California Air Resources Board
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ARB Compliance Offset Program

U.S. Forest Projects Compliance Offset Protocol

Guidance for Verifying Forest Carbon Inventories

The California Air Resources Board's Compliance Offset Protocol U.S. Forest Projects (Protocol) uses inventories of carbon stocks to determine the project baseline and to quantify greenhouse gas (GHG) emission reductions and removal enhancements against the project baseline.. The Cap-and-Trade Regulation (Regulation) requires verification of all offset projects before ARB offset credits can be issued. Verification of carbon inventories consists of ensuring the Offset Project Operator's (OPO) sampling methodology conforms to requirements listed in the Protocol and that the project's inventory based sample plots are within specified tolerances when compared to the verifier's sample plots. Verification of the project's onsite stocks must occur at each full verification and focus on ensuring that the project's inventory methodology is technically sound and that the methodology has been correctly implemented. Once verified, the project's inventory methodology must remain static throughout the project life. Exceptions may be granted by the California Air Resources Board in writing. These exceptions will involve a thorough analysis to determine if the changed inventory methodologies necessitate modifications to the project baseline.

The project must be able to meet inventory standards within Appendix A of the Protocol, prior to the verification body initiating field sampling activities. Table 1 (below) summarizes the requirements in the Protocol and is a non-exhaustive list the verifier may follow to review the OPO's inventory and methodology.

As specified in section 10.2.2 of the Protocol, the verifier will install and measure temporary sample plots or re-measure existing monumented sample plots consistent with the objectives of a random, risk-based and efficient approach. In doing so the verifier may weigh the probability of selecting strata and plots based on various criteria -- including carbon stocking, access difficulty, and vegetation heterogeneity.[1] Verifiers may choose to sample project plots within a given stratum with a cluster design. The selection of a stratum may use probability proportional to carbon stocks or probability proportional to error risk (as hypothesized by the verifier).

Verifiers should use best management practices that will result in high accuracy and guard against variability; verifiers will want to identify and measure a selection of sample

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[1] The terms "stand," "stratum," and "strata" are defined pursuant to section 10.2.2 of the Compliance Offset Protocol U.S. Forest Projects, October 2011, as follows:
1. Stand: An individual unit or polygon that is relatively homogenous in terms of the carbon stocking within its borders. For live and dead trees, the determination of stand boundaries is usually based on forest vegetation attributes, such as species, size (age), and density characteristics. For soils, the determination of soil stand boundaries is made on similar soil orders.
2. Stratum: A group of stands that contain a similar attribute, such as vegetation or soil attributes.
3. Strata: Plural of stratum. The set of different groupings for a specific attribute, such as vegetation or soil.

plots along with a comparison with inventory data to have reasonable assurance that sample plots are measured accurately using the methods identified in Section 10.2.2. Verification plots should reflect the variability in tree species, heights, and diameters existing in the Project Area. Plots need not correspond to the actual plots within the Project Area. The chosen verification approach will determine whether a paired or unpaired test will be used by the verifier.

Sequential Sampling for Verification

In order to determine whether the verifier sampling and the OPO inventory show a trend toward agreement and that the agreement between the two is sustained, the Protocol requires a sequential sampling method for verification of sample plots.

Sequential sampling is intended to provide an efficient sampling method for verifiers to determine if project estimates for carbon pools are within specified tolerance bounds established by the Protocol. Sequential sampling uses stopping rules rather than a fixed sample size to indicate a successful agreement. Verification is successful after a minimum number of successive plots in a sequence indicate agreement. After each successive plot or series of plots, the verifier will either:
   a) Continue to the next plot if the verifier determines an agreement has not been met and further testing is required;
   b) Stop if testing indicates the presence of a potential bias and the OPO does not wish to invest in additional verification effort to determine if an agreement can be reached. Where there is potential presence of a bias, additional verification plots may be collected if it is felt that random chance may have caused the test to fail and a convergence towards agreement is expected with additional samples; or
   c) Stop if testing indicates agreement between the OPO and verifier estimates.

Determination of when the stopping rule is met is done at the end of each sampling day, which will include the full set of plots measured in that day. When no bias is detected and when a stopping rule indicates the minimum number of successive plots is within the specified tolerance bounds, the verification is considered successful.

