) will be eligible for carbon credits, minus any carbon content for which interim credits were issued during the project period. Detailed guidelines for forest carbon documentation are included in Standard Procedure E.

The user of this protocol is directed to the attached Standard Procedures A – E for specifications about each step of the process. The project report shall document that these procedures or equivalent methods for measurement, monitoring, and quantification of forest carbon accrual were applied in the implementation of the carbon project.



STANDARD PROCEDURE A: STRATIFICATION REQUIREMENTS

A.1 Overview and Objectives

This Standard Procedure provides specifications for subdividing the project area to define strata of uniform characteristics in which measurements can be conducted to quantify the net change in carbon content over the true-up period with sufficient accuracy to support the issuance of forest carbon credits.

The project area must be stratified, a process in which the site is divided into strata in which the forest characteristics are sufficiently alike to minimize the natural variability of initial forest carbon content in each individual stratum. Proper stratification may reduce the number of samples necessary to determine initial and future carbon stocks.

The procedures described here may be applied to a single property or to a combination of separate properties that qualify as a "group project," based on demonstration that the properties can meet the same stratification criteria as required for a single property and will enforce consistent forest management practices on each property.

A.2 Definition and Stratification of the Project Area

A.2.1 Identification of Project Location

The forest for which carbon accrual will be measured over time shall be defined in terms of the dimensions and boundary lines of the project area. The project area shall be defined by a GIS file to provide an accurate estimate of the total surface area to be subject to the carbon accrual effort. It is understood that the full extent of the defined project area will be subject to the forest management activities for carbon accrual. If some portion of the defined area will not be actively used for carbon accrual (e.g., an internal drainage way, roadways, etc. that are not accessible or amenable to the forest management activity), such portions of the project area shall be removed from the project area to be used for calculation of carbon accrual.

A.2.2 Stratification of the Project Area

The defined project area must be evaluated to define strata, in which key parameters related to carbon accrual rates are relatively uniform. Such factors include tree species, age class, stocking levels, and current forest management practices. If these parameters vary within the proposed project area, the project area shall be subdivided or "stratified" into strata of similar characteristics. These strata may be contiguous land areas or may incorporate separate, discrete tracts of similar properties. Permanent plot measurements must be conducted in each stratum to quantify the forest carbon content in that stratum.

Different stratum types (e.g., 20-year-old pine vs. 30-year-old oak) on the same property may differ in terms of their initial carbon content, the spatial variability of this carbon content, and the rate at which additional carbon can be accumulated under a given forest management scenario. The variability of forest carbon will commonly be greater between different strata than within a stratum. Consequently, if the project area is subdivided into relatively uniform strata, the forest carbon content may be less variable within each stratum and require fewer permanent plots to achieve a reliable measurement of carbon content. Accurate estimation of the forest carbon content requires that areas of significant differences in forest carbon content must be separated so that low-carbon strata are not mixed with high-carbon strata, resulting in a significant over- or under-estimation of carbon content.

A.2.3 Relevant Information and Considerations for Site Stratification

Information on the tree species, stocking levels, age class etc. on a given property may be available in various published resources. This information, in combination with a physical inspection of the property, can be used to stratify the project area into strata of relatively uniform tree species and age class.

A.2.3.1 Stratification by Forest and Landscape Conditions

Stratification of the project area starts with the identification of forest conditions. For many areas in the US, forest surveys (conducted by the USFS as part of its FIA program) and similar publications provide information about the forests in a specified county or area of interest, including forest descriptions and their location, along with information on their species composition, age class, and other ecosystem properties.[4]

A.2.3.2 Stratification by Forest Management Methods

Stratification of the project area shall also include considerations of the specific forest management practices that are to be applied throughout the project area. Different forest management approaches within the same project area will likely warrant separate stratum types because the carbon accrual rates achieved by the separate approaches may differ significantly. If forest management practices will not be consistent across the project area, the difference in forest management practices shall be considered a variable in the stratification process, whereby strata defined based upon consideration of the criteria in Section A.2.3.1 above are further subdivided based on forest management practices.

A.3 Combining Individual Properties into Group Projects

A.3.1 Overview of Group Project Criteria

In some cases, projects on separate properties can be combined into a “group project” to develop a more cost-effective measurement program due to economies of scale. However, combination of projects in this manner requires that the properties share comparable forest characteristics and are subject to consistent forest management practices, such that forest carbon accrual rates will be comparable across the landscape. Group projects require advance review and approval by BCarbon based on demonstration that the proposed combined areas share consistent stratifying parameters and will be subject to the same measurement and monitoring methods, as well as consistent forest management practices.

