Australian Government

Department of Climate Change and Energy Efficiency

Carbon Farming Initiative (CFI)

Guidelines for the development of field-based reforestation methodologies

Part 1: Methodologies that use single tree allometric equations

•Reducing our carbon pollution•Preparing for climate change•Helping to shape a global solution•

Disclaimer

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GLOSSARY

TERM	DEFINITION
Accuracy	The closeness of an estimate to the exact or true value.
Allometry	The study of the relationship between the size and shape of an organism.
Allometric equation	An equation that quantifies the allometric relationship between different dimensions of an organism.
Allometric domain	The specific range of conditions under which a given allometric equation was developed.
BA - Basal Area (m^2)	The area of the cross section of the trunk of a tree at the reference height (1.3 m).
BAF - Basal Area Factor	Used in variable probability sampling systems (e.g. point sampling) where trees are selected for measurement based on the square of their diameter at breast height.
BH - Breast Height	A standard height on the trunk of a tree. In Australia defined as 1.3 m above ground.
Bias	A systematic distortion in a value. A component of error.
Biomass	Here used to describe the dry mass of organic matter in a given habitat, population, or sample.
Coarse Woody Debris	Larger dead wood (>2.5 cm diameter) material where not included in litter.
CV% - Coefficient of Variation	The standard deviation divided by the mean; expressed as a percentage. Provides a standardised measure of the variation in a population.
DBH - Diameter at Breast Height (cm)	The diameter of a trunk of a tree at the reference height (BH) of 1.3 m above the ground. Commonly estimated from the circumference divided by pi, or using callipers for small trees.
Debris	Here used to describe dead organic matter.
Domain variables	The characteristics and conditions used to describe an allometric domain
Error (E%)- Measurement error	Uncertainty caused by imperfections in measurement techniques or equipment. Typically reported as a percentage around the estimated mean for a given confidence limit.
Error - Modelling error	Uncertainty caused by limitations of any models to achieve exact predictions. Model validation requires comparing predictions with outcomes to establish whether a model is reliable within an acceptable margin of error.
Error (E%)- Sampling error	Uncertainty caused by measuring only a sub-section of a population, as opposed to measuring the entire population. Typically reported as a percentage around the estimated mean for a given confidence limit as for measurement error
Expansion Factor	A constant to convert one estimated variable to another variable of interest—such as volume estimates to above-ground biomass—for a tree. The expansion factors can be wood density estimates (kg m^{-3}) to obtain

TERM	DEFINITION
	merchantable timber weight from volume, or a ratio of merchantable timber volume to total above ground weight (to include branches, bark and leaves).
Explanatory variable	A variable in an equation or a statement, the value of which determines the value of a response variable in the equation. Also known as a predictor, input, independent or X variable.
Inventory	Information on a population that has been systematically collected.
LiDAR	Light Detection And Ranging (LiDAR). A remote sensing tool that uses active pulses of light to determine distance and direction of an object from the transmitter. LiDAR is increasingly used in natural resource management.
Litter	Plant-derived debris occurring at ground-level, typically including fallen leaves, twigs, bark and small woody material (<2.5 cm diameter) in various states of decomposition.
Orthogonal Projection	The projection used to derive conventional maps where the three dimensional landscape is expressed in two dimensions.
Population	A set of units about which information is wanted and estimates are required. For the purpose of this document, the population refers to all units within an area identified as a CFI project for which the field-based inventory is being designed..
Precision	The property of a set of measurements of being very reproducible or of an estimate of having a small random error of estimation.
Residual	The difference between an observed value of the response variable for an individual and the value predicted by the fitted model (Observed – Estimate). May also be termed ‘error’.
Response variable	A variable in an equation or statement value which varies according to the value of one or more explanatory variables. Also known as the Predicted or Y or dependent variable.
Sample	A subset of the units from within a population selected based on a randomised process with a known probability of selection.
Single tree allometric equation	An equation that quantifies the allometric relationship between measureable dimensions of a single tree to tree biomass or carbon.
Stratum	In forest mensuration- an area of forested land with homogenous characteristics.
Sub-sample	A sample selected from within a sampled unit
Unit/s	The primary entity that is being sampled; this can, for example, be a plot, point, or a single tree.
Variance	The mean square deviation of the variable around the average value. It reflects the dispersion of the empirical values around its mean.

1. INTRODUCTION

1.1 BACKGROUND

The Carbon Farming Initiative (CFI) allows farmers and other land managers to earn Australian Carbon Credit Units (ACCUs) by increasing carbon sequestration or reducing greenhouse gas emissions on the land. It is a condition of eligibility that offsets projects must use a methodology approved for use under the CFI. CFI methodologies set out the rules and instructions for undertaking CFI offsets projects, estimating abatement and reporting to the Clean Energy Regulator (CER).

Proposed methodologies are assessed by an independent expert committee, the Domestic Offsets Integrity Committee (DOIC). The DOIC is required to assess whether proposed methodologies meet the requirements of the offsets integrity standards as set out in section 133 of the *Carbon Credits (Carbon Farming Initiative) Act 2011*. For methodology developers, the key offsets integrity standards can be summarised as requiring that:

- the abatement should be measurable and verifiable
- the method should not be inconsistent with the methods set out in the National Inventory Report
- the method should be supported by relevant scientific results published in peer-reviewed literature
- any estimation, assumption or projection in the methodology should be conservative.

The DOIC has approved a methodology for sequestration through reforestation for use under the CFI: the *Methodology for Quantifying Carbon Sequestration by Permanent Environmental Plantings of Native Species using the CFI Reforestation Modelling Tool*. This methodology uses a modelling tool that is freely-available for use on personal computers. The Reforestation Modelling Tool (RMT) accesses relevant components of the National Inventory Model and data to offer a low cost means of estimating and reporting the amount of carbon sequestration achieved by environmental plantings.

Further guidance on methodology development is available within the *Guidelines for Submitting Methodologies*, available at www.climatechange.gov.au.

1.2 OBJECTIVES & SCOPE

This document is intended for proponents who are developing field-based reforestation methodologies (methodologies) that use single tree allometric equations. These methodologies are ones which:

- estimate the sequestration of carbon in trees and forest systems
- use field-based sampling of data to estimate carbon stocks, rather than the use of a purely model-based approach such as the RMT
- use single tree allometric equations to estimate tree biomass from one or more explanatory variables.

