

FIELD MEASUREMENT PROCEDURES FOR CARBON ACCOUNTING



BUSH FOR GREENHOUSE

REPORT NO 2 - VERSION 1 | FEBRUARY 2002



PART ONE

REFERENCE DOCUMENT

BUSH FOR GREENHOUSE
Field Measurement Procedures
for Carbon Accounting

Version 1
February 2002

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This document, background information on the Bush for Greenhouse program and other information on greenhouse are available from the AGO Infoline on 1300 130 606 and on the Internet at the following address:

<http://www.greenhouse.gov.au>

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February 2002

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Invaluable advice on field sampling and measurement was provided by Dr Cris Brack of the Australian National University. Comments on practical implementation of the *Procedures* were provided by David Curtis of Greening Australia. A number of others assisted with the preparation of the *Procedures* including staff of Greening Australia, the Australian Greenhouse Office, Environment Australia, the Bureau of Rural Sciences, Agriculture Fisheries and Forestry Australia and staff and landholders involved in Edison Mission Energy Landcare projects and the Greenhouse Challenge.

Illustrations were provided by Amazing Art. Editing was undertaken by Penny Olsen of the Australian National University. Layout and design was carried out by the Communication Co.

These *Procedures* will be improved as they are implemented in the field in various Government programs. Any comments or queries should be directed to the Greenhouse and Land Management Team.

February 2002

RELATIONSHIP TO OTHER TOOLS AND MANUALS

The *Field Measurement Procedures for Carbon Accounting* manual has been designed to be used in conjunction with several other tools and models that are under development. For example:

The Bush for Greenhouse Tools

The Bush for Greenhouse program is developing a set of carbon accounting, legal and administrative tools which will facilitate private investment in greenhouse sinks. Further information about these tools can be found on the Australian Greenhouse Office website: www.greenhouse.gov.au. The two publications described below provide information on greenhouse sinks and carbon accounting which complements the *Procedures*.

The booklet *Growing Trees as Greenhouse Sinks—an Overview for Landholders* provides background information on carbon sink activities that will contribute to Australia's greenhouse gas abatement effort and how a carbon credit trading system might operate if one is introduced. It also provides estimates of the quantities of carbon taken up by trees in different parts of Australia.

The report *Setting up a Greenhouse Sink Project and Carbon Accounting System* provides information on the international framework and the evolving eligibility rules for greenhouse sinks. It provides general information for carbon accounting, including issues to consider in the overall design of a project level carbon accounting system for a sinks project.

The Project Level Carbon Accounting Toolbox

The CAMFor model is a simple tool developed for the National Carbon Accounting System in Microsoft EXCEL that predicts carbon sequestration (storage) in forests over time, for given management strategies and species characteristics entered by the user. The CAMFor model and other carbon accounting information is available on the Australian Greenhouse Office website www.greenhouse.gov.au/ncas.

CAMFor is being further developed into a project level carbon accounting toolbox which includes an improved version of CAMFor, default sets for major vegetation types sourced from recent research, field procedures (including these *Procedures*), case studies and manuals.

CAMFor has also been incorporated in the FullCAM modelling shell of the National Carbon Accounting System. The modelling shell provides for integration with both soil carbon and growth models.

The National Farm Forest Inventory Manual

This manual was developed in parallel with the National Farm Forest Inventory tree measurement manual for farm foresters (the NFFI manual). The NFFI manual describes methods for estimating wood volumes from farm plantations. For information on the NFFI manual visit the NFI website at www.affa.gov.au.

Estimates of stem volume derived using the NFFI manual can be converted to estimates of carbon stocks using Section 4 of Part 2 of the *Procedures*.

HOW TO USE THIS DOCUMENT

This Reference Document is Part 1 of three volumes that make up *Field Measurement Procedures for Carbon Accounting*. It provides background information on the field measurement procedures.

This Part relates to the others as follows:

PART	PURPOSE
Part 1— Reference Document	Provides readers with background information about carbon estimation in environmental plantings and relates this information to the measurement of field variables and estimation of carbon stocks.
Part 2—Field Measurement Procedures	Provides a measurement methodology to estimate carbon stocks at a given point in time, based on field measurements and known mathematical relationships.
Part 3—Field Sheets and Appendices	Provides users with a standard set of field sheets on which to record measured field variables, and contains more detailed information and discussion on specific sections of Part 2.