A.3.2 Factors for Assessing the Feasibility of a Group Project

When grouping multiple properties together, care must be exercised when delineating and documenting individual strata to demonstrate that environmental conditions and forest management practices in each stratum are sufficiently consistent so that the results of the measurement program can be deemed representative across multiple properties.

A.3.2.1 Need for Comparable Forest and Landscape Conditions Among Properties

All the criteria defined in Section A.2 above regarding the stratification of individual properties pertain equally to stratification of the multiple properties proposed for incorporation as a group project. The proposed area of the group project must be defined as described in Section A.2.1, and those portions of the group project area that will not be actively used for carbon accrual (e.g., an internal drainage way, roadways, etc.) shall be removed from the project area to be used for calculation of carbon accrual. Forest areas in which stratifying criteria are sufficiently uniform to qualify as a stratum may be incorporated into a single stratum without regard for property lines.

[4] USFS The Forest Inventory & Analysis Geospatial Data Showcase, USFS Forest Inventory and Analysis Tools and Data

However, the degree of natural variability in the landscape will determine the feasibility of a group project, as in landscapes where the stratifying parameters vary significantly over a relatively short distance, strata are likely to be relatively limited in size and not extend over multiple properties.

A.3.2.2 Need for Comparable Forest Management Practices

Stratification for group projects also includes consideration of the specific forest management practices as specified in Section A.2.3.3 above for individual properties. The forest management practices being applied on the individual properties must be consistent for each of the individual projects to be grouped together; in other words, the approach must incorporate the same general methodology or strategy, with site-specific modifications in forest management practices as needed among individual properties.

A.4 Readjustment of Strata

Following the initial stratification of the project area, the fieldwork completed as part of the initial measurement program (see Standard Procedure B) may yield additional information regarding site conditions and forest carbon content in each sub-area. For example, floods or fires may have wiped out some of aboveground biomass. Based on this new information obtained about the parameters relevant to stratification, strata must be evaluated to assess the need to adjust their boundaries to meet the criteria specified in Section A.2 above.

STANDARD PROCEDURE B: MEASUREMENTS TO DETERMINE FOREST CARBON CONTENT

B.1 Overview and Objectives

This standard procedure specifies accepted methodologies for the measurement of forest carbon content in the project area for the purpose of quantifying the net change in forest carbon content over the true-up period. These specifications for measurement of forest carbon at the beginning and end of each true-up period include determination of the appropriate number and location of permanent plots for forest carbon measurements. The results of the measurements conducted at these permanent plots shall be used to quantify the forest carbon content accrued over the true-up period in accordance with the statistical procedures described in Standard Procedure D.

B.2 Definition of Forest Carbon Content

This standard procedure is directed toward measurement of the net increase over time of carbon content in the following forest carbon pools:

- *Above-ground live tree:* Live trees with diameter at breast height (d.b.h.) of at least 2.5 cm (1 inch), including carbon content of stems, branches, and foliage.
- *Above-ground dead tree:* Standing dead trees with d.b.h. of at least 2.5 cm, including carbon content of stems and branches.

The following forest carbon pools are optional to include:

- *Below-ground live biomass*: Living carbon content of coarse tree roots (between 0.2 and 0.5 cm).
- *Below-ground dead biomass*: Dead carbon content of coarse tree roots (between 0.2 and 0.5 cm).

B.3 Measurement of Forest Carbon at Start of the True-up Period

The goal of the measurement program is to quantify the content of forest carbon in each designated stratum (see Standard Procedure A) with sufficient statistical confidence to facilitate quantification of the net increase in carbon content at the end of the true-up period. At each permanent plot the relevant biometric parameters like diameter at breast height, tree height etc. shall be measured. Prior to measurements being conducted, a measurement plan shall be prepared and documented describing the rationale and results of the stratification process, the number and location of permanent plots to be analyzed within each stratum, and the measurement methods to be applied. Relevant specifications for determining the necessary number of permanent plots in each stratum, as well as procedures for measurement of required forest inventory data, are laid out below.

B.3.1 Number and Location of Permanent Plots Required from Each Stratum

The number and location of permanent plots in each stratum shall be sufficient to characterize the amount of forest carbon content with sufficient accuracy to be able to quantify the change in carbon content over time. Forest carbon, like all forest properties, varies from one location to another even within a given forest stratum. Due to this natural variability, the forest carbon content of the forest ecosystem cannot be characterized by a single measurement from each stratum. Rather, multiple measurements from different permanent plots are commonly required to achieve a representative measure of the average forest carbon content in each stratum within a certain margin of error. The more variable the carbon content from one location to another within a given stratum, the greater the number of permanent plots that will be required for the initial measurement program, as well as for measurement at the end of the true-up period, to distinguish the net change in carbon content (the “signal) from the natural variability in the forest carbon content (the “noise”). Permanent plot locations shall be selected throughout the stratum, either randomly or systematically, to obtain a reasonable representation of the spatial variability of forest carbon content across the area. Permanent plots should be physically marked with a stake and digitally recorded using a GPS system to facilitate accurate re-measurement.

