A/R Methodological Tool

"Calculation of the number of sample plots for measurements within A/R CDM project activities"

(Version 02)

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

1. This tool is applicable if sample plots are used for monitoring purposes. The tool estimates the number of permanent sample plots needed for monitoring changes in carbon pools at a desired precision level.

Permanent sample plots are to be used because forest inventory involves:

- Measurements taken at specific time intervals;
- High covariance is expected between observations at successive sampling events.

2. Permanent sample plots are statistically efficient in estimating changes in forest carbon stocks because typically there is a high covariance between observations at successive sampling events. However, sample plots must be treated in the same way as other lands within the project boundary, e.g., during site and soil preparation, weeding, fertilization, irrigation, thinning, etc., and should not be destroyed over the monitoring interval. Ideally, staff involved in management activities should not be aware of the location of monitoring plots. Where local markers are used, these should not be visible.

Applicability

3. This tool is applicable under the following condition:

- Variables under consideration are normally distributed or may be transformed into a normal distribution.

4. Normal distribution can be assumed when:

- Many small (independent) effects contribute to each observation in an additive fashion.

Parameters

5. This tool provides procedures to determine the following parameters:

Parameter	SI Unit	Description
n	Dimensionless	Sample size (total number of permanent sample plots required) in the project area
n_i	Dimensionless	Sample size for stratum i

II. PROCEDURE

Method I (samples drawn without replacement)

6. It is assumed that the following parameters are known from the project set up, pre-project estimates (e.g., results from a pilot-study) or literature data:

A	Total size of all strata (A), e.g., the total project area; ha
i	Index for stratum; dimensionless
L	Total number of strata; dimensionless
A_i	Size of each stratum i; ha
AP	Sample plot size (constant for all strata); ha
Q	Quantity being estimated (usually the forest carbon stocks); t C ha^{-1}
st_i	Standard deviation of Q for each stratum i; dimension the same as Q
C_i	Cost of establishment of a sample plot for each stratum i; e.g., US $

then:

$$N = \frac{A}{AP} \;;\; N_i = \frac{A_i}{AP} \qquad \textbf{(1)}$$

where:

N	Maximum possible number of sample plots in the project area
N_i	Maximum possible number of sample plots in stratum i

7. The number of sample plots is estimated as being dependent on accuracy and costs.

8. In addition to the assumptions and parameters listed under “Initial calculations”), it is further assumed that the following parameters are known from the project set up, pre-project estimates (e.g., results from a pilot-study) or literature data:

Q_1	Approximate expected value of the estimated quantity Q, (e.g., above-ground wood volume per hectar); e.g., m^3 ha^{-1}
P	Target precision for estimation of Q (e.g., 10%, expressed as a fraction); dimensionless

then:

$$E_1 = Q_1 \cdot p \qquad \textbf{(2)}$$

where:

E_1 Allowable error of the estimated quantity Q

9. With the above information, the sample size (minimal number of sample plots to be established and measured) can be estimated as follows:

$$n = \frac{\left[\sum_{i=1}^{L} N_i \cdot st_i \cdot \sqrt{C_i}\right] \cdot \left[\sum_{i=1}^{L} N_i \cdot st_i \cdot \frac{1}{\sqrt{C_i}}\right]}{\left(N \cdot \frac{E_1}{z_{\alpha/2}}\right)^2 + \sum_{i=1}^{L} N_i \cdot (st_i)^2} \qquad \textbf{(3)}$$

where:

n Sample size (total number of sample plots required) in the project area

i 1, 2, 3, … L project strata

α 1-α is probability that the estimate of the mean is within the error bound E

$z_{\alpha/2}$ Value of the statistic z (embedded in Excel as: inverse of standard normal probability cumulative distribution), for e.g., 1-α = 0.05 (implying a 95% confidence level) $z_{\alpha/2}$ =1.9599

10. The value n calculated according to formula (2) is the minimal number of sample plots that allows the estimate of the mean to be within the error bound E with probability 1-α. This value is optimal in such sense that it minimizes the sum of costs of establishment and the maintenance of sample plots. The data on costs may be approximate, but shall reflect relative differences of costs among strata.

$$n_i = \frac{\sum_{i=1}^{L} N_i \cdot st_i \cdot \sqrt{C_i}}{\left(N \cdot \frac{E_1}{z_{\alpha/2}}\right)^2 + \sum_{i=1}^{L} N_i \cdot (st_i)^2} \cdot \frac{N_i \cdot st_i}{\sqrt{C_i}} \qquad \textbf{(4)}$$

where:

n_i Sample size for stratum i

i 1, 2, 3, … L project strata

α 1-α is probability that the estimate of the mean is within the error bound E

$z_{\alpha/2}$ Value of the statistic z (embedded in Excel as: inverse of standard normal probability cumulative distribution), for e.g. 1-α = 0.05 (implying a 95% confidence level) $z_{\alpha/2}$ =1.9599

11. When no information on costs is available or the costs may be assumed as constant for all strata, then:

$$n = \frac{\left[\sum_{i=1}^{L} N_i \cdot st_i\right]^2}{\left(N \cdot \frac{E_1}{z_{\alpha/2}}\right)^2 + \sum_{i=1}^{L} N_i \cdot (st_i)^2} \qquad (5)$$

$$n_i = \frac{\sum_{h=1}^{L} N_i \cdot st_i}{\left(N \cdot \frac{E_1}{z_{\alpha/2}}\right)^2 + \sum_{i=1}^{L} N_i \cdot (st_i)^2} \cdot N_i \cdot st_i \qquad (6)$$

It is possible to reasonably modify the sample size after the first monitoring event based on the actual variation of the carbon stocks determined from taking the *n* samples.

