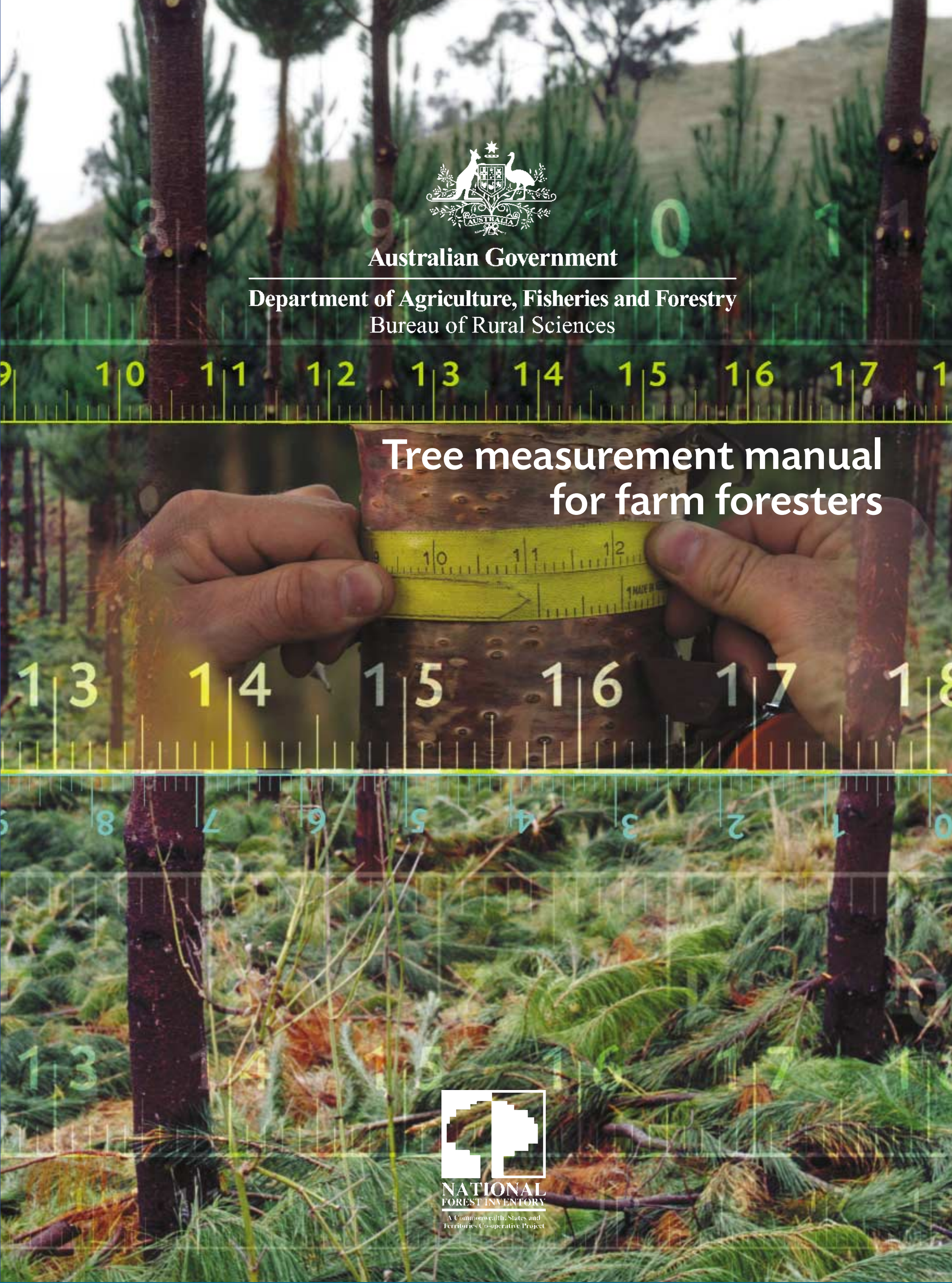

Australian Government

Department of Agriculture, Fisheries and Forestry
Bureau of Rural Sciences

Tree measurement manual for farm foresters

NATIONAL FOREST INVENTORY
A Commonwealth, States and Territories Co-operative Project

AGRICULTURE, FISHERIES AND FORESTRY —AUSTRALIA

Tree measurement manual for farm foresters

Practical guidelines for farm foresters undertaking basic tree measurement in farm forest plantations.

ISBN 0 642 47575 X

Australian Government

Department of Agriculture, Fisheries and Forestry
Bureau of Rural Sciences

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Foreword

There are an increasing number of small stands and shelterbelts on farms and a growing need for farmers to better understand the volume, value and growth of their trees.

This manual is an introduction to forest measurement so that farm foresters can do just that.

This manual provides information for the farm forester to plan and carry out measurement procedures needed to estimate the amount of wood being grown. It covers sampling procedures, tree measurement procedures and data calculations.

Basic and more advanced procedures are set out in the manual providing a choice to the level of accuracy and reliability required.

I hope this manual will help you to better understand your forests and gain a greater appreciation of their value.