In most cases, sample plots will combine measurements of standing live and standing dead wood. In such cases, the verifier will analyze the combined pools. In cases where the OPO did not combine sample data for standing live and dead wood, the verifier must conduct the analysis for standing live and dead wood independently. If the OPO did combine standing live and dead wood and the verifier's finding for that combined pool does not trend toward agreement with the OPOs data, the carbon pools may not be disaggregated unless the OPO revises its inventory to disaggregate the pools, and a new set of sampling occurred by the verifier to determine agreement for each pool independently. The verifier determines when the stopping rule is met at the end of each sampling day, after the full set of plots are measured in that day. If, through repeated verification effort, the carbon estimate does not pass the sequential sampling methodology with an acceptable range of error plus or minus 10% (Section 10.2.2, page 70), the verifier must provide an opportunity for the OPO to correct the error (i.e.

through an amendments to the Offset Project Data report due to an update of its inventory) prior to issuing an adverse option. Sequential sampling applies to standing live and dead wood and, where required, soil carbon. OPO/APDs are not required to account for lying dead wood, no verification for this pool is needed as a result.

Inventory Estimates

The items in Table 1 are measures that Offset Project Operators or Authorized Project Designees (APD) must complete before the verifier goes to the field and analyzes the plots.

Table 1. Inventory Methodology Verification Items

Verification/Evaluation Standards	Protocol Reference	Satisfied
Inventory description provides a general account of the activities and land use patterns influencing carbon stocks in the Project Area.	Appendix A.1	
Forest carbon pools are correctly identified and quantified.	Section A.2; Table A.1	

Develop and document a forest carbon inventory methodology capable of quantifying carbon stocks for required pools to a high degree of accuracy. A complete inventory must include:
1. Description of Project Boundary and carbon pools within boundary
2. Description of inventory sampling methodology and references including:
   a. Standard procedures for collecting field measurements (can they accurately be repeated?) that include descriptions of the types and location of plots, replacement frequency, frequency of updates of inventory
   b. Procedures used to measure parameters in biomass calculations such as dbh and height, classification of dead wood, and other sampling documentation
   c. Stratification rules used for pre and post sampling including vegetation strata map, results of stratification, tools used (GIS, aerial photos), and explanation of how boundaries were determined
3. Analytic methods, biomass equations, and documentation of same - used to translate field measurements into volume or biomass carbon estimates
4. Documented QA/QC plan and internal review plan – does it include all required data entry, maintenance and archiving procedures
5. Data management description and procedures
6. Change log
7. Documented procedures for updating inventory including account for harvest, growth, disturbance, adding new inventory and plot data, retiring older plots, modeling (per Appendix B) and use of appropriate confidence deduction
	Section A.3	

If inventory methodology describes a stratification design, is the stratification methodology clearly defined? Have the rules for stratification been explained? Stratification is not required. If stratification is used, stratification design should be relevant for the sampling of biomass. Verifier should evaluate whether stratification was done consistent with the stratification rules documented in the inventory methodology. Evaluation may be conducted through field observation, aerial photos, and/or other data. If stratification is inconsistent with the document's inventory methodology the verifier must determine that the project has failed to meet the standard.	Appendix A.3, 2(c) Table 6.2	

Inventory methodology states how the inventory is updated on an annual basis to reflect growth, harvest, and other disturbances. Methodology adheres to acceptable forestry practices. 1. Inventory is updated to account for harvest and other disturbances and is truly representative of the harvest and disturbance occurring in the field. 2. Inventory is updated for growth using approved growth and yield model or stand table projection 3. The update methodology addresses the process for updating forest strata, where appropriate. The inventory being verified is determined to be current using the updated methodology.	Appendix A.3, 7 Appendix B	
The inventory methodology and sampling procedures must be consistent over the life of the project. Verifier should check to determine if inventory has been implemented in a consistent manner since the project's inception. If changes have been made to the inventory methodology, have any changes been approved by ARB if required and have changes been documented in the change log? If new methodologies have been introduced, do the new methodologies result in equal or greater accuracy relative to the original sampling design? Verifiers should review and approve the sampling methodology and determine if it is statistically sound and accurate.	Appendix A.3 Section 8.2	
The inventory methodology describes the volume and biomass equations used to compute the project's carbon stocks and these equations are consistent with those required by the Compliance Offset Protocol. The OPO has used appropriate volumetric and biomass equations. The same biomass equations used for tree species and modeling are also used determining Harvested Wood Products. All conversions and expansions are accurate.	Section 10.2.2 Appendix A.3, Section 6.1.2, 6.2.3	