B.3.1.1 Size of Permanent Plots

Permanent plots may be of a single fixed area or consist of multiple, nested plots depending on the nature of tree species being examined, the expected age class of trees being measured for carbon content, and their stocking levels. For example, plantation forests with relatively few tree species and age classes may require only one size of fixed area plot while a diverse, mature forest with multiple tree species and age classes would likely require multiple plot sizes to accurately quantify forest carbon content. If multiple plot sizes are needed, they should consist of a main plot to account for large stems (>5 inches d.b.h.) and sub-plot(s) to account for smaller diameter stems (1-4.9-inch d.b.h.). The main, large stem plot must be of a fixed area, while smaller diameter stem subplots may be of a fixed area or a variable radius. Plots should be laid out according to USDA guidelines on measuring forest carbon sequestration.[5]

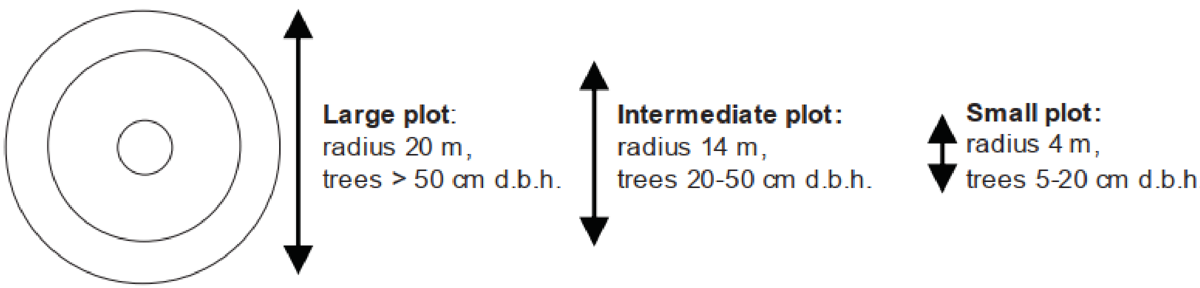


Figure 3.—Schematic of nested, fixed area circular sample plots. The radius and diameter limits for each circular plot would be a function of local conditions and expected size of the trees through time.

B.3.1.2 Estimation of the Necessary Number of Permanent Plots

The minimum number of permanent plots required to characterize the mean forest carbon content in each stratum with sufficient statistical rigor can be derived using the following equations:[5]

Eqn B.1: For L strata, the number of plots needed (n):

$$n = \frac{\left(\sum_{h=1}^{L} N_h * s_h\right)^2}{\frac{N^2 * E^2}{t^2} + \left(\sum_{h=1}^{L} N_h * s_h^2\right)}$$

For a single stratum, this can be simplified as:

$$n = \frac{(N * s)^2}{\frac{N^2 * E^2}{t^2} + N * s^2}$$

[5] Pearson et al. 2007 “Measurement guidelines for the sequestration of forest carbon”

For two strata, this can be simplified as:

$$n = \frac{\left\langle (N_1 * s_1) + (N_2 * s_2) \right\rangle^2}{\frac{N^2 * E^2}{t^2} + N_1 * s_1^{\ 2} + N_2 * s_2^{\ 2}}$$

Where:

*E = allowable error or the desired half width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision, i.e., mean carbon stock * 0.1 (for 10-percent precision)*

t = the sample statistic from the t-distribution for the 90-percent confidence level; t usually is set at 2 as sample size is unknown at this stage.

N_h = number of sampling units for stratum h (= area of the stratum, in ha/area of the plot, in ha)

N = number of sampling units in the population $(N = \sum N_h)$

s_h = standard deviation of stratum h

Variables E, N, and s_h can be calculated from FIA data using the following steps:

1. Download FIA data and apply biomass equations and expansion factors for the specific area and forest type of interest. Sum to obtain plot level results.
2. Calculate mean carbon stocks across the dataset or optionally across strata of interest, then calculate standard deviation and the coefficient of variation.
3. The minimum number of plots required for monitoring is calculated by solving for n in the formula for the confidence interval (CI). Target ± 7 to 8 percent of the mean as a reasonable level of precision (this accounts for the sampling error only; sources of error such as measurement error and model error likely will account for 10 to 20 percent of total error thus, a target of ± 7 to 8 percent CI of the mean for sampling will result in a total error for the confidence interval of about 10 percent of the mean).