Peter O'Brien
Executive Director
Bureau of Rural Sciences

Acknowledgments

This manual is an output of the National Farm Forest Inventory (NFFI). The NFFI aims to facilitate the collection of farm forest resource information by providing measurement guidelines and standards. Funding was provided by the Commonwealth Farm Forestry Program under the Natural Heritage Trust.

The manual was developed in close consultation with an expert working group that has wide experience and knowledge in forest mensuration and farm forestry. Acknowledgment goes to all members of the working group:

Cris Brack – School of Resources, Environment and Society,
Australian National University
David Carr – Greening Australia
Rebecca Ford – Australian Greenhouse Office
Mike Shaw – Department of Primary Industries, Queensland
Peter Stephen – The Master TreeGrowers Program, Melbourne University
Tim Vercoe – Australian Tree Seed Centre CSIRO
Andy Warner – Private Forests Tasmania

The manual was also field-tested to ensure usability. Special thanks go to:
Rebecca Blundell – ACT Forests
Lyn Bottomley – Farm forester
Ian Chalk – Private Forests Tasmania
Don Ryan – Private Forests Tasmania
Stuart Swanson – Private Forests Tasmania
Andy Warner – Private Forests Tasmania.

Photos have been provided by Michael Ryan.

Jerry Leech, Cris Brack and Andy Warner advised on amendments for the second edition.

Disclaimer

This is the second edition of the manual; further editions will be produced as required. Comments are welcome on how the manual can be improved in the future.

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Table of Contents

Tables

Figures

1 Read This First!

This manual provides procedures and information for estimating the volume of standing wood in a plantation.

Why measure the volume of standing wood?

A crop of trees, managed properly, can produce a range of valuable products. Measuring your trees as they grow is an important part of their management, and should be undertaken for the following reasons.

- To find out how much wood you've got at a particular time and how much it might be worth
- To find out how fast the stand is growing and make comparisons with other growers or benchmarks
- To measure the response we get from management activities such as fertilising, pruning or thinning and to better plan, cost and check the quality of such activities
- To understand the growth potential of a site or species
- To better understand how to maximise its value and meet market expectations.

Learning how to measure a few trees properly can be a very powerful way of increasing your understanding, enjoyment and returns from your plantation or shelterbelt.

The Manual

This manual will show you:

- which trees you should measure
- what parts of trees you should measure
- how you should measure it.

The manual is suitable for farm foresters or field officers providing advice to growers, and requires no prior knowledge of forest measurement.

The decision tree on page 4 is your guide to using the manual. It will lead you through each step in measuring a plantation depending on your situation and objectives.

For each step the manual provides two levels of sophistication:

Basic method–provides a ballpark figure and requires cheap, basic equipment or no equipment at all

Advanced method–provides accurate estimates but requires more time and expensive equipment.

An intermediate level is also provided in the volume calculation chapters.

The procedures in this manual have been written specifically for plantation forests, where groups of trees are the same age and evenly spaced at planting. It is strongly recommended that a qualified professional forester or measurement crew be employed for any activity where you require an accurate assessment of timber amounts and values, especially prior to harvesting operations or commercial transactions.

The manual is intended to be a companion to other tools for establishing, maintaining and measuring small scale farm plantations and woodlots. For example, this manual does not include standards and procedures for calculating carbon storage and carbon accounting. These methods are contained in the Bush for Greenhouse publication *Field Measurement Procedures for Carbon Accounting*–(ISBN: 1 876536 62 4). Accounting standard AASB 1037 must be followed for a valuation required by Corporations Law. Consulting an appropriately qualified member of the Association of Consulting Foresters of Australia may be advisable if that is the case.

Equipment: Tree measurement nearly always requires some specific equipment, so it is likely that you'll need to buy or borrow some essentials before you start. Equipment you will need is listed at the beginning of each chapter.

1.1 How the manual works

The manual is divided into four parts:

1. **Decision tree**—leads you logically through the parts of the manual you need to use and chooses an appropriate measurement system. Each step is written as a question. For each question a page reference is provided which has the necessary information.
2. **Instructions and procedures**—provides all the practical information on how to measure area and different parts of the plantation. Depending on the steps taken in the decision tree you may not need to refer to all instructions.
3. **Field recording forms**—have been included in the appendix for you to photocopy and use in the field. These forms are also downloadable from the web at **www.daff.gov.au/nffi**, under the National Farm Forest Inventory.
4. **Additional information**—is provided on measuring growth over time and products.

A calculations worksheet is provided (see section 1.2) to assist with calculations. This sheet should be taken out into the field and filled out as you go along.