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Introduction

By absorbing carbon and storing it in trees, shrubs and soil, vegetation plays an important role in reducing the level of greenhouse gases in the atmosphere. These storage mechanisms are known as carbon 'sinks'. Increasing the capacity of Australia's sinks provides an effective and practical means to reduce net carbon emissions and help meet international obligations. Many other environmental benefits can be achieved through the establishment of sinks, such as reductions in salinity, protection of biodiversity and the prevention of erosion.

The Bush for Greenhouse Program aims to increase Australia's sinks capacity by facilitating investment in revegetation for environmental purposes. The program will provide a range of legal, administrative and technical tools to assist individuals and organisations to account for carbon in environmental plantings and to transfer carbon rights to investors. Further information on the program is available on the Australian Greenhouse Office website.

The *Field Measurement Procedures for Carbon Accounting* are intended to provide individuals and staff of organisations managing revegetation with the information and tools to measure carbon sequestered (stored) by human induced reforestation activities.

The *Procedures* have been designed for use with permanent plantings established for a range of environmental reasons (such as biodiversity and water protection) and for the purpose of generating carbon rights for transfer to an investor. The *Procedures* can also be applied to commercial plantations. For example, the *Procedures* will be used by government programs such as the Greenhouse Gas Abatement Program and the Greenhouse Challenge. They may also be used by private landowners, regional organisations, Landcare groups, or forest managers engaged in other carbon offset arrangements, or considering participation in a possible future carbon credits scheme.

The *Procedures* have been designed to be applied in the field by people who may not themselves be qualified in forest inventory techniques, but who are trained and supervised by a person who is qualified and experienced in these techniques. For example a qualified person should make decisions on which calculation methods to use and in some cases on the sampling method. Lack of qualified supervision could lead to results that are inaccurate, imprecise or not statistically significant.

At the time of publication there is no national emissions trading system in Australia and no formal register of carbon credits or verification processes. The *Procedures* have been designed to collect the kind of information that may be required in the future to register carbon credits, such as spatially referenced site boundaries and documentation to demonstrate consistency with international rules for carbon sink eligibility. The *Procedures* also establish a Bush for Greenhouse standard of

precision for monitoring carbon in environmental plantings. It is important to note that in the absence of a national emissions trading system the *Procedures* do not represent a national standard. Following the instructions in the *Procedures* may not produce tradeable credits under any future trading system that may be established.

This document is the first of three parts that make up the *Procedures*, and contains background and explanations for the methodologies.

Objective

To provide standard, reliable and cost-effective field procedures for estimating carbon sequestration in Bush for Greenhouse plantings.

Prediction of carbon sequestration

Arrangements to transfer carbon rights generally require an initial prediction of changes in carbon stocks (amount stored) over time.

To predict growth in carbon stocks and ensure consistency with international rules for greenhouse sinks, site specific information on the initial condition of the area to be revegetated is required. The *Procedures* provide instructions for documenting initial site condition and recording area.

Carbon sequestration predictions can be made using the Carbon Accounting Model for Forests (CAMFor), a Microsoft EXCEL based carbon accounting tool.

Monitoring and measurement of carbon stocks

Following the establishment of plantings, regular monitoring is required to ensure that the predicted carbon stocks are actually present on the site. Where carbon stocks are below threshold levels for plantations of that age, remedial action may be required. The monitoring will also indicate whether there is significant additional carbon, over and above that predicted.

The *Procedures* provide a methodology for taking simple tree measurements to estimate carbon in forests from about five years of age. They also provide instructions for calculating carbon stocks from these measurements.

The *Procedures* allow measurement of carbon stored in trees to a defined level of precision. Where a transfer of carbon rights is envisaged, a maximum target error for field measurements of 15% is recommended. This is referred to in the *Procedures* as the Bush for Greenhouse standard. This target has been selected to provide confidence to investors while still being achievable in the field.

The *Procedures* also provide instructions for lower cost, less precise sampling, for users who may want to measure carbon in trees for purposes other than the transfer of carbon rights.

Basis for monitoring approach

Bush for Greenhouse plantings are likely to be a planted or direct seeded area with a mixture of tree species and understorey. Plantings are likely to be greater than about 10 hectares in area to achieve economies of scale and are likely to have been established on land which was cleared before 1990 to ensure consistency with the evolving international rules for carbon sinks. The *Procedures* have been designed with this in mind.