$$n = (s \times 2.1)/\ (\text{mean} \times 0.08)^2$$

Where: s = standard deviation

This approach requires that the margin of error (i.e., the difference between the upper and lower confidence limits) on the mean at a 90% level of confidence not exceed 10% of the value of the mean. Alternative approaches to determining the necessary number of permanent plots in each stratum, such as conducting a preliminary timber cruise of the stratum, may also be used so long as they meet the requirement that the margin of error on the mean at a 90% level of confidence not exceed 10% of the value of the mean. The 90% confidence interval requirement must be met for the project as a whole, not at the individual stratum level.

B.3.2 Measurements to be Collected from Permanent Plots

The following measurements shall be taken at each permanent plot to quantify the amount of forest carbon in the project area. Individual trees in the permanent plots shall be marked to measure the growth of individuals over the true-up period so that the growth of survivors, mortality, and ingrowth of new trees can be tracked and used to calculate the net change in carbon over time.[6]

B.3.2.1 Tree Variable Table

Variable	Description
Tree_ID	Tree identification code
Plot_ID	Plot identification code
Tree_Count	Number of trees
History	History code: 0-5 are live trees, 6 and 7 died during mortality observation, 8 and 9 died before mortality observation period
Species	Tree species code: Can be the FVS alpha code, FIA species code, or USDA plant symbol
DBH or Diameter	Diameter at breast height (d.b.h.) in inches
Ht	Height in feet
CrRatio	If the number is 0-9, then it is considered a crown ratio code; If the number is 10-99, the value is considered a percent live crown
TreeValue	Tree value class code 1 for desirable, 2 for acceptable, 9 for non-stockable, and any other number represents a live cull
Prescription	Prescription code

B.3.2.2 Stand Variable Table

Variable	Description
Region	USFS region name
Forest	USFS forest name
District	USFS district name
Stand_ID	Stand identification code
Variant	The two-character FVS variant identification code
Inv-Year	The stand’s inventory year

[6] Hoover and Rebain 2011 “Forest carbon estimation using the Forest Vegetation Simulator”

Location	Location code representing the relevant region/forest/district/compartment
PV_Code or Habitat	The habitat type or plant association code
Age	Stand age in years
Aspect	Aspect in degrees
Slope	Slope in percent
ElevFt	Elevation in feet
Basal_Area_Factor	Basal area factor used for sampling large trees
Inv_Plot_Size	The inverse of the fixed plot size in acres used in sampling small trees
Brk_DBH	Breakpoint d.b.h. in inches between small tree and large tree plots
Num_Plots	Number of plots
NonStk_Plots	Number of non-stockable plots
Site_Index	Site index
Forest_Type	Forest type code
State	FIA state code
County	FIA county code

B.3.3 Calculation of Forest Carbon Content using the USDA Forest Vegetation Simulator

Inventory data collected using the procedures laid out above shall be input into the USDA Forest Vegetation Simulator (FVS) to determine the initial amount of carbon stored in the relevant carbon pools of the forest ecosystem.

B.3.3.1 Setting up the USDA Forest Vegetation Simulator

FVS is free and can be downloaded from the USFS website, under the software tab.[7] The 'Complete Package' should be downloaded as this will include all necessary files. FVS releases quarterly updates of the program, so it is important to ensure the most recent version is installed. Follow the installation instructions listed on the webpage.

Detailed FVS user guides can be found in the FVS folder created on the computer upon installation. Locate the FVS folder > open the folder > open 'Training Guides' > open '*FVSTrainingGuide.pdf*'. This document will help walk through the FVS interface, provide guidance on creating projects, uploading data, and running models. *Essential FVS: A User's Guide to the Forest Vegetation Simulator* is a detailed user guide available on the USFS website that will help with understanding keywords, data input requirements, model output

[7] FVS Software

interpretation, and other details about the program.[8] *The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation* contains details on forward carbon accumulation modeling.[9]

B.3.3.2 Preparing Input Databases

Next download the blank FVS database Excel file from the FVS Data Acquisition page.[10] The database file can also be found in the FVS folder upon download. Using these templates is important to upload data to FVS in the correct format. There are three sheets in the spreadsheet: (1) FVS_StandInit, (2) FVS_PlotInit, and (3) FVS_TreeInit. If no data is available for a specific variable, leave that variable blank. It is important to have the three sheets in one file. FVS may assign a value to blank cells in the database, but this should not impact the results so long as all the data needed to compute carbon content is included. FVS does not like spaces in the variable text, so '_' needs to be used in place of spaces (i.e., Stand ID should be Stand_ID.