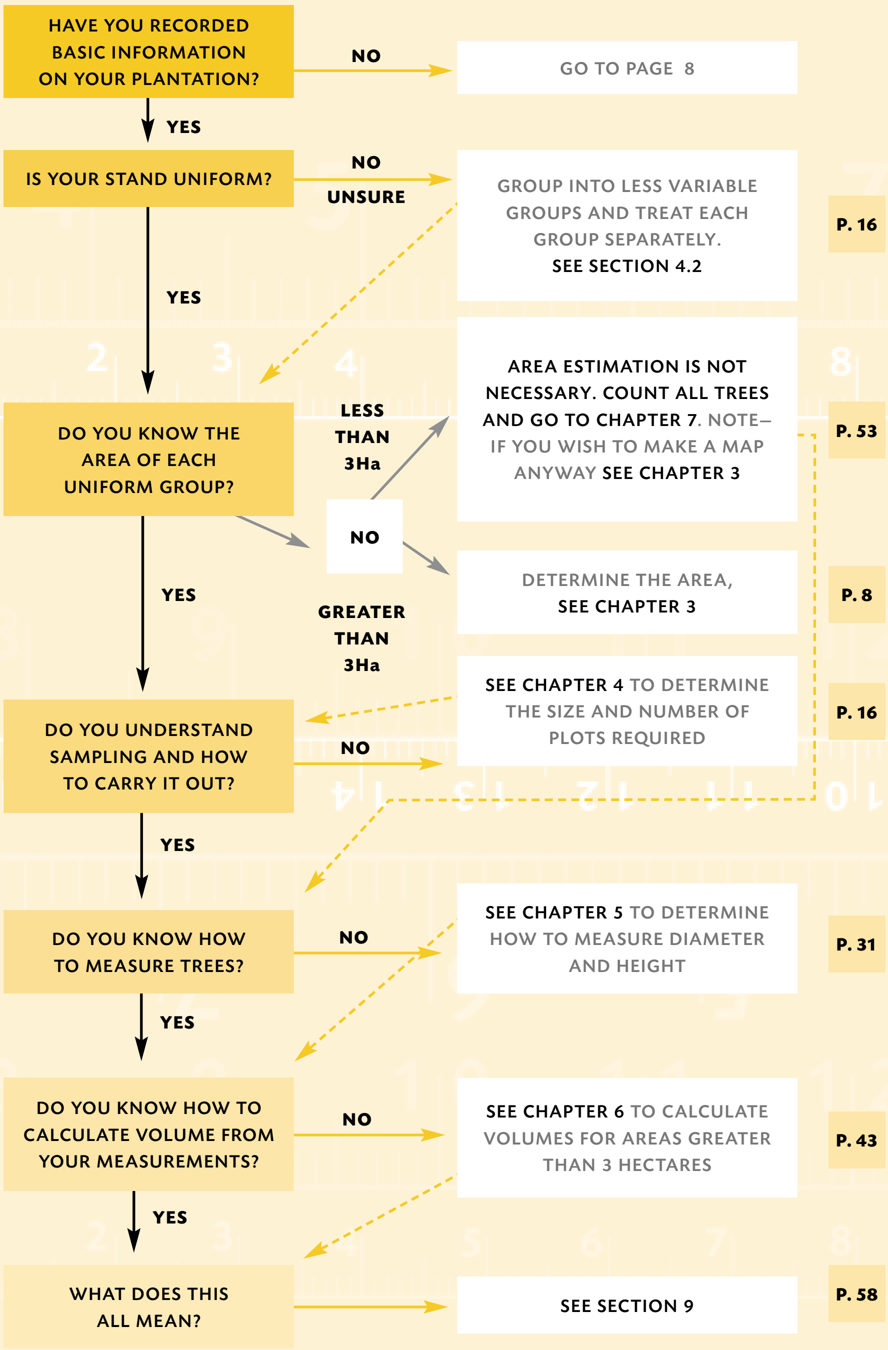
Terms within the text that are written in ***bold italics*** are defined in the glossary at the back of the manual. Each chapter begins with a brief summary (under 'Objective') of why each section is important and the essential and desirable equipment required. Practical examples are provided in shaded boxes throughout the manual to explain procedures.

A light globe identifies handy hints.

The most reasonable approaches for farm forestry are described taking into account cost, time and expert knowledge. In general terms, the more reliable the data is, the more expensive or time-consuming it is to put together. However, high cost does not guarantee quality data if incorrect or poorly applied techniques are used.

You are now ready to begin using the manual by referring to the decision tree overleaf.

FIGURE 1.1 DECISION TREE



1.2 Calculations/Checklist Worksheet

Use this sheet for recording essential information as you work though the manual.

1. **Plantation area** *(see chapter 3)*

   Area = ...hectares

2. **Stocking rate** *(see section 4.3)*

   Stocking (stems/ha)

   = 10,000/(Distance between rows x distance between trees within row)

   = 10,000/(.........x.........)

   = ...stems/ha

3. **Plot area** *(see section 4.3)*

   Plot size is according to stocking using the following table

TABLE 1.1: PLOT SIZE ACCORDING TO STOCKING

STOCKING RATE (STEMS/HECTARE)	PLOT SIZE (HECTARES)	RADIUS OF CIRCULAR PLOT (METRES)	DIMENSIONS OF RECTANGULAR PLOT
100	0.2	25.2	***See section 4.7*** ON RECTANGULAR PLOTS TO DETERMINE THE REQUIRED DIMENSIONS
200	0.1	17.8	
400	0.05	12.6	
500	0.04	11.3	
600	0.033	10.2	
800	0.025	8.9	
1000 +	0.02	8.0	

4. **Number of plots** *(see section 4.4)*

   The number of plots required is based on area of the plantation.