Method II (samples drawn with replacement)

12. It is assumed that the following parameters are known from the project set up, pre-project estimates (e.g., results from a pilot-study) or literature data:

A	Total area of all strata (i.e., the total project area); ha
i	Index for a stratum; dimensionless
L	Total number of strata; dimensionless
A_i	Area of each stratum i; ha
st_i	Standard deviation of the estimated quantity Q for each stratum i; dimension the same as Q
C_i	Cost of establishment of a sample plot for each stratum i; e.g., US $
Q_2	Approximate expected value of the estimated quantity Q, on a per plot basis (e.g., m^3 above-ground wood volume per plot); e.g., m^3
p	Desired level of precision (e.g., 10%, expressed as a fraction); dimensionless

then:

$$M_i = \frac{A_i}{A} \qquad (7)$$

where:

M_i Share of area of stratum *i* in the project area *A*

and:

$$E_2 = Q_2 * p \tag{8}$$

where:

E_2 Allowable error of the estimated quantity *Q*

13. The number of permanent sampling plots for monitoring of an A/R CDM project activity may be estimated by means of the following approximate formula according to Wenger (1984):[1]

$$n = \left(\frac{t_{n-L,\alpha}}{E_2}\right)^2 \left[\sum_{i=1}^{L} M_i \cdot st_i \cdot \sqrt{C_i}\right] \cdot \left[\sum_{i=1}^{L} M_i \cdot st_i \Big/ \sqrt{C_i} \cdot\right] \tag{9}$$

$$n_i = n \cdot \frac{M_i \cdot st_i \Big/ \sqrt{C_i}}{\sum_{h=1}^{L} M_i \cdot st_i \Big/ \sqrt{C_i}} \tag{10}$$

where:

$t_{n-L,\alpha}$ Student's *t*-distribution value for a confidence level 1-α (e.g. for α=0.05 the confidence level equals 95%) and *n-L* degrees of freedom

E_2 Absolute value of allowable error per plot (e.g., m^3)

14. The standard deviation of each stratum (st_i) can be determined through *ex ante* estimates of variance of carbon stock in pools considered by the methodology. Student's *t*-distribution value for 95% confidence level is approximately equal to 2 when the number of sample plots is over 30. As the first step, use 2 as the $t_{n-L,\alpha}$ value and if the resulting *n-L* is less than 30, use the new value of *n* to get a new $t_{n-L,\alpha}$ value (from statistical tables or the embedded function in Excel - inverse of Student's *t*-distribution) and conduct a recalculation. This iterative process shall be repeated until the calculated value of *n* is stabilized.

15. It is good practice to reasonably modify the sample size after the first monitoring event based on the actual variation of the carbon stock changes determined from taking the *n* samples.

- If modified sample size is smaller than the initially estimated one, then the measurements shall be continued on all sample plots initially identified;
- If modified sample size is greater that the initially estimated one, then the relevant number of "new" sample plots shall be partitioned among the project areas of land proportionally to number of already established sample plots. The "new" sample plots shall be distributed in approximately uniform way over the areas of land and located in centers of cells of the existing sample plot grid.

[1] Wenger, K.F. (ed). 1984. Forestry handbook (2nd edition). New York: John Wiley and Sons.

Sample plot size (for both methods)

16. The plot area *AP* has major influence on the sampling intensity and time and resources spent in the field measurements. The area of a plot depends on the stand density. Therefore, increasing the plot area decreases the variability between two samples. According to Freese (1962),[2] the relationship between coefficient of variation and plot area can be denoted as follows:

$$CV_2^{\,2} = CV_1^{\,2} \cdot \sqrt{\frac{AP_1}{AP_2}} \quad \textbf{(11)}$$

where AP_1 and AP_2 represent different sample plot areas and their corresponding coefficient of variation (*CV*). Thus, by increasing the sample plot area, variation among plots can be reduced permitting the use of small sample size at the same precision level. Usually, the size of plots is between 100 m^2 for dense stands and 1000 m^2 for open stands.

Determining plot location (for both methods)

(a) It is recommended that permanent sample plots be located using the approach of aligned systematic sampling. In this approach a grid is laid over the entire project area, and the centre points of a permanent sample plots are taken as those grid intersection points that fall within a stratum. The grid shall have a random origin (i.e. the origin is a randomly selected set of map coordinates), and optionally a random orientation (a randomly selected compass orientation);

(b) To obtain the correct number of permanent sample plots in each stratum, vary the spacing of the grid (the distance between grid intersections) until the necessary number of grid intersections in a stratum is obtained. It is not necessary to retain the same grid spacing for each stratum; however the same origin and orientation should be retained for the grid;

(c) Having assigned the centre points of the permanent sample plots using the above procedure, it is possible that, due to inherent and unavoidable uncertainty in mapping and/or sample plot location, during sample plot installation part of a sample plot may be found to fall outside of the area that is forested. In this case, move the plot centre towards the centre of the parcel of land such that the outer edge of the plot coincides with the estimated position of the outer edge of the forest canopy at tree maturity. The direction of movement of the plot centre shall be at right-angles to the edge of the parcel of land;

(d) Sufficient sample plots should always be allocated to a stratum so that it is possible to omit any sample plots that prove to be inaccessible — while still maintaining the minimum number of sample plots calculated in Section II.1 or II.2.

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[2] Freese, F. 1962. Elementary Forest Sampling. USDA Handbook 232. GPO Washington, DC. 91 pp

History of the document

Version	Date	Nature of revision(s)
02	EB 46, Annex 19 25 March 2009	Further clarification of practical aspects on location of permanent sample plots for data collecting and improvement in clarity of formulae
01	EB 31, Annex 15 04 May 2007	Initial adoption.