Below are some details on each sheet in the database spreadsheet. Additional information can be found in the USFS Training Video Series.[11] The stand and tree level data will need to be input into these fields. Data may be entered spanning multiple years for each stand in the database, as FVS will calculate the carbon stock of the stand for each of the inventory years measured. Multiple stands may also be input in the same database.

<u>FVS_StandInit (stand-level data)</u>

- Sample point information (plot size)
    - Large tree plots (Basal_Area_Factor)
        - Prism plot needs to be 'positive' value (i.e., 10 = 10 BAF)
        - Fixed plot needs to be 'negative value (i.e., -10 = 1/10 ac plot)
    - Small tree plots (Inv_Plot_Size)
        - *Always fixed radius* (can't use variable radius plots)
        - Fixed plot needs to be positive value (i.e., 100 = 1/100-acre plot)
    - Breakpoint d.b.h. (BRK_DBH) refers to whether a tree was measured in the large or small plot
    - Region, Forest, District are all based on the closest national forest
        - FVS recommends entering the closest or most similar national forest reference codes to the stand of interest
        - These can be found in the 'Variant Overviews' section of the FVS User Guides webpage.[12]
- See the Stand Variable Table in Section B.3.2.2 of this protocol for a list of the minimum needed variables.
    - Include as much information as possible on this sheet.

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[8] Essential FVS
[9] The Fire and Fuels Extension to the Forest Vegetation Simulator
[10] FVS Data Acquisition Page
[11] FVS Training Videos
[12] FVS User Guides

FVS_TreeInit (Tree-Level Data)

- See the Tree Variable Table in Section B.3.2.1 of the protocol for a list of the minimum needed variables.
    - Include as much information as possible on this sheet.

FVS_PlotInit (Plot-Level Data)

- Optional, used to run stands individually in FVS.

B.3.3.3 Create Forest Carbon Project

Next create the project file and upload the database populated in Section B.3.3.2. The USFS video '*Getting Started with FVS'* gives details on installing FVS and explains the components, interface, and creating new projects. This video will be helpful for running FVS if not familiar with the program, and references '*FVSTrainingGuide.pdf'* in the FVS folder. The section on creating new projects and importing the database starts at 12:04 in the video. First, the database file needs to be uploaded (Step 1). Then it needs to be installed (Step 2). Another option is to create a new project, load the project, and on the Simulate tab click the quick link option titled 'Upload inventory database'. Make sure that the Project Title lists the newly created project (this may open in a new window and the default project that opens when FVS starts up can be closed). Another video from the USFS titled *'How to Create a Project and Load Data'* into FVS provides additional tips on using FVS.

B.3.3.4 Run Forest Carbon Model

The next step is to run the project to calculate the carbon stock of the stand. The USFS videos for Module 1 describe how to compute data for data with single-stand or multi-stand runs. Steps for running a projection are as follows:

- Follow the above steps above to populate the dataset and create the project.
- Change the run title (if desired, by default it will be titled 'Run 1') and click save.
- Click 'Stands' tab
    - Select 'Variant' for the region
    - Select 'Group' based on the forest type code (can be found in FVS guide)
    - Select 'Stands' for the stand of interest (may be multiple stands if there are multiple stands in the dataset)
        - Click 'Add selected stands'
- Set time scale > click 'Time' tab
    - The default starting year is the current year and the default ending year is 10 years in the future.
        - Can be changed if desired.
        - Read 'Projection Timing Summary' to confirm that the timeframe is correct.
- Outputs > 'Select Outputs' tab

        - Select 'Carbon and Fuels' tab and other data of interest
            - More information on each output option can be found by going to 'Describe table' tab and click on the output of interest and a table will be shown on the screen
- Run > click 'Run' tab
    - MgmtID is needed
        - 4-character code for different managemtent activities or for no stand management
            - Single run > 'Base'
            - Multi-stand run > 'PIPO'
                - If management activities have been conducted between inventories, there are codes for different scenarios such as types of thinning, timber harvests, wildfire, and salvage harvests, etc.
                - Different options can be found in the '*FVS Training Guide'* and other documents by searching for MgmtID
    - Click 'Save and Run'
- Results
    - Click 'View Outputs' tab to see the table output
        - Click 'Load'
        - Select run title chosen above in 'Runs to consider' box
        - Select table of interest in 'Database tables to consider' (i.e., FVS_Carbon)
            - If unsure of what is contained in the tables, select the table in 'Describe tables' box to see more details
    - Click 'Explore' for table and graph output
        - Can select specific years if needed
        - Can select specific variables in the table to condense table
            - Check variables of interest in 'Select variable' boxes
        - Click 'Download table' to download the results
            - Either.xlsx or .csv
        - Graphing tab
            - Can show carbon stock for each year in a graph
            - X-axis > year
            - Y-axis > carbon
            - Can add title and label X and Y axis
            - Click 'Copy plot to clipboard' to put into a document
        - 'Visualize' tab for visualization of data as a figure (not a graph)