TABLE 1.2: NUMBER OF PLOTS BY PLANTATION AREA

AREA OF PLANTATION	NUMBER OF PLOTS REQUIRED
< 3 HA (CHAPTER 7).	SAMPLE INDIVIDUAL TREES INSTEAD OF USING PLOTS
3 – 5 HA	5 PLOTS
5 – 10 HA	8 PLOTS (12 IN A VARIABLE STAND)
> 10 HA	10 PLOTS (16 IN A VARIABLE STAND)

5. **Map location of plots** *(see section 4.5)*

6. **Locating plots on the ground** *(see section 4.6)*

7. **Setting up the plot** *(see section 4.7)*

8. **Measuring trees in the plot** *(see section 4.9)*

   Measure the diameter and heights of trees and record those measurements on the inventory form supplied in appendix 2.

9. **Convert diameters into tree basal area (TBA)** *(see section 6.2)*

   TBA = pi x (DBHOB/200)^2
   = 3.142 x (………/200)^2
   = ……… m^2.

10. **Stand basal area (SBA)** *(see section 6.2)*

    SBA = (sum of BA of each tree in plot)/(area of plot)
    = ………m^2/ha.

11. **Use collected measurements to calculate stand volume** *(see section 6.3)*

    Stand volume = stand basal area x mean top height x form factor
    = ………m^2/ha.

FF (form factor) is explained in the Glossary and Section 6.1. A form factor of 1/3 is commonly used if a measured value is not available.

NB: The above checklist sets out the basic methods for plantations greater than three hectares.

2 Recording Stand Information

Objective: **To record details of species, age and location**

2.1 Species

Full species details should be recorded using scientific names and provenance details where known. For mixed species stands, all species planted and the proportion of each species within the stand should be recorded.

2.2 Age

It is preferable that separate records are kept for each stand planted in a particular year. This may not be possible when one 'block' was planted up over a few years and the history is not known. Maintaining statistics according to age are very useful for monitoring the growth of the plantation and managing thinning, pruning or other management activities.

2.3 Location

The location, that is latitute and longitude coordinates, of a stand can be determined from a topographical map or global positioning system (GPS). There are two map grid systems in use. Older maps use Australian Map Grid (AMG). New maps use Geocentric Datum of Australia(GDA). A GPS must be set to refer to the same grid system as the map. A map reference (latitude and longitude for a specified grid system) for the centre of a stand would be suitable for locating the stand for the National Farm Forestry Inventory and other purposes.

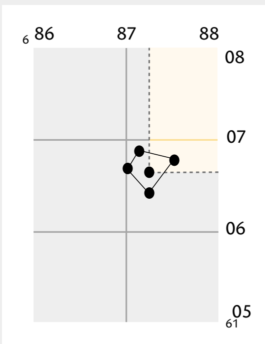
A grid reference of the central point is derived by using a grid-lined map of a scale between 1:10,000 and 1:100,000.

EXAMPLE:

Use an AMG reference map to determine the coordinates of the central point in the stand. For a map scale of 1:100 000 each gridline is 1 000 m apart on the ground and 1 cm apart on the map. Therefore, 1 mm on the map is equal to 100 m on the ground. Using a ruler, the coordinates are measured as:

Easting – 687 150 m

Northing – 6 106 650 m



3 Area of the plantation

Objective: To accurately record plantation boundaries and area, accounting for slope; and to generate a useful map.

Essential equipment: Measuring tape, compass, ruler, and protractor. Use Form 1 in Appendix to enter distances and bearings.

Desirable equipment: recent aerial photo of plantation.

3.1 Area

An accurate calculation of the area of the stand is very important, because measurements are usually taken from only a ***sample*** (or portion) of the whole stand, and extrapolated to estimate for the whole stand. This is covered further in section 4.1 —What is Sampling?

It is best to calculate the ***net stocked area*** of the stand. This is the area on which trees are actually growing and excludes areas within the stand perimeter such as roads, creeks or failed plantings.

For stands less than three hectares or of long narrow shape (e.g. shelterbelts), you can determine wood volumes based on the total number of trees rather than total area. However, you may wish to follow the procedures below to produce a scaled drawing of the stand and to determine the area for other purposes, such as reporting to the National Farm Forest Inventory.

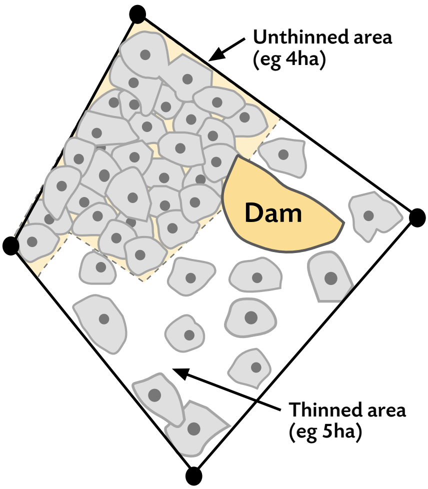
3.2 How to determine plantation area

Basic level

STEP 1: DEFINE THE PLANTATION BOUNDARY

Area calculations can differ depending on how the boundary of the stand is defined. The plantation boundary, or perimeter, is defined by the extent of tree foliage in straight lines, as shown in Figure 3.1.