Monitoring is based on a simple forest inventory sampling technique for measurements of individual tree height and diameter, combined with a point to plant sampling technique for estimates of tree stocking. Description of a further point sampling technique, using basal area sweeps, has also been included. These sampling approaches are expected to suit most environmental plantings and will also be applicable to most plantations, but may not suit every situation. Major considerations in selecting the sampling approach were:

- ▶ the need to capture the variability of environmental plantings, particularly where survival is poor;
- ▶ ease of use for measurers not trained in forest inventory techniques;
- ▶ applicability to 10 hectare (or greater) mixed species forests;
- ▶ ability to estimate plot sizes and numbers required to achieve a desired precision;
- ▶ ease with which carbon stocks can be calculated to compare with CAMFor predictions;
- ▶ ease with which measurements can be audited and verified; and
- ▶ costs of equipment and time required to take measurements.

There will be opportunities to review the sampling methods in future versions of the *Procedures*.

Measurement costs

The *Procedures* have been designed for use with low cost equipment that is available from forestry equipment suppliers.

Recognising that users of the *Procedures* may have different access to time and equipment, wherever possible a range of methods have been provided, giving differing levels of precision at differing cost. Users will need to judge the most appropriate methods for their situation.

To achieve a given precision, the time required to measure a small planting is not much less than the time required to measure a larger area of similar variability. Small projects will therefore suffer much higher costs per hectare than larger projects. The *Procedures* have been specifically designed for plantings over 10 hectares in area, but some guidance is given regarding ways to reduce costs on small sites.

Measurement steps

The steps for measurement are as follows:

STEP/SECTION	ACTIVITIES	RESOURCES
<p>Section 1: Measuring initial site condition</p> <p>Age 0</p>	<p>Record history of land-use on the site</p> <p>Estimate the area to be established with revegetation</p> <p>Estimate initial condition carbon stocks</p> <p>Record site establishment information</p> <p>Develop a carbon prediction using CAMFor</p> <p>Conduct a biodiversity and ecosystem health assessment</p>	<p>Input from the land manager</p> <p>1 person in most cases; 2 people if existing trees are measured</p>
<p>Section 2: Monitoring survival</p> <p>Age 4-6 weeks for planted areas and Age 1 year for planted and direct seeded areas</p>	<p>Check survival of planted/seeded trees and replace if necessary</p> <p>Ensure the full net area is established</p>	<p>2 people</p>
<p>Section 3: Measuring carbon in vegetation</p> <p>Age 5 and 5-yearly thereafter</p>	<p>Identify the field measurements needed</p> <p>Using the <i>Procedures</i>, monitor carbon on the site by field sampling</p> <p>Conduct a biodiversity and ecosystem health assessment</p>	<p>2 people</p>
<p>Section 4: Calculating carbon stocks</p>	<p>Calculate carbon stocks from measurements</p>	

Further information

For further information on the Bush for Greenhouse program, the CAMFor model and user manual, and information on other greenhouse related issues, visit the Australian Greenhouse Office web site at <http://www.greenhouse.gov.au>.

Section One

Background information on measuring the initial site condition

'Initial site condition' is the state of the site before tree planting or direct seeding begins. It is recorded to:

- ▶ provide information on area and site characteristics to enable carbon sequestration predictions using the CAMFor model;
- ▶ determine the location of the project and its land-use history to ensure that the planting is consistent with international rules for eligible greenhouse sinks; and
- ▶ establish the initial carbon stocks in any existing trees as a basis to compare with future measurements.

Conducting an initial site condition assessment is necessary, especially if the planting is being considered for the transfer of carbon offsets or rights, or for possible future carbon credit trading.

1.1 DOCUMENTING THE SITE AND ITS LAND-USE HISTORY

A reference location is established on the project site to provide a single point for future location and measurement of the planting. This should be a fixed and known point relative to the planting site, such as the front door of the farmhouse.

The reference location and other general information about the planting site is recorded on a field sheet for future reference. A sketch map is drawn to enable maps later drawn by a computer to be checked.

Documenting previous land-use history is an important step in ensuring that the project is likely to qualify as an eligible sink under international agreements.

It is particularly important to demonstrate that the land was not forested at 1 January 1990.

Land-use history is also important for predicting future carbon changes on the site. Past events, such as removal of vegetation and soil cultivation for cropping, may indicate that a site is depleted of much of its soil carbon. Past fertiliser application and pasture improvement can indicate that a site has significant soil carbon, which could be lost during the process of establishing revegetation. Grazing pressure is also important. The history of land-use on the site will also affect subsequent rates of tree growth and related carbon sequestration. Any significant events that have occurred since 1990 should be documented.