The aim of this document is to assist proponents to develop methodologies that meet the requirements of the CFI. The DOIC will use these guidelines to assess whether methodologies meet the CFI integrity standards and are suitable for use under the CFI.

These guidelines are not designed to provide a manual for designing sampling. It is anticipated that users of the guidelines will have experience in the design and implementation of broad scale inventories. These guidelines describe the underlying principles for obtaining accurate and precise estimates of carbon stock through field-based measurement, and outline the information that should be included in a proposed methodology. The document provides guidance on:

- developing, validating and using allometric equations
- developing a sampling design
- data management
- reporting and keeping records.

Where appropriate, principles are illustrated through examples. The guidelines are not designed to prescribe specific approaches to field-based sampling. Proposed methodologies may include approaches that differ from those described in guidelines provided that any differences are clearly identified and justified. These guidelines will be reviewed and updated from time to time to accommodate new and credible estimation approaches as identified by the Australian Government or proposed by external parties.

1.3 GENERAL PRINCIPLES

Precise and unbiased estimates of carbon in trees and forest ecosystems can be obtained by applying the general principles outlined below.

1.3.1 Identifying the population

- For the purpose of this document, the population refers to all entities within an area identified as a CFI project for which the field-based inventory is being designed.
- Boundaries of the project area must be identified in accordance with the current version of the *Spatial Mapping Guidelines*, available at www.climatechange.gov.au.

1.3.2 Identifying sampling units in the population

- A unit is the primary entity that is being sampled. A unit can, for example, be a plot, a point, or a single tree (Section 3.2).
- The units in the population being sampled, as well as any exclusions and their treatment, must all be clearly described (Section 3.2).
- The identification and selection of units must be clear, transparent, independent of subjective choice, and repeatable (Section 3.3).
- The probability of selecting any unit within the population must be greater than zero and known (Section 3.3).
- The units must be able to be identified, located and remeasured by a third party to enable sampling to be audited as part of the offsets reporting process (Section 3.3).

1.3.3 Identifying and measuring parameters

- The basis of any assumed relationship[1] between any two parameters (e.g. diameter at breast height (DBH) and biomass or carbon) must be clearly specified. Relationships between non-destructive measures and biomass or carbon may take the form of allometric equations (Section 2).
- The accuracy and precision of estimates must be clearly identified (Section 2).
- Errors associated with inappropriate multiplication or division of two or more component estimates must be minimised[2]. For example, where a methodology allows that $A \times B = C$, it should not be assumed that $\overline{A} \times \overline{B} = \overline{C}$ or similarly where a methodology deals with ratios and allows that $B = C/A$ it should not be assumed that $\overline{B} = \overline{C}/\bar{A}$ (see also Section 4.1).

1.3.4 Factoring up sample measurements to estimate carbon in the target population

- Double-counting of carbon pools must be avoided if total population estimates are derived by combining estimates from different levels in the sampling design, separate models or relationships (Section 3.2).
- The number of units selected for measurement should be sufficient that the sample reflects the variability within the target population (Section 3.4).
- Where sampling is undertaken in a multi-stage or multi-phase approach, the relevant sampling errors for each stage or phase must be reported as well as the overall estimate of the population error. Any assumptions underpinning the estimation of the overall error must be identified and justified (e.g. independence of errors in each of two phases) (Section 4.1).
- Errors of material consequence must be identified, quantified and managed. These errors include but are not limited to, sampling error; measurement error and modelling error (Sections 2.4 and 4.1).

2. ALLOMETRIC EQUATIONS IN CFI METHODOLOGIES

2.1 BACKGROUND

Allometric equations quantify the relationships between different dimensions of individual organisms. Field-based forest methodologies are likely to use allometric equations to estimate forest carbon from indirect measurements because direct measurement of forest carbon is costly and destructive. The allometric equations used generally relate the size of an easily accessible or measurable part of a tree, for example the diameter of a tree trunk over bark at a specified height to the total dry weight of the tree (see Appendix A). Allometric equations are established through the measurement of the variable of interest coupled with destructive sampling of biomass and statistical modelling.

Methodologies can make use of existing allometric equations from third party sources (e.g. peer-reviewed journals) when the allometric domain is specified and the measurement protocols used to develop the equation are known and appropriate. Methodologies must limit the use of allometric

[1] Specifically in this case, the allometric equations. However also more generally can be applied to root:shoot ratios; volumetric equations along with basic density estimates; biomass expansion factors etc.

[2] See Jasienski and Bazzaz 1999; Welsh *et al.* 1988.

equations to the specified domain or circumstances where the allometric equation is known to be valid. The DOIC will assess whether the allometric equations, the described allometric domain, and the proposed application of the equation, including the sampling design, satisfy the CFI offsets integrity standards.

Alternatively, methodologies can include instructions for project proponents to develop allometric equations for their project. In these circumstances, the DOIC will assess whether the methods for developing and applying the allometric equations, including the proposed sampling design, meet the CFI offsets integrity standards.

Change in biomass/carbon stock can also be estimated using growth and yield models. Such models include a large number of potential forms; many are based on multiple linear equations that use DBH and some form of site index as the explanatory variables. Field-based sampling is used to provide the initial estimates of these explanatory variables for use in the model to estimate the change in biomass/carbon. While growth models can be used in CFI methodologies, the selection, validation and application of such models is outside of the scope of these guidelines.

2.2 ALLOMETRIC EQUATIONS FOR BELOW-GROUND BIOMASS

Below-ground biomass is often estimated differently to above-ground biomass due to the disproportionately higher cost of direct estimation. A methodology can, for example, specify that a proponent must:

- apply the root:shoot ratio, as used in the National Inventory, or
- develop an allometric equation to estimate below ground or total tree biomass.

A methodology that involves the development of a new allometric equation for below-ground biomass, must address the same minimum standards for above ground allometric equations[3].

Note that *NCAS Technical Report 31*[4] describes some approaches for destructive sampling of below-ground biomass.

2.3 WELL FITTED ALLOMETRIC EQUATIONS

Allometric equations are statistical models that need to strive for parsimony. Allometric equations are premised on underlying assumptions that any variables not included in the explanatory variables do not have an important impact on the model predictions or are collinear with the included explanatory variables[5]. Allometric equations that exclude important explanatory variables or are applied inappropriately may result in biased estimates. For example, tree dominance class can influence the relationship between DBH and biomass. If dominance class is excluded as an explanatory variable in

[3] Root:shoot ratios can be highly variable in the early stages of stand development and between sites. The allometric domain for equations relating to root:shoot ratios are therefore likely to be constrained by the site and age or successional stage of the population sampled.