FIGURE 3.1: PLANTATION BOUNDARY DEFINED BY EXTENT OF TREE FOLIAGE.



STEP 2: MEASURE THE LENGTH ALONG EVERY SIDE OF THE PLANTATION

Either use a measuring tape or pace out the distance to get an estimate of length. Simply determine your stride distance by counting the number of steps you take over a known distance, and use the following formula:

$$\text{Stride distance} = \frac{\text{Known distance (m)}}{\text{Number of steps}}$$

Then multiply the stride distance by the number of steps you take along the unknown distance.

Unknown distance = Stride distance x Number of steps

EXAMPLE:

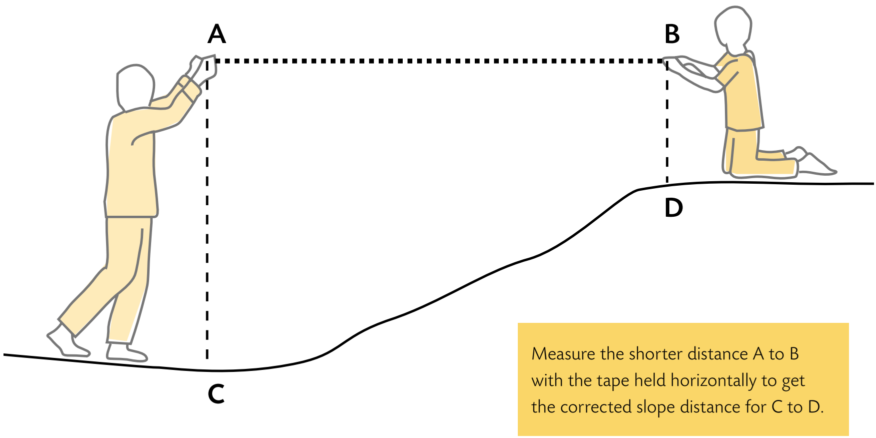
An estimate of the length of a plantation can be obtained by pacing. First, determine the distance covered with each pace by walking a known distance, for example 20 m, and counting the number of steps. Let's say it is 22 steps. Therefore each pace is 0.91 m (i.e. 20/22). Then pace the side of the plantation. If it took 510 steps, the length would be about 464 m (i.e. 510 x 0.91 m).

STEP 3: MEASURE SLOPE

It is essential to measure horizontal area, not slope area, because forest growth is related to horizontal area. Slope area is not meaningful and would depend on measurement of all slopes, hollows and bumps.

Manually adjust for slope by holding the measuring tape horizontally—*see Figure 3.2*. Or while going up or down hill, take longer strides to keep the same horizontal distance.

FIGURE 3.2 MANUALLY ADJUSTING FOR SLOPE



STEP 4: MEASURE THE ANGLE OF EACH LENGTH

Use a compass to determine the bearing of each length measured. A compass must be level when the bearing is read and a back bearing should be taken at the end of each leg to check initial bearings.

Fence wire and metal posts can deflect a compass—stand clear of these when taking bearings.

The difference between an initial bearing and back bearing should be approximately 180 degrees. An error of 5 degrees or less is acceptable.

EXAMPLE:

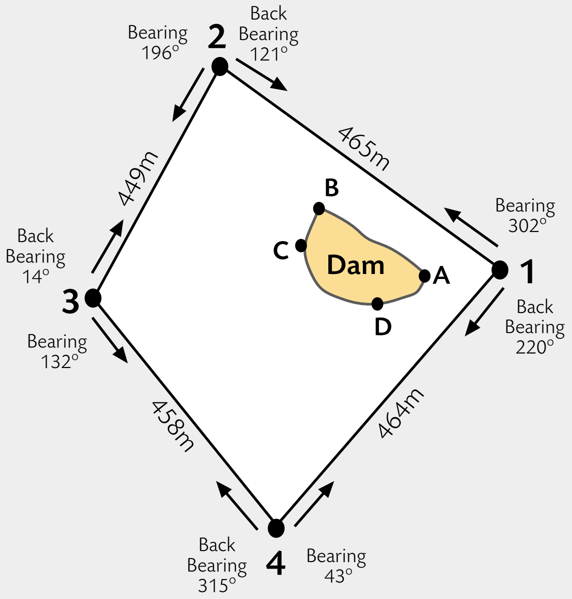
A scaled diagram of a stand can be used to determine its area. To make a scaled diagram, first define the boundary of the stand and peg it, numbering each corner. Standing at a corner (call this corner point 1), take a compass bearing to the next corner (point 2). Measure the distance between point one and two. Measure the slope so that the measured distance can be adjusted to get horizontal distance. After reaching point 2, take a bearing back to point 1 to check the accuracy of the first bearing. Continue around the stand until all sides have been covered, adjusting each distance for slope and checking back-bearings from all points.