1.2 IDENTIFYING AND DESCRIBING STAND-TYPES

Large sites that are complex and include more than one major ecosystem or soil type (stand-type) should be divided (stratified) along ecosystem or soil type boundaries. This will allow a separate CAMFor prediction to be made for each stand-type. Stratification is necessary only for larger projects in which there are major differences between growth characteristics across the site. For these projects stratification will result in more accurate predictions of carbon sequestration and may reduce the cost of subsequent measurements. Examples are provided in Part 2 of the *Procedures*.

The Field Sheets in Part 3 indicate the information required on each stand-type for use as the basis for predicting carbon sequestration. The following sections describe why this information is required.

1.3 RECORDING GROSS AND NET AREA AND STAND-TYPE BOUNDARIES

CAMFor provides carbon predictions on a tonnes of carbon per hectare basis. To ensure that carbon sequestration predictions are applied to the right area (number of hectares), a best possible estimate of the area to be established with vegetation is required. Use of a GPS to record the boundary will allow the site to be stored in a geographic information system, facilitating future verification.

The gross area is the overall area of the project. The net area is the area actually established with vegetation that is likely to be eligible under international rules for greenhouse sinks. In some cases the gross and net area will be the same, but in many cases the gross area will include roads, swampy ground and/or existing remnant vegetation that will not sequester carbon according to the predictions. To avoid overestimating the carbon potential of the site, the area of these features needs to be subtracted from the gross area to arrive at a net area. All subsequent measurements will be undertaken on the net area.

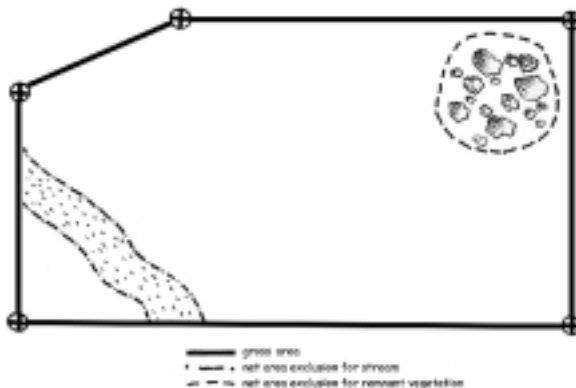


Figure 1 – Gross and net area

1.4 RECORDING STAND-TYPE INFORMATION FOR PREDICTING CARBON SEQUESTRATION

In addition to the general information on the site and its history described in section 1.1, more details—including soil type, position on slope, rainfall and any existing trees and litter—are required for each stand-type on the site. An understanding of these site characteristics is needed to develop inputs, such as tree growth, for the CAMFor model, so that changes in carbon stocks over time can be predicted.

Most of the information required is general site information to inform predictions. The landholder should have much of this information, avoiding the need for detailed measurements.

However, if there are existing trees and tree litter on a site, measurements should generally be taken at the initial condition stage, to provide a basis for predictions and comparison with later monitoring measurements. Sites without existing trees can be assumed to have no tree or tree litter carbon present at the start of the project.

Soil carbon

Generally, some soil carbon is lost through the process of site preparation to establish trees. Soil cultivation and weed control slow inputs of carbon to the soil, while carbon continues to decay back to the atmosphere. When a new forest becomes established it generates litter, debris and dead root material, which contribute to soil carbon as they break down, and soil carbon is built up again over time.

Because it is difficult and costly to undertake measurements with adequate precision, soil carbon is generally not measured. Instead, predicted changes in soil carbon are modelled in conjunction with CAMFor modelling of tree carbon. The modelling of both tree and soil carbon will be informed by basic inputs about the starting soil carbon. To provide this basic information, some simple soil classifications are used in Part 2 of the *Procedures*. Recent land-use history also provides information about initial soil condition, as described in the previous section.

For large projects where relevant soil carbon models are not available, and where soil carbon changes are likely to be significant it may be appropriate to arrange for qualified professionals to undertake soil carbon measurements. These measurements are not covered by the *Procedures* but can be made in accordance with the National Carbon Accounting System's Technical Report 14 "Sampling, Measurement and Analytical Protocols for Soil, Litter and Course Woody Debris" (McKenzie *et al.* 2000). Depending on the measurements taken, the information collected can be used to calibrate or check soil carbon models.