[4] http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr31final.html,accessed 14 November 2012.

[5] DBH and tree height, for example may be consistently related for a given species, stand development and location. However a different relationship may be observed for different species, different ages or different locations.

an allometric equation and only dominant trees were sampled during the development of the allometric equation, then using it to estimate the mass of suppressed trees may result in biased estimates.

Methodologies should provide for accurate and precise estimates of abatement; that is, for abatement to be estimated using well fitted allometric equations. For the purposes of these guidelines, a well fitted allometric equation should:

a) be un-biased or conservative e.g., the mean of the residuals is not less than zero
b) have appropriate levels of precision i.e., the model satisfies pre-determined thresholds of acceptability for the random error of estimation, confidence limits or prediction limits.

Methodologies proposing to use third party allometric equations must demonstrate that the equations were well fitted to the original datasets providing for an unbiased, or conservative, and precise allometric equation. Similarly, methodologies proposing to develop new allometric equations must provide instruction on how the allometric equation will be fitted to the dataset, providing for an unbiased, or conservative, and precise allometric equation, including precision thresholds and justification for their selection. Direction should also be given on how alternative models will be fitted and selected.

If the variance of the response variables is not constant across the range of values of an explanatory variable[6], and either variable is transformed to overcome this problem, methodologies must include instructions on how to calculate the back-transformed predictions and their unequal back-transformed confidence limits.

2.4 ALLOMETRIC DOMAINS

An allometric domain describes the specific conditions under which an allometric equation is likely to be applicable because the assumptions that underpin it are likely to be satisfied. The domain must be limited to the population characteristics from which the allometric equation was derived or validated.

Allometric domains can be defined by, for example:

- species of tree(s) and, where appropriate, growth form(s)
- the range of plant ages, or development stages or vegetation community successional stages
- the range of tree characteristics, such as stem diameters, heights, or other descriptors
- the range of site quality / topography / climate
- geographic distribution
- management regime.

The domain of an allometric equation must be well defined, and may need to go beyond the included explanatory variables. As an example, where an allometric equation uses stem diameter as the only explanatory variable, the domain should be restricted to the range of stem diameters over which the equation was shown to apply and may need to be restricted to the range of tree heights, ages and site types of the trees sampled in the development of the allometric equation. This is because these covariates may influence the relationships of interest but may not have implicitly been included in the model.

Methodologies must clearly define the domain of any allometric equation, and limit the use of the allometric to projects within the defined domain. Large and varied projects may not be covered by a

[6] Demonstrates heteroscedasticity of the residuals

single domain and may need to apply multiple allometric equations. Methodologies that provide for allometric equations to be developed as part of the project must also require the project proponent to specify the allometric domain.

Methodologies must also require project proponents to use measurement procedures for collecting data for explanatory variables that are consistent with the measurement procedures used during the derivation of the allometric equations.

2.5 PERIODIC VALIDATION OF ALLOMETRIC EQUATIONS

All allometric equations must be validated periodically to ensure that they provide reliable estimates of carbon stocks. For the purposes of these guidelines, validation tests that an allometric equation yields predictions that satisfy the minimum accuracy and precision requirements throughout the target population. Minimum accuracy requirements include that the allometric equation yields predictions that are unbiased over the project area[7] (i.e. the mean residual is not different to zero), or where appropriate, are conservative (the mean residual is not less than zero[8]). The minimum precision required as reflected in the confidence intervals or prediction intervals of predictions derived from the equation must be defined, justified and tested by the proponent.

Validation must include destructive sampling[9] and compare predicted and measured estimates of tree biomass or carbon. At a minimum, equations must be validated within either 5 years of planting or the first reporting period of a project, and again in the final reporting period at the end of the 15 year crediting period.

Methodologies therefore need to describe the procedures for collecting and analysing data to validate allometric equations. Methodologies must also describe the procedures to follow if allometric equations are found to yield predictions which do not meet minimum accuracy and precision requirements. These procedures must effectively align project crediting with project sequestration and could include recalibrating allometric equations, or redefining allometric domains.

The processes described within methodologies for the selection of sample units and the number of units to be sampled should be consistent with the guidance provided on sampling design (*see Section 3*).

[7] For example, if the domain includes two species, then the mean residual for each species must be unbiased or conservative.

[8] If the mean residual (Observed – Estimate) is greater than zero, then the model is conservative (does not over-estimate the carbon. Such a conservative result may be justified by the proponent.

[9] These guidelines will be reviewed in the future and amended should alternative, non-destructive, approaches be developed that achieve an appropriate level of statistical certainty.

3. SAMPLING DESIGN

Project proponents will need to collect field data to develop, validate and use allometric equations. Methodologies must therefore include a comprehensive set of instructions to ensure sampling designs are developed for the selection and measurement of samples that minimises the bias and imprecision of the estimates of carbon stocks.

A sampling design must define: the total target population; the units; the manner in which sample units will be selected; the number of sample units to be selected; and what variables relating to the units will be measured.

The following sections describe the core principles associated with these components of a sampling design. Sampling approaches may vary under different circumstances given the inherent properties of a given population (size, variability, remoteness, economic value), information already available (for example maps or remotely-sensed data), and available technology and other resources. Proponents of methodologies should select an approach that is consistent with the sampling principles outlined below, which are designed to ensure that estimates are unbiased and of sufficient precision to satisfy the CFI offsets integrity standards. The DOIC will use these guidelines when considering whether the proposed sampling approach, including levels of precision, meets the CFI integrity standards.

The sampling design for the development and validation of an allometric equation will likely differ from the sampling design for estimating carbon stock. Nevertheless, the overarching principles behind stratification, defining units, selecting units, and determining the number of units to sample, are consistent across all sampling designs.

3.1 STRATIFICATION OF THE PROJECT AREA

Under the CFI, a project area is the area of land on which the project is located, or will take place. All sequestration and emissions reductions projects that relate to a defined area of land must provide information to the CER about the project area[10].

Depending on the conditions of the project, project proponents can stratify a project area by dividing it into more homogenous areas of land (strata/ Carbon Estimation Areas or CEAs) and a 'stratified' sampling approach can be used. In stratified sampling, the strata means are combined in a weighted process to calculate the total estimates for the project.