The verifier must review the descriptive statistics of the carbon stocks associated with standing live and dead trees or as a combination and ensure that the required ±20% at the 90% confidence interval is achieved through sampling design and implementation. Offset Project Operators and Authorized Project Designees can improve the precision of their estimates through additional inventory effort, but can only include it in their reporting after the confidence estimate has been verified. Projects must include the uncertainty adjustment associated with their most recent verification effort.

Emissions associated with site preparation activities (soil, shrubs, and herbaceous understory) are not subject to the same sequential sampling requirements and shall be verified as follows:

- **Reforestation Project types:**
  The Offset Project Operator or Authorized Project Designee must measure site preparation emissions according to Section 6.1.1(2) using one of the following methods:
    - sample 20 plots located in the portion of the Project Area containing the greatest amount of biomass in the pool that will be affected;

o stratify the Project Area into similar densities and measure stocks within the carbon pools using 20 sample plots per density class; or

o measure the affected carbon stocks based on a grid system across the Project Area.

- **Improved Forest Management or Avoided Conversion Project types:** Emissions (soils) resulting from site preparation activities must be captured by measuring changes in included carbon reservoirs as part of sequential sampling.

Measurement Specifics for Verifiers

Verifiers must use the highest professional standards (e.g. USDA Forest Service Forest Inventory and Analysis (FIA) inventory standard practice guidance documents) to conduct field measurements. Measurements utilized by verifiers during fieldwork should be consistent with the tolerance standards for measurements identified within Appendix A and should be obtained using the best management practices for data collection and review of forest carbon inventory as required in Section 10.2.2:

1. Verifiers should be aware that the Compliance Offset Protocol does require that verifiers measure tree height and diameter at breast height (DBH). If the OPO uses height estimates as a function of DBH to estimate heights, the verifier must always measure tree heights directly in the sample plots and take extra care and vigilance in thoroughly reviewing the results, and must measure each tree height in the sample plots. Verifiers cannot use estimators, models or regressions to impute heights, all measurements must originate from sampling in the field.

2. Verifiers shall measure the heights of all trees according to the height measurement used for the species-specific biomass equations (found on the ARB Forest Resource webpage).

3. ARB suggests that tools and methods used for distance measurements for plot boundaries be accurate within 1"/30'.

4. ARB suggests that tools and methods used for distance measurements for height measurements be accurate within 6"/100'

5. ARB recommends that borderline trees be measured to determine their status as an 'in' or 'out' tree.

6. ARB recommends OPO/verifiers follows industry standard to measure DBH to the nearest inch.

Verifying a Stratified Inventory

Where the project's inventory is stratified, the strata to be verified may be selected by the verifier according to the presumed risk of measurement error or presumed risk of the effects of measurement error on the overall inventory estimate, as described above. Individual stands and plot locations must be independently selected using a random selection design. The verifier shall select three strata (or the maximum number of strata present) based on the verifier's evaluation of risk. The minimum number of passing plots varies by project size and number of strata verified. (See Table 3, which is a copy of Table 10.1 in the Protocol).

Verification within a Stand
Section 10.2.2 states that stands of a given stratum must be independently selected using random selection design. No more than 6 plots or clusters can be assigned to a stand, unless the groups of plots required for verification exceed the number of stands that exist for the project.

Table 3. Minimum number of sample plots in sequence, as a function of project size

Test	Number of Strata Verified	Project Acres				
		<100	100 – 500	501 - 5,000	>5,000	> 10,000
Paired/Unpaired	3	2	3	4	5	6
	2	4	6	8	10	12
	1	8	12	16	20	24

There are two possible statistical procedures that can be applied to the stratum-level verifications. A paired test can be applied when plot locations can be found and it is statistically appropriate to use a paired test (i.e. plot measurements can be replicated). An unpaired test can be applied when plots cannot be relocated. The range of acceptable error (δ, delta) is fixed at 10 percent for both tests.