1.5 MEASURING INITIAL CONDITION CARBON STOCKS

Measuring existing live trees

Generally, significant patches of existing trees will have been excluded from the net area, as they are unlikely to be consistent with international rules for carbon sinks. On some sites there may be scattered existing trees that will either be removed or surrounded by new plantings. Scattered native trees that are retained as part of the revegetation project will make an important contribution to biodiversity within the newly established area.

As a general rule, native trees that will have revegetation established around them should be measured to establish the initial carbon stocks on the site and facilitate comparisons with later measurements. However, this can add considerably to the work of establishing the initial site condition. In some cases it may be reasonable to treat mature remnant trees as a store of carbon that will not change significantly over time and, therefore, does not need to be measured. This assumption can be made only if the existing trees are likely to remain in something like their existing state. It is also necessary to ensure that the trees can be readily identified at later measurement periods. If these trees are not measured at the initial condition stage, they should also be excluded from any future measurements that will be compared to the initial condition.

Some projects may involve removing existing trees of non-native weed species (such as willows or camphor laurel) for environmental reasons. Carbon losses from tree removal can be significant, and can continue over many years, and will therefore need to be accounted for as part of the project. Killing and/or removing trees from a site will result in the carbon in those trees being released to the atmosphere when they are burnt or decay. To enable carbon losses to be predicted, trees that are to be killed and/or removed from within the net area need to be measured.

Measuring fine litter and coarse woody debris

Fine litter (leaves, twigs and bark) and coarse woody debris (stems or branches) on the forest floor, and standing dead trees, are a carbon store and, if significant, should be measured as part of establishing the initial condition. The measurements will provide the starting point for predicting changes in future carbon stocks in CAMFor, and will be compared with later measurements.

The procedures include methods for measuring fine litter and coarse woody debris. Further information on these measurements is available in the National Carbon Accounting System's Technical Report 14 "Sampling, Measurement and Analytical Protocols for Soil, Litter and Course Woody Debris" (McKenzie *et al.* 2000).

There is likely to be significant tree litter and debris only when there is tree cover on or adjacent to the net area. Where there is no existing tree cover on a site, tree litter and debris will be negligible and will not need to be measured.

1.6 SITE PLAN

The proposed works to be undertaken on a site need to be documented, both for general management purposes and because tree species and activities such as ground preparation and fertilising affect soil carbon loss on establishment and tree growth. The site works plan will therefore inform CAMFor predictions of carbon sequestration.

1.7 BIODIVERSITY AND ECOSYSTEM HEALTH ASSESSMENT

Periodic recording of simple environmental health indicators such as weed species, stand health, remnant vegetation, fauna habitat and water quality can enable reporting on the biodiversity achievements of sinks projects. This assessment is undertaken for each stand at the initial condition stage and again at regular carbon monitoring measurements.

The methodology in the *Procedures* has been designed for ease of data collection. More detailed assessment of biodiversity and ecosystem health may be appropriate for some projects but is not covered by the *Procedures*.

1.8 RECORDING WORKS UNDERTAKEN

If the work undertaken differs from the site work plan, a separate works record should be made to document the actual work undertaken.

A photographic record of the site before, and during or immediately after establishment, can help to demonstrate that the project is consistent with international rules regarding eligible sinks. For example photographs can be used at some future time to demonstrate that the land was clear of vegetation before planting and that the new forest was established as the direct result of human activity rather than natural regeneration.

Photographs can also be used to illustrate the success of the project over time. A general record of works undertaken, such as site preparation, length of fallow, number of seedlings planted and their species, will assist in understanding and improving the performance of plantings over the longer term.

Section Two

Background information on monitoring seedling survival

CAMFor predictions assume that the net area of the planting maintains an adequate number of trees per hectare to use the carbon sequestration potential of the site over the long term. Survival is monitored to ensure that establishment has been successful and adequate trees remain on the site.

The boundary of the area established with revegetation should be checked against the net area measured at the initial condition stage. If the area established is significantly less than the net area, additional planting may be required to fill gaps.

To meet the Bush for Greenhouse standard, tree stocking thresholds have been set (see Part 2 of the *Procedures*) as a minimum number of trees per hectare at three time periods:

- ▶ establishment;
- ▶ 4 to 6 weeks for planted areas; and
- ▶ 1 year after planting for planted and direct seeded areas.

A survival count will assess the success or failure of planting or seeding in terms of the number of trees per hectare in the net area. Where the survival rate for trees falls below the relevant threshold, it will be necessary to take remedial action.

While the main focus is on trees, which carry most of the carbon, understorey survival is also monitored to assess the need for replanting to meet biodiversity objectives.