Generally, stratified sampling is more efficient than a non-stratified approach if the strata are more homogenous (less variable) than the total population. This improves the precision of the overall population estimate for a given sample size. Homogeneity may be increased if the strata/CEAs included areas that have similar species, establishment histories, vegetation structure and/or other factors (e.g. management or planting densities) that influence carbon stocks or other aspects of abatement of greenhouse gas emissions. Separate sampling is required for each stratum.

Methodologies must require boundaries of all strata to be clearly described. Where necessary, methodologies can allow boundaries to be amended or a new stratification applied after the project area has been approved by the CER, provided the number of samples remains above the minimum per strata and the samples can be uniquely allocated to the relevant strata. Additional sampling may

[10] See DCCEE Spatial Mapping Guidelines, available from www.climatechange.gov.au.

be required where an amendment of the boundaries of strata results in samples within the initial strata no longer being representative of the new strata. An existing stratum should generally not be expanded unless the additional area exhibits similar characteristics that were used to define the original area. Amendments to the strata boundaries should not change the project area boundary: such changes must be approved by the CER.

Methodologies may allow strata boundaries to be determined through consideration of a variety of sources such as aerial photography, site survey or maps (e.g. soils, native vegetation classes, and climate). Post-sampling stratification may also be used where observations are made from an initial survey. When using post-sampling stratification, the mean and variance estimates must account for the sampling errors introduced by the two phases of sampling. Ignoring the impact of multi-phase or double sampling will bias estimates of variance, but a conservative estimate is possible if the calculations are made as though stratification was not carried out.

Refer to the CFI Mapping Guidelines[11] for further guidance on mapping strata.

3.2 DEFINITION OF UNITS

Methodologies must clearly define and describe the units that will be sampled. Common units in a forest inventory are single trees, plots, points, or clusters. During a field survey, neither the units nor the unit characteristics should be altered part way through an inventory (e.g. changing plot size or Basal Area Factors). The following section describes some of the options and key considerations in defining the units in a sampling design.

The definition of units must be sufficiently detailed to ensure that potential units on the boundary or edge of the stratum can be reliably classified as in (or out) of the target population. Methodologies must describe best practice procedures to be followed to avoid bias in the location and treatment of borderline units (i.e. units that are partially in and out)[12].

3.2.1 Single Trees

Methodologies may opt to define single trees as units. This is common in the development and validation of allometric equations. All relevant carbon pools must be identified and estimated. This can represent whole trees, or subdivisions into above-ground and below-ground, and living and dead biomass. Above ground biomass can be further divided into bole and crown, or alternatively bole, branch, twig, and leaf. Using single trees as units is less common when estimating the total carbon stock of a CEA, as it requires knowledge of the total number of trees in a CEA. In this circumstance, individual trees can be selected for measurement using an appropriate sampling approach. Allometric equations would then be used to relate the biometric measurements made to whole tree biomass and/or carbon. The mean carbon per tree ($\overline{C}$) can then be estimated and multiplied by the number of trees in the CEA (N) to estimate the total carbon stocks for all trees in the CEA. ($\boldsymbol{C}$) (e.g. as in equation 1).

$$\boldsymbol{C} = N\overline{C} \qquad \text{equation 1}$$

[11] http://www.climatechange.gov.au/government/initiatives/carbon-farming-initiative/methodology-development/spatial-mapping-guidelines.aspx, as accessed 14 November 2012.

[12] See, for example, the Code of Forest Mensuration Practice, Section 3.3.2. http://fennerschool-associated.anu.edu.au/mensuration/rwg2/code/3-3-2.htm last accessed 14 November 2012

In this case, If the number of trees in the CEA is estimated from a sample of the population, then the overall error of $\boldsymbol{C}$ must also account for the error of this estimate of N.

If a proposed sampling approach defines trees as the unit, proponents of methodologies must explicitly consider the biomass/carbon contributed by dead tree biomass (standing and/or on the forest floor) and other relevant pools which are not intuitively associated with a single tree, such as leaf litter and coarse woody debris. For example, a methodology proposal could provide evidence to justify the use of Expansion Factors or develop a sampling protocol for these pools. Alternatively the methodology could use a conservative approach for these pools that by justifying an assumption that the relevant carbon pool (e.g. coarse woody debris) is not a net source of emissions over the life of the project and excludes the relevant pool from sampling.

3.2.2 Points

Forestry inventories often use point-based sampling (points) in their inventory approaches and this approach could be acceptable in a CFI methodology.

Point-based sampling, such as basal area sweeps, is an efficient approach for estimating forest-based resources that are correlated with stand basal area. In this case the *point,* as defined by the Basal Area Factor of the measurement instrument, becomes the unit in the sampling design. Basal Area Factors are commonly selected so that 7-12 trees are included within each sample.

The biomass or carbon stocks of trees selected at each sample point, as determined with the measurement instrument, is estimated using the relevant allometric equations and a biomass to basal area ratio is estimated. The mean of this ratio is multiplied by the total basal area to estimate the total biomass or carbon. The total basal area is normally estimated using a relatively large number of point samples, which must be selected using an appropriate probability-based approach[13]. There will be some level of imprecision associated with this estimate which must be factored into the calculation of the cumulative error or level of precision.

As with single trees (3.2.1) if a methodology proposes points as the units for measurement, it must explicitly consider treatment of the biomass or carbon stocks contributed by pools which might not intuitively be associated with a single tree, such as dead trees, litter and coarse woody debris. Standing dead trees can be selected at each point and appropriately classified to contribute to an estimate for a standing dead pool.

Methodologies must describe best practice procedures to be followed to avoid bias in the location of points and treatment of borderline trees[14].

3.2.3 Plots

Methodologies can define a fixed area or plot (and all the trees and other components within that area) as the unit for sampling purposes. The fixed area is normally defined using a predetermined geometric shape (circle, square, or rectangle) with set dimensions that enclose a known and constant

[13] This is another example of a two-phase sampling approach.

[14] See, for example, the Code of Forest Mensuration Practice, Section 3.3.2. http://fennerschool-associated.anu.edu.au/mensuration/rwg2/code/3-3-2.htm last accessed 14 November 2012.

orthogonal area[15]. Where fixed areas are relatively long narrow plots, they may be described as transects. Commonly, smaller areas (sub-plots) where more detailed information is collected can be nested within a plot. Plot level estimates incorporate sub-plot level estimates.