FROM POINT	TO POINT	BEARING	BACK BEARING	MEASURED DISTANCE
1	2	302°	121°	465 M
2	3	196°	14°	449 M
3	4	132°	315°	458 M
4	1	43°	220°	464 M

Repeat the process around the dam.

A	B	297°	119°	125 M
B	C	194°	15°	53 M
C	D	125°	301°	78 M
D	A	51°	236°	64 M

EXAMPLE *CONTINUED*:



Once the plantation boundaries and any internal unstocked areas have been measured accurately they need to be drawn to scale onto a blank sheet of paper or preferably a topographical map or existing farm plan using a ruler and protractor. This involves:

- converting your measured distances (in metres) to centimetres or millimetres– *see Table 3.1.*
- using a ruler to draw each length
- using a protractor to draw each length at the correct angle (bearing)
- if you choose to draw onto a topographical map, adjust bearings from magnetic north to grid north (*see Figure 4.4 on magnetic declination*).

Once the map is drawn to scale you can calculate the area by using the dot grid provided in Appendix 3. Place the dot grid randomly over the map and count the number of dots inside the boundary of the plantation. Each dot represents a particular area depending on the scale of the drawing.

Try not to align the rows of dots along a long straight boundary like a road or fence line—you will have more work guessing if the dots are in or out and may introduce errors into your area estimates.

TABLE 3.1: LENGTH AREA CONVERSIONS

MAP SCALE	1 CM EQUALS	1 MM EQUALS
1:5,000	50 METRES	5 METRES
1:10,000	100 METRES	10 METRES
1:15,000	150 METRES	15 METRES
1:25,000	250 METRES	25 METRES
1:50,000	500 METRES	50 METRES
1:100,000	1 KILOMETRE	100 METRES

Five dots equal 1 cm, 25 dots equal one cm^2. *See appendix 3.*

Advanced level—Length

More sophisticated devices are available which give quick distances, such as a hip chain or laser-based distance finder; however, they may be costly or difficult to borrow.

Advanced level—Slope

Distances measured on a slope can be converted to horizontal distance by using the table in Appendix 5. This requires measuring the slope, which can be done with a clinometer (refer Section 5.5). Simply look through the peephole at the rear of the clino, and read off the number on the left-hand scale aligned with the horizontal line—*see Figure 5.3.*

Over rolling terrain:

- divide the terrain into sections of uniform slope
- establish a mark on the ground whenever the slope significantly changes
- read the distance off the tape, then correct the distance if needed by using the correction table included in Appendix 5.

While using a clinometer, the slope should be measured to a point equivalent to the height of the observer's eye level.

3.3 Alternative methods for area calculation

Aerial photos

Aerial photographs are commonly used for farm planning, and are available from land management agencies. They are useful in cases where the plantation area is large or broken up by watercourses or failed plantings. Aerial photographs enable you to identify areas within the plantation where no trees are growing, such as roads, clearings, and therefore better estimate the net stocked area.

On reasonably flat ground you can use aerial photos to draw the plantation boundary onto a map of equivalent scale, then calculate the area using the dot grid provided (appendix 4). Use an existing topographical map or farm plan as the basis for mapping the plantation stand. The base map must be to a known scale (preferably 1:10,000 to 1:25,000).

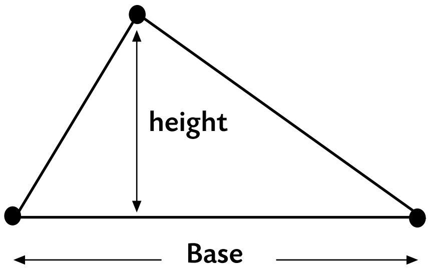
Aerial photos may show distortion if not taken at right angles looking straight down to the ground. Watch out for distortion around the edge of the photo—due to the geometry of the lens. Most aerial photo work only uses the 'middle' of each photo, with consecutive shots taken to cover larger areas.

To obtain an aerial photo of your property see chapter 12 to determine the contact number for your State.

Area formulas

If the shape of your plantation is fairly simple, then area can be estimated by dividing the shape up into a collection of triangles. Calculate the area of each triangle using the formula:

$$\text{Area (ha)} = \frac{(\frac{1}{2} \times \text{base} \times \text{height})\ \text{m}}{10{,}000}$$



If the stand is square or rectangular (i.e. has 4 sides and 90° corners) you can measure the boundaries on the ground, correcting for slope as described above, and calculate the area using the formula:

$$\text{Area (ha)} = \frac{\text{Length (m)} \times \text{Width (m)}}{10{,}000}$$

Survey programs

The *Farm Forestry Toolbox* (available from Private Forests Tasmania) includes a program that calculates map area using bearings and distances.

4 Sampling and plot layout for stands greater than 3 hectares

Objective: **To determine the number and size of plots required and where and how to locate them.**

Essential equipment: measuring tape, ruler, and spray paint.

Desirable equipment: aerial photo, compass, and pegs.

4.1 What is sampling?

Since it is unlikely that we can measure every tree in a plantation we usually collect information by measuring only a proportion of all the trees in the stand—this is known as ***sampling***.