- Can compare by selecting run title and another year in the other boxes
- To save > right click and save image

■ 'View on Maps' tab to see data overlaid on a stand map

- Works if the data is input for the stand

B.3.3.5 Reporting Carbon Output

Calculating stand carbon using the above table uses the CARBREPT keyword to request the stand carbon report and will include output for 'live' and 'dead' pools. The output of carbon stocks will be expressed as metric tons of C per acre and will need to be converted into units of metric tons of CO_2 equivalent / acre by multiplying by 44/12. This can also be done by using the CARBCALC and CARBREPT keywords and setting different carbon accounting algorithms. If this is preferred, see the CARBREPT keyword to "2" for units to be reported in metric tons of CO2 equivalent / acre.

Do not use any functions related to harvesting, fires, or other disturbance unless management activities or a disturbance occurs (i.e., MgmID Base or PIPO from above results). The output table will have the carbon stock in the 'Stand Carbon Report' and the column to focus on is the 'Total Stand Carbon' column (see figure below) which provides the carbon stock for a specific year in ton per acre unless the user specified to change the units. See example table below.

****** CARBON REPORT VERSION 1.0 ******
STAND CARBON REPORT
ALL VARIABLES ARE REPORTED IN TONS/ACRE

STAND ID: 9999114 MGMT ID: NONE

	Aboveground Live		Belowground			Forest			Total	Total	Carbon	
YEAR	Total	Merch	Live	Dead	Stand Dead	DDW	Floor	Shb/Hrb	Stand Carbon	Removed Carbon	Released from Fire	
2005	74.1	53.5	18.8	0.6	11.9	10.5	10.3	0.1	126.3	0.0	0.0	
2010	29.9	22.4	8.2	12.2	11.6	18.5	11.1	0.9	92.4	38.1	0.0	**
2015	31.3	23.6	8.6	2.3	9.2	17.2	9.6	0.9	79.1	0.0	0.0	
2020	33.5	25.4	9.2	0.4	6.7	16.6	9.6	0.8	76.8	0.0	0.0	
2025	33.0	25.4	8.9	0.9	7.2	5.7	2.2	0.8	58.9	0.0	18.7	**
2030	35.2	27.1	9.5	0.2	5.1	7.2	2.4	0.9	60.4	0.0	0.0	
2035	37.4	28.9	10.1	0.1	4.1	7.7	2.4	0.8	62.6	0.0	0.0	

B.3.4 Alternative Methods for Calculation of Forest Carbon Content

The process laid out in B.3.3. is the standard process for calculating initial and true-up forest carbon content, the use of which will expedite certification of forest carbon credits by BCarbon. Alternative methods to calculate forest carbon content may be used if they are reviewed and approved by BCarbon based on scientific information demonstrating that the proposed alternative methods provide a rigorous estimate of the net change in forest carbon content over time.

B.4 Measurement of Forest Carbon at the End of the True-up Period

B.4.1 General Procedures for Measurement at the End of the True-up Period

The direct measurement of forest carbon content at the end of the true-up period shall apply the same methodologies applied in the initial measurement to minimize the variability introduced by changes in methodology. All other provisions of Section B.3 related to measurement procedures apply equally to the end of the true-up measurement program, including the approach used to determine the necessary number and location of permanent plots.

Measurement at the end of the true-up period shall take place during the same season (whether growing or dormant) as at the start of the true-up period. The intent is to calculate the inter-annual change while minimizing the effects of seasonal changes.

The time when the end of true-up period sampling will be conducted is a site-specific decision at the discretion of the project owner or manager. Note that BCarbon requires that direct measurement must be conducted in Year 5 from the beginning of the true-up period.

STANDARD PROCEDURE C: MODELING OF FOREST CARBON ACCRUAL

C.1 Overview and Objectives

Measurements of forest carbon stocks at the beginning and end of the true-up period, supported by appropriate statistical analyses, is required to quantify the accrual of forest carbon with adequate confidence to support issuance of carbon credits. However, during the lifetime of the project, which may extend on the order of ten years or more, forest carbon modeling may optionally be employed to estimate the rate of carbon accrual for the issuance of annual interim credits. This standard procedure provides specifications for modeling the rate of carbon accrual rates using analytical or numerical models of forest carbon dynamics.