In a similar manner to equation 1, total carbon stock ($\boldsymbol{C}$) in a CEA can be calculated from the sample mean carbon stock per plot ($\overline{C}$) and the total CEA area (A), where A is also determined from an orthogonal projection (equation 2).

$$\boldsymbol{C} = A\overline{C} \qquad \text{equation 2}$$

Commonly a plot size is selected that is large enough to contain 20 or more living trees, with sizes ranging from 0.02 ha to 0.15 ha (and in tropical rainforests up to 1 ha[16]). Generally, the larger the plot size, the smaller the variance between the plots and the fewer plots are required to achieve a defined level of precision. However, larger plots are more expensive to measure than small plots.

3.2.4 Clusters

Methodologies can define groups of points and various sized plots as units for sampling, and combined them to define a cluster. In this case the total of the measurements from the cluster becomes the equivalent of the measurement unit.

If, for example, a cluster of three small plots is proposed to be established by sampling at each of the three apices of a triangle, the data from these sub-plots is defined as coming from one sample unit, not three.

Where clusters are used, it is important to identify the specific pools that each type of sub-plot, point or other units, contributes towards the total estimate to ensure there is no double counting or incompletely considered carbon pool.

3.2.5 Multi-phase sampling

Under multi-phase sampling approaches, units can be subject to different types of measurement. Double sampling or a volume-basal-area-ratio (VBAR) is a relatively common multi-phase approach where a large number of points are selected to determine stand basal area (phase 1), while a small number are selected for more detailed measurement to estimate a volume to basal area relationship (phase 2).

Airborne Light Detection And Ranging (LiDAR) technology can also be used in a multi-phase approach. Long transects over the forests can be used to determine the average height and density of the vegetation (phase 1), while a small number of field locations are used to relate biomass to the LiDAR measurements (phase 2).

Multi-phase approaches will be effective where extensive data can be collected at relatively low cost (phase 1) and a strong relationship between measurements and carbon stocks can be demonstrated and validated (during phase 2).

[15] The on-ground dimensions of plots located on slopped ground should be adjusted to ensure constant orthogonal area.

[16] Although plots of this size are more useful to ensuring adequate capture of species diversity.

3.3 THE SELECTION OF UNITS FOR SAMPLING

Once defined, samples from the population can be selected for measurement in one or more stages, using equal or unequal probability approaches. In any case, the probability of any unit in the total population being sampled must be greater than zero and be quantifiable.

Subjective and opportunistic sampling must not be used because it is impossible to ensure freedom from bias or to calculate the precision of the estimates.

3.3.1 Procedures for unbiased and objective sample selection

Samples and sub-samples must be selected objectively (not subjectively or on a *convenience*[17] basis) and allow coverage of the entire population. This can include systematic sampling as well as random sampling, which are both equal probability sampling systems. In these systems, each unit has the same chance of being selected as a sample, but in systematic sampling not all combinations of units are possible.

A systematic approach is often selected to provide a representative coverage of the geographical area as well as being easier to establish and monitor. Such an approach may use a randomly placed grid over the CEA with units located at each of the grid intersections.

If a methodology opts for random sampling and requires the generation of random locations, a pseudo-random number generator that uses a known seed value is required. Pseudo-random number generators produce lists of numbers that appear random, that is without apparent pattern and can be related to the sample selection. The advantage is that the same exact list can be recreated if the “seed” conditions are repeated. This recreation allows a check on the numbers used in the sample selection. Methodologies must require that the generator and seed value used be included in the project report.

Efficient unequal probability selection systems select samples in proportion to some aspect of their size. For example, angle-count sampling systems select individual trees in proportion to their tree basal area – a tree with twice the basal area of another has twice the chance of being selected in a sample. Once these probabilities are known, they can be used to calculate unbiased estimates for the population (and their precision). If these probabilities are proportional to biomass or carbon stock, then the precision of the final estimate will be better than that from an equal probability selection system that measures the same number of units.

To allow for auditing, methodologies must require that project proponents determine and document the plot location within sampling plans prior to undertaking field surveys. Project proponents must also compare these plot locations with the realised plot locations to demonstrate that plots were not moved so as to deliberately affect estimates.

3.3.2 Stratified sampling

The most common multi-stage system is stratified sampling. If a methodology includes stratified sampling, the probabilities of sample unit selection can differ between strata and must be identifiable. An efficient approach would be to determine the number of units to be measured in each stratum as a proportion of the area and the variance of the stratum.

[17] Convenience sampling, instead of selecting units using some probability-based approach, uses units that are easily available – for example, trees that have been felled in a nearby logging coupe.

3.3.3 Permanent plots

Measurements of change or growth through time will be more precise if the units sampled are locatable or permanent – that is, the same unit can be found and remeasured at each reporting period. Given this, methodologies may opt to use permanent plots, noting the importance of permanent plots being representative of the area sampled. It is generally more expensive to establish permanent plots because durable markers must be placed in the field. Estimates of change from multiple measurements of permanent plots may be more precise than those estimated from the difference between the means from two independent sets of sample measurements. If methodologies monitor forest change by measuring the growth of individual trees in permanent plots, project proponents must quantify mortality/loss (trees present in 1st measurement but not second), and in-growth of new trees (trees present in 2nd) measurement but not 1st. Where permanent plots are measured repeatedly across time analyses of the resulting longitudinal data should consider the dependence structure of the data.

Further information on sample establishment and location are defined in Section 4 of *NCAS Technical Report 31*[18].

3.4 NUMBER OF SAMPLE UNITS

3.4.1 Development of allometric equations

The number of samples required to develop an allometric equation will be dependent on the inherent variability of the target population and the selected test (thresholds) for goodness of fit (unbiased and precise). The sample size should be sufficient to reflect the range of relevant characteristics present within the population (or domain). Further information on sampling size for destructive sampling can be found in Appendix 3 of *NCAS Technical Report 31*[19].

3.4.2 Validation of allometric equations

The sample size required to validate an existing allometric equation would normally be smaller than that required to develop a new allometric. The size of the sample for validating an existing allometric test need only be sufficient to reliably determine that the sample mean carbon stock estimated by direct measurement is not significantly less than the sample mean carbon stock estimated indirectly using the allometric equation of interest (e.g. a statistical test rejects with a predetermined threshold probability the hypothesis that the mean residual is less than zero). Samples should reflect the range of characteristics present in the population/CEA, noting that this may represent a sub-set of what is covered by the allometric domain.