Sampling is usually carried out by establishing ***plots*** within the forest. A ***plot*** is an area in which all trees are measured. The most common plots have a fixed area and are circular or rectangular in shape. The shape will not affect the number of same-sized plots used.

4.2 Is your stand uniform?

Generally speaking plantation stands that have been satisfactorily established and maintained are relatively consistent in size, age, growth and species compared with natural forests. However, you may have sections within your plantation which are noticeably different to the rest due to:

- Management practices—for example:
  - A section of the stand is thinned or pruned and the remainder unthinned or unpruned.
  - A section of the stand has been damaged during a storm event.
  - A section has been fertilised or ripped and the remainder unfertilised or not ripped.

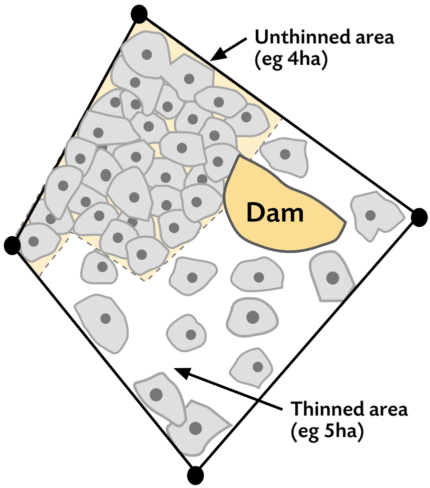
- Soil changes—for example:
  - A section of the stand is on poor soils and has poor growth, and the remainder is on good soils and has relatively good growth.
- Species mix—for example:
  - You may have planted one species in one section of the stand and another species, or set of species, in the remainder.

If there are significant differences within the stand, i.e. you can visibly see them, the stand needs to be partitioned into separate uniform groups and then each group sampled separately.

How to partition areas:

1. Consider whether you have significant (i.e. clearly visible) differences in the stand to warrant partitioning the stand into uniform areas.
2. If so, document the differences between the uniform areas, draw their boundaries on the plan or map and calculate the area of each uniform area (*refer to Chapter 3*).

FIGURE 4.1: PLANTATION WITH TWO UNIFORM AREAS (THINNED AND UNTHINNED AREAS)



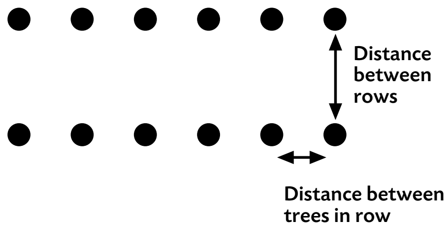
4.3 What size should plots be?

It is generally recommended that a plot should be big enough to contain about 15 to 20 trees. Therefore the plot size will depend on how many trees there are per area (i.e. the ***stocking*** rate) of the stand. The more sparse the trees, the larger the plot needs to be to include sufficient trees. If you clearly have different stocking rates in different areas these should be measured as different partitioned groups within the stand.

Stocking (stems/ha) =

$$\frac{10{,}000}{\text{(Distance between rows x distance between trees in rows)}}$$

FIGURE 4.2: DISTANCE BETWEEN ROWS AND DISTANCE BETWEEN TREES IN ROWS



If rows are easy to see, rectangular plots are easier to use than circular plots. In older stands, where thinning has taken place and rows are no longer obvious, stocking rate is calculated by counting the number of trees in a fixed area and converting this to a number per ***hectare***.

Use Table 4.1 to determine the plot size according to the stocking.

TABLE 4.1: PLOT SIZE ACCORDING TO STOCKING

STOCKING RATE (STEMS/*HECTARE*)	PLOT SIZE (*HECTARES*)	RADIUS OF CIRCULAR PLOT (METRES)	DIMENSIONS OF RECTANGULAR PLOT
100	0.2	25.2	*See section 4.7* ON RECTANGULAR PLOTS TO DETERMINE THE REQUIRED DIMENSIONS
200	0.1	17.8	
400	0.05	12.6	
500	0.04	11.3	
600	0.033	10.2	
800	0.025	8.9	
1000 +	0.02	8.0	

4.4 How many plots should be established?

Basic level

A minimum of five plots should be established in every uniform area of plantation. Statistical errors can be significant where less than five plots are used, especially if there is considerable variation within the stand. Table 4.2 provides a guide to the number of plots required by plantation area.

TABLE 4.2: NUMBER OF PLOTS BY PLANTATION AREA

AREA OF PLANTATION	NUMBER OF PLOTS REQUIRED
< 3 HA	SAMPLE INDIVIDUAL TREES INSTEAD OF USING PLOTS (CHAPTER 7).
3 – 5 HA	5 PLOTS
5 – 10 HA	8 PLOTS (12 IN A VARIABLE STAND)
> 10 HA	10 PLOTS (16 IN A VARIABLE STAND)

Advanced level

Table 4.2 provides a simple guide to determining the number of plots required. If a reliable figure is required, then the size of the plantation will not determine the number of plots required. It will depend on two main factors:

- The degree of variability between the trees; and
- The desired level of precision.