C.2 Forecasting of Carbon Accrual Using Modeling

C.2.1 Standard Interim Credit Calculations using FVS

If interim credits are applied for, forward modeling of forest carbon dynamics shall be conducted using the USDA Forest Vegetation Simulator. After entering forest inventory data into the platform, model simulations shall be conducted using parameters appropriate to the project at hand to determine annual carbon sequestration rates over the next 10 years according to the process laid out in Section B.3.3 of the protocol. The management options used in modeling shall be the same as those documented in Standard Procedure E.

C.2.2 Alternative Methods for Calculating Interim Credits

The process laid out in B.3.3 is the standard process for calculating interim credits, the use of which will expedite certification of forest carbon credits by BCarbon. Alternative methods to calculate forest carbon content may be used if they are reviewed and approved by BCarbon.

STANDARD PROCEDURE D: STATISTICAL METHODS TO QUANTIFY CHANGE IN FOREST CARBON CONTENT

D.1 Overview and Objectives

This standard procedure specifies the statistical methods that will be applied to quantify the net change in the forest carbon content in the project area over time. Even within a single forest stratum, carbon content can vary widely from one location to another. Consequently, multiple permanent plot measurements are needed from each stratum to estimate the mean carbon content with adequate precision to quantify the net change from the beginning to the end of the true-up period. Statistical methods provide a mathematical means to account for this natural variability and estimate the net change from the beginning to the end of the true-up period with a specified degree of confidence.

This standard procedure describes how to quantify the net gain in forest carbon content over the true-up period through estimation of the difference in the initial and final mean carbon content of each stratum by subtracting the initial mean carbon content from the final mean carbon content, estimated within a specified same margin of error.

D.2 Parametric Statistical Approach to Quantify Change in Forest Carbon Content

If the forest carbon inventory data is not normally distributed, a power transform shall be conducted to convert it into normally distributed data, and the following method shall be used to determine the net change in forest carbon over the true-up period. Equation D.1 will be used to the statistical variability of forest carbon content using initial measurements as well as final true-up measurements.

For any data set of samples collected and analyzed for carbon content from a stratum, the mean carbon content with 90% margin of error is:

Eqn D.1: $C = (\sum C_j)/n \pm [t \times \frac{s.d.}{\sqrt{n}}]$

Where: C = *mean carbon content*

C_j = *carbon content in units of mass/unit area, in sample j in a given stratum*

n = *number of samples collected in the stratum*

t = *t-statistic for 90% (0.1) confidence interval for the n measurements collected in the stratum*[13]

$s.d.$ = *standard deviation of carbon content in data set*

And: C_i = *C calculated based on the measurements in the stratum at the beginning of the project period*

C_f = *C calculated based on the measurements in the stratum at the end of the project period*

The margin of error, which corresponds to the second term in Equation D.1 (after the +/-), defines the upper and lower bound of the estimated mean carbon content within a 90% level of confidence. For quantification of the initial and final carbon content within a given stratum, the target shall be to achieve a margin of error at a 90% level of confidence that is no greater than 10% of the value of the mean.

[13] NIST/SEMATECH e-Handbook of Statistical Methods

If the margin of error for either C_i or C_f exceeds this target, the estimated forest carbon content at the beginning or end of the true-up period will be adjusted as indicated in Equations D.2 and D.3 below:

Eqn D.2: $C_i = beginning\ carbon\ content\ \times \left(1 + [(\frac{margin\ of\ error}{sample\ mean}) \times 100\% - 10\%]\right)$

Eqn D.3: $C_f = ending\ carbon\ content\ \times \left(1 - [(\frac{margin\ of\ error}{sample\ mean}) \times 100\% - 10\%]\right)$

The criterion for the margin of error (i.e., that the 90% confidence limit on the mean be within +/- 10% of the estimated mean) can be used to estimate the number of samples that will be necessary to measure the mean forest carbon content with adequate precision at the beginning of the true-up period (see Standard Procedure B).

Eqn D.4: $\Delta C = C_f - C_i$

Where: *C_i and C_f are obtained from Equations D.2 and D.3, respectively*

Values of the carbon content at the beginning (C_i) and end (C_f) of the specified true-up period meeting the margin of error criterion (or adjusted as needed per Equations D.2 and D.3) are used in Equations D.6 through D.8 below to calculate the net increase in forest carbon content for the project area.