If the testing indicates the original allometric equation is valid, the validation (independent) and original destructive sampling data sets can be pooled to re-fit the allometric model.

[18] http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr31final.html , as accessed 14 November 2012.

[19] http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr31final.html , as accessed 14 November 2012.

3.4.3 Estimating project characteristics

Methodologies must clearly describe and justify how the number of units to be sampled is to be determined. The sample size is a compromise between the desired level of precision, the cost of measurement and the resources available. The inherent variation between units creates an overall constraint on the precision that can be achieved. This can be managed to some extent by manipulating the definition of the unit (for example adjusting plot size[20]) and using multi-stage approaches.

Project proponents may wish to undertake a reconnaissance survey or use relevant existing information to estimate the variance of the population. The proponent can then estimate the sample size, n (for example[21], equation 3). The planning of the inventory to achieve the desired levels of precision is facilitated by more accurate initial estimates of variance.

$$n = \frac{CV\%^2 \times t^2}{E\%^2} \qquad \text{equation 3}$$

Where:
CV% denotes the coefficient of variation for the population of interest (CEA, or project) expressed as a percentage.
E% denotes the allowable level of sampling error (expressed as a percentage, typically 10% for forestry projects.
t denotes the student-t value for the appropriate degrees of freedom (n -1) and level of confidence.

It is good practice to have at least five units selected for sample measurement in any stratum, and commonly about 25 – 35 sample plots are established. More sample plots will be required to achieve a given level of precision for more variable areas.

3.5 TIMING OF SAMPLING

Well defined and implemented sampling designs using the principles described above will provide unbiased and precise estimates of the biomass/carbon at the time of measurement. These estimates will be conservative if measurements are taken shortly before the project reporting date, unless there is a significant disturbance after measurement. Given this, methodologies should require that all field measurements for use in a given project report be completed within a six month period. It is preferable for all field measurements to be made within six months of the end of the project reporting period. All measurements need to allow for relocation of the relevant units in the event of an on-site audit subsequent to reporting. Methodologies must require the dates of data collection to be included within the project reports.

[20] Larger plots incorporate more variation within themselves and consequently the variation between these larger plots is reduced.

[21] It is noted that other peer-reviewed equations are available.

4. DATA MANAGEMENT

4.1 ERROR ESTIMATES

Errors are uncertainties that are introduced into estimates through a variety of sources. There are many taxonomies of uncertainty but modelling, measurement and sampling error are often distinguished. These errors influence the accuracy of estimates, their precision and bias. Methodologies must be designed to minimise errors.

Methodologies must specify the desired level of reliability–within specified confidence limits–of final estimates of project carbon stock or carbon stock change, and describe how this is to be calculated. The confidence limits and level of error should reflect best practice for the abatement activity covered by the methodology. Australian forestry literature commonly indicates that sampling errors of ±10% at the 95% confidence level are desirable. The IPCC suggests the same target[22]. However, targets ranging from 5% to 20% at the 95% confidence level may be justified as relevant for forest decision-makers. The DOIC will assess whether the proposed methodology will result in estimates that have an acceptable level of precision.

Methodologies must require proponents to account for measurement and sampling error in estimating carbon stocks. Measurement error (if material) and sampling error should be quantified and propagated into the final estimates of abatement.

If measurement error is considered to be immaterial (i.e. treated as zero), methodologies must contain provisions designed to ensure they remain immaterial, for example periodic calibration of measuring equipment and reference to standards or procedures for measurement. Methodologies should also require that where such assumptions are found to no longer be valid, for example where a systematic measurement error is identified and its magnitude and direction is known, it must be managed or removed by applying a correction.

Methodologies must also describe how modelling error is to be treated. The methodology proposal must justify the allowable treatments and the adequacy of the model (see also Sections 2.3 and 2.5). . Where the overall error is shown to be dominated by sampling error[23], the modelling error for an unbiased allometric does not need to be propagated into the final estimates of abatement.

Methodologies must also provide specific instructions for circumstances where the desired level of error of an estimate of carbon stock or carbon stock change is surpassed in a given reporting period (e.g. due to insufficient sampling). These provisions must minimise the potential for significant over-crediting as a result of error. Provisions may include, for example:

- requiring additional sampling in accordance with principles for sample selection
- requiring that the conservative estimate of carbon stock be reported, as defined by a lower confidence limit, and a 'true-up' be carried out in the next reporting period to align project crediting with project abatement. A true-up may require a more comprehensive sampling process to achieve the desired level of error.

[22] IPCC (2003), Good Practice for Land Use, Land-Use Change and Forestry, Chapter 4.

[23] For example where the Root-mean square error (RMSE) is less than 5% of the population standard deviation, or sensitivity analysis indicates the modelling error introduces less than 5% into the variance of the outputs.

Where methodologies calculate change in carbon over time as the difference between two estimates each based on an independent sample, the error of the difference must be accounted for (for example, equation 4).

$$E = \sqrt{\left({B_1}^2 + {B_2}^2\right)} \qquad \text{equation 4}$$

Where:

E denotes the overall standard error of the estimate of the change in carbon.

B_t denotes the standard error of each estimate of carbon at time t.

Where sampling is undertaken in a multi-stage or multi-phase approach, the relevant sampling errors for each stage or phase must be reported as well as propagated to provide an overall estimate of the population error. Any assumptions underpinning the estimation of the overall error must be identified and justified (for example independence of errors in each phase).

4.2 ESTIMATING CARBON FROM BIOMASS

Allometric equations are commonly used to estimate the biomass of a tree on a dry mass basis, rather than mass of carbon of a tree. Where this is the case, all the dry mass data obtained in field measurements must be converted to carbon by multiplying by the carbon fraction of dry biomass. This value varies depending on species and the biomass component in question (trunk, branches, roots, understorey vegetation etc.). The carbon percentages for a range of tree components can be found in *NCAS Technical Reports 7*[24] and *22*[25]. However, an approximate value of 0.50 for the conversion is indicated in the *IPCC Guidelines*, and must be applied if no local values are available. Tonnes of carbon can be converted to tonnes of carbon dioxide equivalents using the standard conversion ratio of 44/12 (approximately 3.67; the molecular weight ratio of carbon dioxide to carbon).

4.3 DATA ANALYSIS

A methodology must set out the process for calculating biomass and carbon stocks at a particular point in time based on sample data. These calculations must include details of how estimates of carbon stocks are derived from other measurements and how sample statistics are scaled up to estimate population totals. Where multi-stage or multi-phase approaches are used, calculations for each stage / phase and the overall sampling error must be included.