Verifying a Non-Stratified Inventory
If the project is not stratified for each applicable pool, the verifier shall select the plots randomly (if plot locations can be relocated) or allocate the plots systematically (i.e. using a grid with a randomized start) or in clusters for efficiency. If the verifier uses a cluster design, the mean of the cluster accounts for one observation (plot). Plots may be measured and assessed one at a time or in reasonable batches that correspond to logistical realities such as crew-days of effort.

Verifying Emissions Corresponding to Site Preparation
If biological emissions from site preparation activities (RF-9, IFM-9, AC-9; Table 5.1;) are significant enough such that soil carbon accounting is required, these activities are captured by measuring changes in other carbon reservoirs for shrubs and herbaceous understory carbon (RF-2) and for soil (RF-2) for Reforestation Projects; or for soil alone (IFM-6; AC-6; Table 5.1) for Improved Forest Management and Avoided Conversion Projects. If the project meets the threshold to include soil carbon due to Project Area soil disturbances exceeding baseline characterization by 25% over the life of the project (Table 5.1) then soil carbon must be accounted for as an emission and verified through sequential sampling as an independent pool (see RF-6). No crediting of increased soil carbon is allowed. Site preparation emissions from mobile sources (RF-10, Table 5.1) are required to be accounted for by Reforestation Projects only; these would not be quantified through sequential sampling; a default factor is provided.

Paired Plots

The statistical test is based on a comparison of the verifier's measurements of plots within a selected stratum, calculated as CO_2-equivalent compared to the Offset Project Operator's or Authorized Project Designee's measurements of plots, which may include any adjustments for growth. Verifiers must use α=0.05 and β=0.20 to control for error. The null hypothesis (H_0) is that the verifier's plots and project plots are equal.

Verifiers sample to compare two populations with respect to two types of error Type I and Type II.

- A Type I error occurs when the hypothesis is rejected despite the hypothesis being true. An example of a Type I error is the incorrect assessment that the verifier's plots and the project plots are not equal when they are equal. Alpha represents the probability (0 to 1) of committing a Type I error. Alpha is set at 0.05, to protect against the likelihood of a Type I error occurring.

- A Type II error occurs when the hypothesis is wrongly accepted despite the hypothesis being false. An example of a Type II error is an incorrect assessment that the verifier's plots and the project plots are equal when they are not equal. Beta, set at 0.20, represents the probability (0 to 1) of a Type II error.

- Alpha and beta are inversely proportional, so as the likelihood of committing a Type I error is reduced (by setting a low alpha) the likelihood of committing a Type II error increases. To protect against a Type II error, the verifier needs to use a test with high power, or the ability to reject the null hypothesis when it is incorrect. The statistical power of a test is denoted by 1- β. Conventionally, a test with power greater than 0.80 is considered statistically powerful. A test of high power ensures that one can detect differences if they exist regardless of the sample variability and the size of the difference.

1) Perform verification sampling on at least the minimum number of plots required in a sequence from Table 10.1 in the Protocol (shown as Table 3 above).

2) If $n \geq ((Z_\alpha + Z_\beta)^2 \times S_n^2) / D^2$ then stop and evaluate. Otherwise take another sample.

   Where:
   n = Number of verification plots measured
   Z_α = α/2% N(0,1) = 1.645
   Z_β = β/2% N(0,1) = 0.8416
   S_n^2 = sample variance of the differences
   D = δ × project average estimate
   δ = standard deviation

3) If stopped, then evaluate.

> If $\bar{X}_N \leq K$ then accept H_0,
> If $\bar{X}_N > K$ then reject H_0.

Where:
$\bar{X}_N$ = sample mean of the differences,
N = total number of plots measured,
$K = (Z_\alpha \times D) / (Z_\alpha + Z_\beta)$.

4) If H_0 was rejected then additional samples may be taken as long as the verifier is of the opinion that there is a chance that H_0 may be accepted based on the variability and trend observed.