D.3 Calculation of Forest Carbon Content Accrued in Each Stratum

In each stratum of the project area, the forest carbon content accrued over the course of the true-up period is defined as the net difference in carbon content at the beginning and end of the true-up period:

Eqn D.6: Net Carbon Content Accrued in Stratum = (ΔC) x (A_i)

Where: ΔC = *The difference in the mean carbon content (in mass per unit area) between the initial and final measurement programs, as derived using either Eqn. D.4 or Eqn. D.5, above for the stratum.*

A_i = Area of stratum, corrected for portions that are not available or not amenable to carbon accrual

The net forest carbon content for the full project area, combining all strata, is:

Eqn D.7: Net Carbon Content Accrued in Project Area = Σ (Net Carbon Content Accrued in Each Stratum)

D.3.1 Alternative Methods to Quantify Change in Forest Carbon Content

The process laid out in D.1 through D.3 is the standard process for measuring the change in forest carbon content over time, the use of which will expedite certification of forest carbon credits by BCarbon. Alternative methods to calculate the change in forest carbon content over time may be used if they are reviewed and approved by BCarbon.

STANDARD PROCEDURE E: SPECIFICATIONS ON FOREST MANAGEMENT PLAN USED IN CARBON PROJECT

E.1 Acceptable Forest Management Plans

BCarbon requires forest carbon projects certified under our system to have a forest management plan in place that protects forest ecosystem integrity. The following are a few resources for acceptable plans:

1. Forest management plans in accordance with the protocols created by the Sustainable Forestry Initiative, the Forest Stewardship Council, the American Tree Farm System, and other analogous natural forest management organizations.
2. Forest management plans approved by individual state forestry agencies in accordance with local best management practices.
3. Forest management plans developed by university academic departments.
4. Forest management plans approved by the Bureau of Indian Affairs.
5. Forest management plans developed by a Society of American Foresters Certified Forester, Association of Consulting Foresters, and/or state-licensed/registered foresters.
6. Forest management plans created in conjunction with the Natural Resource Conservation Service.
7. Forest management plans created by a Professional Wetland Scientists, Professional Wetland Delineators, and/or other certified ecological restoration professionals.

STANDARD PROCEDURE F: DOCUMENTATION OF FOREST CARBON PROJECT

F.1 Overview and Objectives

The goal of forest carbon project reporting is to create a verifiable record of each key data input, field measurement, and project decision point, as well as all calculations supporting the modeled and/or measured increase in carbon content. This Standard Procedure provides guidance on how to organize this report and the minimum required information.

F.2 Documentation of Forest Carbon Project

The final report will contain the following sections (or equivalent appendices). Suggested lengths are provided for each report section, with the understanding that lengths will vary based upon the nature of the project.

1. **Executive Summary (2 to 3 pages):** Summary of the report addressing the project area, the forest management methods applied, the results of the initial and final measurements, and the calculated net increase in forest carbon content over the true-up period. If any interim credits were issued within the true-up period, these should also be documented in the Executive Summary.
2. **Project Methodologies (1 to 2 pages):** Description of the forest management practices applied to increase forest carbon accrual in the project area. Identify the methodologies used for stratification, forest carbon measurement, and statistical evaluation.
3. **Definition of Project Area (1 to 2 pages):** Description and map of the project area, corrected for portions of the area that are not included in the forest carbon project.
4. **Stratification of Project Area (2 to 3 pages):** Detailed description of the stratification process and results, including each of the datasets (e.g., GIS files, remote sensing data, forest inventory results, etc.) used during the process.
5. **Permanent Plot Description (1- 2 pages):** A summary describing the process used to select permanent plot locations, as well as any statistical procedures and calculations used during this process to determine the necessary number of permanent plots, etc.
6. **Timber Cruise Records (1 to 2 pages)**: Description of sampling programs for forest carbon, including number and location of permanent plots, measurement approach etc. with accompanying maps.
7. **Forest Carbon Inventory Results (1 to 2 pages):** Summary specifying the methods used, data QA/QC, detection and quantitation limits, and analysis results of initial and true-up forest carbon inventory calculations.
8. **Forward Modeling Records (2 to 3 pages):** A description of the modeling employed to support issuance of interim forest carbon credits over the project lifetime.
9. **Project Results (2 to 4 pages):** Documentation of the quantity of forest carbon accrued over the true-up period. All statistical calculations used to quantify the forest carbon accrued, including references for any statistical procedures that are utilized, shall be discussed. Address any necessary adjustments to forest carbon content due to any uncertainties in the measurements or forward modeling over the ensuing 10-year period.
10. **References:** Citations for any references in the project report.