Section Three

Background information on monitoring carbon stocks

Measurements of field variables such as tree height, diameter and stand basal area should be undertaken at 5-yearly intervals. These measurements are used to calculate carbon stocks by applying equations that convert the measured variables to estimates of biomass and carbon. The results are used to check carbon stocks against the initial prediction of carbon sequestration. The measurements will also help to calibrate CAMFor to improve predictions for other sites.

Currently, the *Procedures* only provide methods to measure trees, defined as woody plants with a defined stem. This is necessary for two reasons:

- ▶ carbon predictions using CAMFor are based on tree growth information only, because growth of other woody vegetation such as shrubs is not well understood at the time of publication of the *Procedures*; and
- ▶ further work is required to review and develop simple field methods for measuring biomass in shrubs and other non-tree woody vegetation.

Subsequent versions of the *Procedures* may include methods to predict and measure biomass accumulation in shrubs and other understorey species.

Trees may be further divided into:

- ▶ long-lived trees, with a lifespan greater than 100 years, generally found in the overstorey; and
- ▶ short-lived trees, with a lifespan between 30 and 100 years, generally found in the understorey.

These will grow at different rates during the life of a planting. Typically, long-lived trees contain most of the carbon on a mature site, while short-lived species may make up a considerable proportion of the carbon stored during the early years of growth. Short-lived species may seed and provide secondary regrowth over the life of the planting.

Bush for Greenhouse plantings generally contain a minimum number of trees on planting, of which a proportion should be long-lived to ensure that they will continue to sequester and store carbon at predicted rates over the long term. Both long- and short-lived trees, including secondary regrowth, may be measured using the *Procedures*. In calculating carbon stocks from tree measurements, results for long- and short-lived trees may be treated separately to improve understanding of carbon stocks in short-lived trees.

3.1 SELECTING BIOMASS MODELS AND FIELD VARIABLES

To calculate biomass and, hence, carbon stocks, from field measurements an important first step is to check which equations and models are available and applicable to the site. Relevant equations should be scrutinised by a qualified person to identify the field variables that need to be measured to calculate carbon stocks. Considerable time can be saved in the field if, for example, it is known that the model uses overbark diameter measurements, removing the necessity to measure bark thickness.

Three different calculation methods are available in the *Procedures*, depending on the equations and models available:

- ▶ Method 1—Allometric equations which relate measured variables such as diameter and height to above-ground biomass;
- ▶ Method 2—Stem volume models and conversion to above-ground biomass using an expansion factor; and
- ▶ Method 3—Stand basal area to biomass relationships.

Part 3 of the *Procedures* describes the sources of these equations and models, and the tree variables that should be measured.

3.2 SELECTING SAMPLING METHOD AND TARGET ERROR

Accuracy, precision and bias

Accuracy and precision describe the ability of measurements to estimate the true value of tree variables such as diameter, height and stand basal area.

An unbiased estimate will depend on repeated measurements being similar (precise) and averaging at close to the true value (accurate).

Accuracy is defined as the closeness of the measurements to the true value. Inaccurate or biased measurements will give an average away from the true value.

Precision of the estimate is defined as the repeatability of measurements. It is possible for repeated measurements to be precise, that is, close to each other in value, but biased or inaccurate, that is, some way off the true value.

The degree of precision of each measurement undertaken depends on the maximum precision that the equipment can provide. For example, a measuring tape can only provide measurements down to 0.1cm.



Figure 2 – Accuracy vs precision

The sampling concept

The *Procedures* aim to provide a simple and cost-effective method for measuring carbon stocks in environmental plantings. To achieve this it is not necessary to measure every tree. Instead, trees in small representative areas are measured.

The sampling approach used in the *Procedures* involves the establishment of a series of sample points or ‘plots’ within the net area of the site. The approach is based on statistical theory and forest inventory techniques.

Compared with plantations, environmental plantings are often very patchy. To sample this patchiness adequately, two kinds of plots are used: fixed area plots to sample trees and point to plant plots to sample patchiness (tree stocking). Trees within the fixed area plots are counted or measured. At the point to plant plots, the distance to the 4th nearest tree is measured. The sample data collected is then averaged for all the plots and extrapolated to form an estimate for the entire planting.

With knowledge of the variability of a site and the number of trees per hectare it is possible to estimate the number and size of plots needed to reach a target precision. The number of plots required to reach a given precision does not vary greatly with the size of planting and, if the sites have similar variability, is the same whether the site is 1 hectare or 1,000 hectares in size.