Unpaired Plots

The statistical test is based on comparing the average CO_2-equivalent estimates for each stratum between the verifier plots and the Offset Project Operator's or Authorized Project Designee's plots. Verifiers must use $\alpha=0.05$ to control for error; the β is not specified because we are constructing a confidence interval in this case (rather than a test). The null hypothesis (H_0) is that the verification and stratum averages are equal. The following procedure is appropriate for the unpaired test.

1) Perform verification sampling on at least the minimum number of plots required in a sequence
   from Table 10.1 in the Protocol (shown as Table 3 above). Calculate n as the sum of the number of plots from both the stratum and the verification.

2) Calculate the following:

   $T_n = \bar{X}_p - \bar{X}_n$

   Where:
   $\bar{X}_p$ = stratum mean
   $\bar{X}_n$ = verification mean after sample n
   S_n^2 = sample variance of the verification plots
   S_P^2 = sample variance of the stratum plots
   $D = \delta \times$ stratum average estimate
   a = the percentile from a standard normal distribution for one half of alpha; is 1.96 for $\alpha=0.05$

3) If $n \geq (a^2/D^2) \times (S_n^2 + S_P^2)$, then stop and evaluate. (Note: $n = n = n_P + n_V$). Otherwise take another sample.

4) If stopped, then evaluate. Construct a confidence interval $T_n \pm D$.
   If the confidence interval includes zero then accept H_0,
   Otherwise reject H_0.

5) If H_0 was rejected then additional samples may be taken until as long as the verifier is of the opinion that there is a chance that H_0 may be accepted based on the variability and trend observed.

If the stopping rule in step (3) above cannot be attained within 100 plots then apply a standard unpaired t-test comparison using alpha of 0.05 and beta of 0.80.

Steps to Performing the Verification

Introduction

The verifier must sample plots consistent with the objectives of a random, risk based and efficient approach. Thus, the verifier may weigh the probability of selecting strata and plots based on appropriate criteria such as carbon stocking, access difficulty, and vegetation heterogeneity. The verifier may choose to sample project plots within strata with a cluster design. The selection of a stratum may use probability proportional to carbon stocks or probability proportional to error risk. The following steps are provided from the Protocol Section 10.2.2 for the verifier's convenience:

Step 1: Assigning Risk to Strata

The verifier must determine for standing live and standing dead trees (and soils if required) if the Offset Project Operator or Authorized Project Designee has stratified the Project Area into strata that reflect common characteristics that influence carbon stocks. The verifier may presume risk exists in the highest stocked strata, strata that are unique or difficult to access due to topographical, vegetative, or other physical barrier, strata that represent a large portion of the project's inventory due to the area they represent, or any other risk perceived by the verifier. The determination of risk must be applied to the stratum as a unit and not individual stands of a given stratum.

Step 2: Selecting Strata based on Risk

Based on the assessment of risk, the verifier will query, or request that the OPO/APD query, the set of stands that are associated with the strata selected. The queried stands must have an identifier which can be based on the Offset Project Operator's or Authorized Project Designee's identification convention or one assigned by the verifier. Three strata must be selected, or the maximum number of strata stratified by the OPO/APD for each pool. Table 4 below, which is a copy of Table 10.2 in the Protocol, displays an *example* of ordered strata for standing live and dead trees selected by stratum with random number assignments.

Table 4. Stands selected by vegetation strata and risk class with random number assignments.

Stand Number	Stratum (from Forest Owner or Verifier)	Risk Class	Order of Random Selection
2	Dense Intermediate Conifers	High Stocking	5
3	Dense Intermediate Conifers	High Stocking	3
4	Dense Intermediate Conifers	High Stocking	1
8	Dense Intermediate Conifers	High Stocking	8
9	Dense Intermediate Conifers	High Stocking	2
10	Dense Intermediate Conifers	High Stocking	1
15	Dense Intermediate Conifers	High Stocking	4
18	Dense Intermediate Conifers	High Stocking	7
Stand Number	**Stratum (from Forest Owner or Verifier)**	**Risk Class**	**Order of Random Selection**
8	Dense Mature Conifers	High Stocking	4
9	Dense Mature Conifers	High Stocking	3
10	Dense Mature Conifers	High Stocking	5
15	Dense Mature Conifers	High Stocking	2
18	Dense Mature Conifers	High Stocking	1
Stand Number	**Stratum (from Forest Owner or Verifier)**	**Risk Class**	**Order of Random Selection**
13	Medium Dense Mature Riparian	Difficult Access	2
14	Medium Dense Mature Riparian	Difficult Access	1
17	Medium Dense Mature Riparian	Difficult Access	3