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[24] http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr07r1final.html, as accessed 14 November 2012.

[25] http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr22final.html, as accessed 14 November 2012.

5. SUMMARY OF METHODOLOGY REQUIREMENTS

All methodologies that are submitted to the DOIC are assessed against CFI offsets integrity standards, including the requirement that abatement must be measurable and verifiable. The following section details what needs to be described within a methodology to allow the DOIC to assess it against the CFI offsets integrity standards.

5.1 VALIDATING/DEVELOPING ALLOMETRIC EQUATIONS

Methodologies must contain detailed instructions on how allometric equations will be validated, and where applicable, developed or continuously improved. In doing so, methodologies must adhere to the overarching principles for validation and development of allometric equations that are described earlier in this document. While more specific guidance is provided later in this document (Appendix B), in broad terms instructions in methodologies need to cover:

- what allometric equations can be used (*if using existing allometric equations*)
- how the project and/or allometric domains are to be determined and defined to ensure the project occurs within the allometric domain to be used
- what will be sampled (sample units, sub-samples, and parameters)
- how samples are to be selected in an objective manner
- the necessary sample sizes and/or how this is to be determined
- the methods and procedures to be used for sampling in the field (e.g. instructions on destructive sampling)
- the methods and procedures to be used for laboratory-based sampling
- how any new allometric equations are to be developed from the sample data (i.e. process form model fitting and selection)
- how the allometric equations will be validated.

5.2 SAMPLING DESIGN

Project proponents must collect comprehensive data from the project area for input into allometric equations in order to estimate carbon stocks.

All methodologies must explicitly describe the sampling design and steps for field-based sampling. Project proponents will use the design for developing sampling plans for individual projects. Sampling plans should include project-specific information, for example, a description of the target population and means of identifying the location of sample units.

Methodologies must clearly outline how project proponents are to demonstrate adherence to the sampling design or framework in a way that is auditable and can be assessed by the CER. The sampling design should include instructions on:

- how to map the boundaries of the project and each CEA
- what units are to be sampled (e.g. points, plots or trees)
- how the necessary sample size required is to be determined
- how the locations of units will be determined
- the method to be used for sampling
- timing requirements of sampling
- how the final estimate of carbon will be determined (e.g. expansion procedure).

Further guidance is provided in Appendix C.

5.3 REPORTING AND RECORD KEEPING

All processes applied in a methodology must be auditable. Records kept and reports to the CER must provide a transparent, auditable and repeatable representation of each step undertaken in the application of the methodology.

Methodologies must provide for the following information to be included in Project Reports:

- a copy of the sampling plan
- the allometric domain for each allometric equation being used as compared the range of conditions under which it is being applied in the project
- the month and year in which measurements were made
- all assumptions and calculations used in deriving estimates (of means and errors)
- all summary statistics of data collected, and all original data must be retained by the proponent and accessible for audit
- the proponent must keep comprehensive records of all plot locations (e.g. GPS coordinates) and data as necessary to support an audit.

6. REFERENCES

Jasienski M, Bazzaz FA (1999) The fallacy of ratios and the testability of models in biology. Oikos 84, 321-326.

Welsh AH, Peterson AT, Altmann SA (1988) The fallacy of averages. The American Naturalist 132, 277-288.

APPENDIX A

WHAT ARE ALLOMETRIC EQUATIONS?

Allometric equations can take many forms. Allometric equations can take the form of a power function (equation 5a) which can be linearised by natural logarithm transformation (equation 5b). Allometric equations can also include linear equations fitted using regression and include more than one explanatory variable (equations 6a) which can be back transformed to a power function (equation 6b).).

$Y = aX^b$ equation 5a

$LnY = a + blnX_1$ equation 5b

$LnY = a + blnX_1 + clnX_2 \ldots$ equation 6a

$Y = e^{a+blnX_1+clnX_2}$ equation 6b

Where Y denotes the response variable of interest, e.g. carbon stock; and $X_{1,2,..}$ denote the explanatory variable(s), e.g. DBH, tree height, and $a, b, c \ldots$ are constants.

Allometric equations can encompass statistical models that, for example, enable estimation of total volume of a bole or trunk (V), based on non-destructive measurements (equation 7a).

$Ln(V) = a + blnX_1 + clnX_2 \ldots$ equation 7a

The predictions may then be input to a further equation (7b) which multiplies the estimate by mean tissue or wood density (D) and carbon content (C%, to estimate bole carbon), and by an expansion factor (E) to derive indirect estimates of total carbon.

$C = e^{lnV \times D \times C\% \times E}$ equation 7b

Where e is a constant approximately equal to 2.71828.

Any transformations used for the explanatory and response variables (e.g. natural logarithm in equation 6a and its back transformation in equation 6b) should be chosen so that the underlying assumptions of the regression model fitted (e.g. normality and constant variance) are not violated. The transformation implicitly alters the error structure of the data as well as changing the mean function. Predicted means and their confidence limits derived from these models must be back-transformed and reported on their original scales.

APPENDIX B

VALIDATING/DEVELOPING ALLOMETRIC EQUATIONS

Additional information on the points considered in section 5.1 is provided below.

What allometric equations can be used (*if using an existing allometric equation*)

- Identify the existing allometric equations that may be used as part of a methodology, including citing the original reference.

How the project and/or allometric domains are to be determined and defined so as to ensure the project occurs within the allometric domain to be used

- Identify key conditions which will influence the applicability of the allometric, this can include:
  a) species of tree(s) and, where appropriate, form
  b) plant age or development stage or the successional stage of the vegetation community
  c) DBH, height, or some other descriptor of canopy structure
  d) site quality / topography
  e) geographic distribution
  f) management regime.
- Describe what project proponents require to establish the project domain

a) Describe the characteristics to be tested in defining the project domain.

What will be sampled (sample units, sub-units, and parameters)

- Identify the pools and sub-pools for which estimates will be developed
- Ensure processes for aggregation result in no overlap / double counting or missing pools
- At minimum, estimates can be developed for live above-ground biomass. Other pools can include dead above-ground biomass, roots (live and dead), above-ground debris (litter and coarse woody debris), and non-tree vegetation (e.g. grasses, shrubs). Any pool can, optionally, be sub-divided, e.g. above-ground biomass split into live stems, live branches and leaves (crown), and dead attached material (mostly dead branches).