For most reasonably large sites, sampling will reduce costs as it reduces the number of trees measured, but for some very small sites the total plot area required may be almost as large as the site and it will be simpler to measure every tree. The *Procedures* provide guidance as to the size of planting below which plot sampling is not worthwhile.

Acceptable level of error in carbon estimates from variation in tree measurements

To meet the Bush for Greenhouse standard the overall target error acceptable in field measurements used as the basis for calculating stem volume has been set at a maximum of 15% of the mean, with a confidence level of 95%. That is, it has been set so that the estimate of mean stem volume will fall within 15% of the actual mean 95% of the time. Carbon stocks are calculated from stem volume using conversion equations. In practice, this means that sites must be sampled to an intensity sufficient to produce estimates within this level of error. This can be achieved simply, by ensuring that sampling plots are of an appropriate size and number (see charts in Part 2).

In recognition that this may lead to relatively high measurement costs for smaller projects, for plantings less than 20 hectares in size an overall target error of a maximum of 20% is acceptable. Similarly, a maximum error of 20% is acceptable for very patchy sites, which would otherwise require sampling of an unmanageable number of plots. To reduce the sampling effort needed to meet the 15% level of acceptable error, projects can be pooled. However, it should be noted that, when sites are pooled, it is not possible to extrapolate from the overall result to obtain a carbon estimate for individual sites within the pool.

These target maximum error levels are based on variation in tree measurements and tree stocking estimates and do not take into account any error in conversion equations. The Appendices include a method for calculating the actual error in field measurements.

In the *Procedures*, the sampling concept is applied to survival counts, tree stocking assessment, litter measurement and measurement of tree height, diameter and stand basal area. The target maximum error of 15% applies only to the overall error associated with measurements of area, tree height, diameter and tree stocking

or to measurements of stand basal area. Estimates of survival do not need to be made to a required precision as they are used to determine management actions and are not used to estimate carbon on the site.

Some users may find that errors of 20% or 30% may be acceptable, particularly if quantities of carbon rights are not being sold or otherwise transferred on the basis of measurements. Fewer plots are required to achieve these higher error targets and selection of a higher target will reduce costs significantly. However this may have implications for transfer of carbon rights and it is advisable to consult any investors or potential investors regarding the trade-off between error and measurement cost. The *Procedures* provide methods for measuring carbon stocks in trees to these lower levels of precision.

Selection of sampling approach

The main sampling approach adopted in the *Procedures* is fixed area plot sampling for tree height and diameter, combined with simple point to plant measurements taken between plots to enable an assessment of tree stocking (number of tree stems per hectare).

Tree stocking is the number of tree stems per hectare. In many cases this may be more than the number of trees, as some trees will have more than one stem.

Out of the many sampling approaches that are potentially applicable to forests, three have been selected for inclusion in the *Procedures*. These are fixed area plots, with point to plant stocking plots established between them, point basal area sampling and single trees sampling.

Circular or rectangular fixed area plots are suited to measuring height and diameter and gaining some information on stocking. Point to plant plots are measured en route to the fixed area plots, to gain further information on stocking and capture the patchiness of plantings.

Stand basal area sampling is an alternative that is suited to larger areas of older forest and can be considerably cheaper than plot sampling, particularly when undertaken by experienced measurers.

Single tree sampling is used where there is only a small number of trees, for example at the initial condition stage and when monitoring very small sites.

At this stage, fixed area plot sampling with point to plant plots between fixed area plots has been selected as the main sampling technique despite being more time-consuming than some alternative methods. Plot sampling is simple to understand and apply, is suited to measuring young stands and can be readily audited and verified.

The selected sampling approaches are expected to suit environmental plantings, and will also be applicable to many plantations, but may not suit every situation. The advice of a qualified person should be sought before using a sampling method that is not described in the *Procedures*. There will be opportunities to review the sampling methods in future versions of the *Procedures*.

Systematic sample (with random start)

To provide statistically valid results, sample plots must be randomly located within the net area. The *Procedures* use a simple random sampling approach to determine plot locations. It involves overlaying a map of the planting with a grid and systematically locating a plot point on the map at each intersection of the gridlines. Each point represents a sample location. These points provide a spread of sampling locations within the net area.

Dividing large sites into stand-types to make sampling easier (stratification)

If they consist of two or more major ecosystems or soil types, larger or more complex projects may have been divided into two or more stand-types at the initial condition stage. The stand-types may have been further divided into stands of different age-classes. Each stand should be sampled separately.