Step 3: Planning and Implementing Field Verification Sampling

The selected stands should be mapped and labeled with the random number to assist in developing a strategy to perform field sampling activities. Up to 6 plots or clusters may be re-measured in a stand (if plots are monumented by OPO/APD) or installed (if plots are not monumented) in each stand. If the project area has not been stratified or there are less than 3 strata, the verifier shall locate the plots or clusters using a random process of their own design. For efficiency, it is acceptable for the verifier to relocate to a new area at the beginning of a day without having completed all the plots in the previous day.

Step 4: Determination if the Stopping Rules have been met

The verifier must determine if the stopping rules have been met for each stratum after the measurement of each plot or at a minimum the end of each day. ARB will provides tools to assist verifiers with determining if the stopping rules have been met or not.

It is required that the verifier apply the random order selection in the sampling process. The verifier is free to measure the set of plots that were randomly selected in any order that provides the greatest efficiency while sampling in the field, but when the verifier inputs data into the spreadsheet, the verifier must follow the random selection order in order to properly conduct the analysis and maintain the integrity of the sequential analysis. This may provide significant efficiencies when selected stands and/or plots are in close geographic proximity and it is hypothesized that the stopping rules will require the full number of plots. Table 5 below, which is a copy of Table 10.3 in the Protocol, displays a hypothetical sampling schedule planned by the verifier and the

hypothetical verification results. In this case, the sequential sampling is conditionally satisfied after Day 3 but requires the full set of randomly selected stands to be sampled up to the point of satisfying the sequential statistics, which is met after sampling Stand 3 on Day 4.

Table 5. Example of Randomly Selected Plots   (copy of Table 10.3 in Protocol)

Stand	Stratum (from Forest Owner)	Risk Class	Order of Random Selection	Sampling Schedule (Planned)	Verification Effort	Verification Results
4	Dense Intermediate Conifers	High Stocking	1	Day 3	Day 1	Inconclusive. Stand 9 sampled. Sequential sampling criteria not satisfied - More plots are needed
9	Dense Intermediate Conifers	High Stocking	2	Day 1	Day 2	Inconclusive. Stand 15 sampled. Sequential sampling criteria not satisfied - More plots are needed
3	Dense Intermediate Conifers	High Stocking	3	Day 4	Day 3	Inconclusive. Stand 4 sampled. Sequential sampling criteria satisfied but stand order must be satisfied. Stand 3 must be sampled
15	Dense Intermediate Conifers	High Stocking	4	Day 2	Day 4	Conclusive. Stand 3 sampled. Sequential sampling criteria is met and adherence to random selection is maintained
2	Dense Intermediate Conifers	High Stocking	5	Day 6		
10	Dense Intermediate Conifers	High Stocking	6	Day 5		Further Verification Effort not Necessary
18	Dense Intermediate Conifers	High Stocking	7	Day 7		
8	Dense Intermediate Conifers	High Stocking	8	Day 8		

Use of Sampling Results
If a project includes multiple strata it is possible the test may result in a partial passage whereby one or more stratum passes the sequential sampling test while one or more stratum does not. In this case, because each stratum is tested independently, a verification body should treat the strata that does not pass the sequential sampling test as a non-conformance and provide an opportunity for the OPO to correct the error.   If the OPO chooses to re-inventory the strata or take similar action in order to correct the issue, the verifier may re-sample the strata using a statistically valid sampling approach with a new randomized set of sample plots, coupled with the same sequential sampling technique described above, for retesting. If randomization results in the inclusion of plots that have already been sampled during a previous site visit, that data from the initial test may be used.