How samples are to be selected in an objective manner

- Include procedures for unbiased and non-subjective sampling.
- Multi-stage, for example stratified sampling, can be used within the sampling framework.
- Sample units (e.g. whole trees) and sub-samples (e.g. disks from a trunk) must be selected objectively (not subjectively or on a convenience[26] basis). Systematic sampling of an area (using a spatial grid) or of trees (say selecting every n^{th} tree) is an acceptable approach. Random sampling approaches must use a “pseudo-random number generator” – one with a seed number that is known – so that the sample selection can be verified

[26] Convenience sampling, instead of selecting units using some probability-based approach, uses units that are easily available – for example, trees that have been felled in a nearby logging coupe.

- Sample units must be representative of the populations for which an estimate will be derived from the sample. Similarly sub-samples must be representative of the unit for which an estimate will be derived from the sub-samples. Sub-samples of a tree (unit) are often taken by removing disks from a tree bole to allow the estimation of that tree's mass. These disks must therefore cover the range/heterogeneity within the bole by, for example, being selected systematically along the stem/trunk. The trees selected for these sub-samples, must cover the diameter/height/species range as defined by the allometric domain.
- Unless a sample unit is small enough to dry whole, sub-samples may need to be taken to determine percentage moisture content or relationships between fresh and dry biomass. Any sub-sample must be attributed to the appropriate sample unit.

The necessary sample size and/or how this is to be determined

- Specify and justify the size of the sample/sub-samples, or provide instruction on how to determine the appropriate sample sizes. It is noted that the number of destructive measurements required will depend on the heterogeneity of the proposed allometric domain (i.e. the range of size classes, age classes and numbers of species, etc., it is intended to apply to).
- This could include a description of the importance of any sub-sample estimate in relation to the overall estimate; and the expected variance of the (sub-) population(s). For example, field-based direct measurements of below-ground pools are often not practicable due to their high cost and inherently high variation, and "default" or simplified models that are conservative may be proposed instead.
- Generally, the sample size for the testing of an existing allometric would be smaller than for developing a new allometric.

The methods to be used for in-field sampling (e.g. instructions on destructive sampling)

- Explicitly describe the procedures for field-based measurements.
- List the appropriate explanatory and domain variable(s) that will be measured.
- Where possible include references to professional[27] or published measurement procedures[28]. Where procedures are referred to within a methodology, deviations from referenced procedures are permitted and must be identified. Where it is not possible to reference third party material, the methodology should include detailed instructions that would allow reliable and repeatable measurement of the selected variables.

The methods to be used for laboratory-based sampling

- Describe the procedures for laboratory-based measurements.
- Include references to professional or published procedures wherever possible, including instructions on the storage and transport of specimens from the field.

[27] For example, the Code of Mensuration Practice authored by the Research Working Group #2. http://fennerschool-associated.anu.edu.au/mensuration/rwg2/code/, as accessed 23 April 2012

[28] For example, *NCAS Technical Report 31* describes an approach for destructive tree sampling for the development and verification of allometric equations. http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tr31final.html , as accessed 14 November 2012.

How any new allometric equations are to be developed from the sample data

- Justify the form of the allometric equations (or other equations) used to relate the explanatory variable(s) to measured biomass / carbon.
- Describe the statistical tests, diagnostics and thresholds used to ensure that the underlying assumptions of regression models fitted or used are not violated (e.g. extent of bias and homogeneity of the residuals).
- Describe the acceptable precision and degree of bias and what remedial action will be taken if the tests fall outside the thresholds.

How the allometric equations will be validated

- Describe how the allometric equations will be validated, including a description of statistical tests to be carried out and corresponding acceptable thresholds.
- Describe what remedial action will be taken if the thresholds are not met.

APPENDIX C

DESIGNING A SAMPLING FRAMEWORK

Additional information on the points in section 5.2 is provided below.

How to map the boundaries of the project and each CEA

- Describe the process for determining the total population relevant to the Project, including where appropriate (for further information refer to the *Spatial Mapping Guidelines*, available at www.climatechange.gov.au):
    a. project area boundaries and clear maps of any excluded areas
    b. strata boundaries
    c. rules for recombination or sub-division into new strata.

What units are to be sampled (e.g. plots, points or trees)

- Describe in detail the shape of any units, sub-units or clusters to be used in the inventory, as well as their size and spatial arrangement, or means for determining these.

How the number of samples required is to be determined

- Describe the process for estimating the number of sampling units needed, including any equations and sources of input data (e.g. coefficient of variation, sampling error etc.).
- Describe the process for adding sample units if thresholds for PLE or error are exceeded.
- If applicable, include the details of stratification (two-stage inventory) or multi-phase sampling if appropriate, including the number of units in each stratum / phase.

How the sample locations will be determined

- Include procedures for unbiased and non-subjective sample selection
- Multi-stage, for example stratified sampling, can be used within the sampling framework
- Sample units and sub-samples must be selected objectively (not subjectively or on a convenience[29] basis). Systematic sampling of an area (using a spatial grid) or of trees (say selecting every n^{th} tree) is an acceptable approach. Random sampling approaches must use a "pseudo-random number generator" – one with a seed number that is known – so that the sample selection can be verified
- Include sufficient details for audit and/or long term identification of the location of units.
- If appropriate, describe how non-representative field locations or statistical outliers will be treated to ensure absence of bias (in both the estimates of the mean and precision).

The method to be used for sampling

- Describe the requirements for direct measurements.

For example, *NCAS Technical Report 31* describes an approach for destructive tree sampling for the development and verification of allometric equations. http://pandora.nla.gov.au/tep/23322

    a. This could include a description of the variables which will be measured directly, such as DBH (1.3m) or height.
- Where carbon stocks for debris, litter and herbaceous plant are included in the project and/or baseline estimates, methodologies should include procedures for their estimation.
    a. Where a methodology requires herbaceous plants to be factored into the baseline, carbon stocks attributable to herbaceous plants must continue to be estimated after planting/seeding to determine changes in the baseline.

Timing requirements for sampling

- Clearly describe the time constraints for sampling (e.g. sampling must occur over a period of no more than six months prior to reporting)

How the final estimate of carbon will be determined (e.g. expansion procedure)

- The methodology must describe all calculations (including for estimating precision), assumptions, and sources of error.
- Procedures need to deal with discrepancies between multiple measurements over time .e.g. how estimates might be "trued-up".