For some sites it may be appropriate to divide (stratify) the net area into stand-types and stands prior to measurement. This could be based on areas where a distinct growth difference is evident. If this succeeds in significantly reducing the variability within each of the resulting stands it may reduce the overall number of plots which need to be measured, thereby reducing cost and effort. Section 1 of Part 2 of the *Procedures* provides some examples of stratification.

Combining small sites to reduce the cost of sampling

For groups of similar sites of similar age (for example Landcare or Catchment group plantings), costs of measurement can be reduced by applying the sampling methodology across a group of sites rather than to each site. This approach needs to be carefully designed to achieve statistically valid results, particularly where there are several age groups and more than one stand-type (for example more than one ecosystem or soil type). The *Procedures* do not cover this approach in detail and the advice of a qualified person should be sought before sampling multiple sites together.

3.3 DETERMINING PLOT NUMBER, SIZE AND SHAPE

Number and size of sample plots

To sample sites to an intensity sufficient to approximate a 15% maximum error, a decision needs to be made on:

- ▶ the size of fixed area plots in each stand; and
- ▶ the number of plots to measure in each stand.

Charts and tables in Part 2 of the *Procedures* provide a method for working out these sampling parameters.

Working out the number of plots required

The number of fixed area, point to plant or basal area plots required depends on the variability of the site. The more variable the planting, the more plots will be required to sample the variability. Factors affecting variability include number of species, soil type, establishment technique, slope and aspect, and growth form.

A simple method of estimating variability has been developed for the *Procedures*. An alternative, more accurate method of measuring variability and determining the required number of plots has been provided in Appendix 2.

As noted previously, the size of the area to be sampled does not impact on the number of plots required. The key factor is the variability of the site being sampled.

Working out plot size for fixed area plots

For circular or rectangular fixed area plots, plot size is related to the number of trees that will be sampled in each plot. In practice the aim will be to include between 10 and 20 trees in a plot. To calculate the size of plot required for the sample, an initial estimate of the tree stocking (the number of tree stems per hectare) of the planting is required. Once plot size is determined, the same plot size should be used throughout the stand.

An initial estimate of tree stocking may be estimated from the planting history provided no significant change in stocking has occurred. If stocking is not known, it can be quickly and simply estimated in the field using the *Procedures*.

3.4-3.7 FIELD MEASUREMENTS

Part 2 of the *Procedures* describes methods for mapping plot locations in the office, getting to the site, laying out plots and recording field information within the net area. These methods are designed to ensure the statistical validity of measurements.

Part 2 describes preferred and acceptable equipment. Use of this equipment together with the sampling approach should provide acceptable precision to meet the 15% maximum error target in most cases. The equipment described in the *Procedures* was chosen for ease of use and low cost. Appendix 4 of Part 3 of the *Procedures* provides instructions on the use and maintenance of equipment to maintain the precision of measurements.

Section Four

Background information on calculating area and carbon in trees and litter

Section 4 of Part 2 of the *Procedures* provides instructions for calculating area from GPS or hip chain and compass measurements. It also provides instructions for calculating carbon stocks from field measurements using the three methods described in Section 3.1 above.

Field measurements are converted to estimates of carbon stocks using models that predict above-ground biomass from the measured field variables. Below-ground biomass is then calculated as a simple ratio of above ground biomass. Carbon stocks are calculated on the basis that tree biomass is approximately 50% carbon.

Carbon stocks in fine litter and coarse woody debris are calculated from measurements using a similar method.

Further reading and references

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USEFUL WEB SITES

Australian Greenhouse Office http://www.greenhouse.gov.au	NCAS Technical reports Emissions trading reports
Code of Forest Mensuration Practice http://www.anu.edu.au/Forestry/	Information on measurement of trees and forests
Australian Geological Survey Organisation http://www.agso.gov.au/	Information on magnetic declination
GPS Satellite tracking http://www.cnde.iastate.edu/staff/swormley/gps/tracking.html http://sirius.chinalake.navy.mil/satpred/	Software that allows scheduling of GPS measurements to times when satellite availability and geometry are optimal
Waypoint+ http://www.tapr.org/~kh2z/Waypoint/	Software for use with GPS units, allowing the uploading and downloading of data files
Softree Natural Resource Software http://www.softree.com/index.htm	Terrain Tools™ software which will calculate area from distance and bearing measurements
Prospectors Earth Sciences http://www.earthsciences.com.au/	Measurement equipment