The variability of the forest may be broken into three classes:

Low variability – This level of variability would be found in a thinned plantation where the suppressed and mal-formed trees have been removed.

Medium variability – This level of variability may be found in unthinned plantations established with genetically improved planting stock and if stocking is fairly uniform across the stand.

High variability – This level of variability should be assumed for unthinned plantations and for most special purpose hardwood plantations, especially if a mixture of species is planted.

The desired level of sampling precision depends on the time available to establish and measure plots, and how the answer will be used. For example, a sampling precision of 10% indicates that the actual volume per hectare is likely to be plus or minus 10% of the estimate obtained from plot measurements. That level of precision would usually be considered acceptable for a commercial timber inventory. A lower level of precision, perhaps as low as plus or minus 20%, may be acceptable for non-commercial purposes.

TABLE 4.3: NUMBER OF PLOTS IN RELATION TO VARIABILITY AND SAMPLING ERROR

NUMBER OF PLOTS	LOW VARIABILITY	MEDIUM VARIABILITY	HIGH VARIABILITY
4	MUST DO AT LEAST 5 PLOTS FOR STATISTICAL COMPARISON		
6	10%	ESTIMATE TOO POOR	ESTIMATE TOO POOR
8	8%		
10	7%	18%	
12	6%	16%	
14	6%	14%	
16	5%	13%	
18	5%	12%	
20	5%	12%	
22	4%	11%	
24	4%	11%	
26	4%	10%	20%
28	4%	10%	19%
30	4%	9%	19%
32	4%	9%	18%
34	3%	9%	17%
36	3%	8%	17%
38	3%	8%	16%
40	3%	8%	16%
42	3%	8%	16%
44	3%	8%	15%
46	3%	7%	15%
48	3%	7%	15%
50	3%	7%	14%

Sampling error is the percentage above and below the sample value where the actual value is likely to occur. Sampling error is stated for a particular level of confidence, commonly 95%. For example, if the average log volume measured on the plots is 100 m^3/ha and the sampling error is 15%, there is a 95% probability that the real answer is between 85 and 115 m^3/ha.

It might be better to divide a highly variable forest into two areas of medium variability. For example, it may take 26 plots in a highly variable forest to get a result within 20% of the actual answer. If the forest were divided into two areas of medium variability, then 10 plots in each area (a total of 20 plots) would achieve a better result.

4.5 Where should plots be located?

Basic level

Plots can be randomly located on the map, making sure they are evenly spread over the entire plantation.

Advanced level

Plots can be laid out on the map in a systematic manner. This involves superimposing a grid pattern on the map, and selecting plots where the grid lines intersect—*see Figure 4.3.*

This method ensures that plots evenly cover the plantation area and makes compass navigation in the field easier because all plots are evenly spaced and on the same bearing. Great care must be taken to ensure that edge trees are not over or under represented and the grid provides the correct number of plots.

FIGURE 4.3: MAP OF PLANTATION WITH GRID OVERLAY

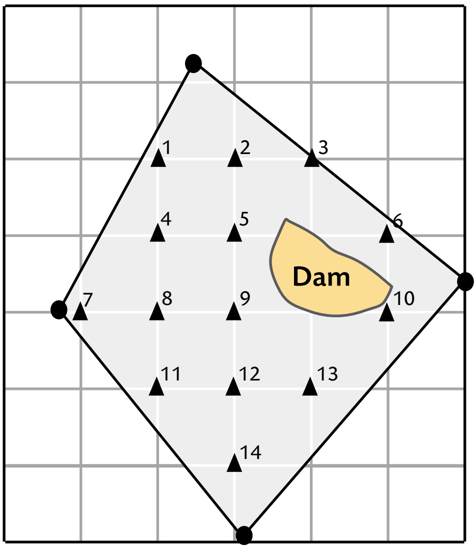


TABLE 4.4: STEPS FOR ESTABLISHING PLOTS

STEP		EXAMPLE
1	CALCULATE THE AREA OF THE STAND AND IF NECESSARY THE AREA OF EACH UNIFORM GROUP WITHIN THE STAND	20 HA
2	CALCULATE THE STOCKING RATE	250 STEMS/HA
3	CALCULATE THE PLOT SIZE REQUIRED ACCORDING TO THE STOCKING RATE IN TABLE 4.1	FOR STOCKING RATES OF AROUND 200 USE 0.1 HA SIZE PLOT
4	CALCULATE THE NUMBER OF PLOTS REQUIRED, SEE TABLE 4.2	10 PLOTS
5	USE GRID TO SYSTEMATICALLY LOCATE THE PLOTS	

4.6 Locating plots on the ground

Once the number of plots has been decided, plot them on a map and locate them in the plantation.

Plots can be located in the field by:

- measuring on the map with a ruler the distance along a road (use Table 3.1 to convert the map distance to ground distance)
- measuring on the map with a ruler the distance and compass bearing into the plantation to the plot
- pacing out those distances in the field (*see section 3.2 on pacing*).

It is not important to precisely locate a plot on the ground. However, it is important to have some 'rule of thumb' to avoid placing a plot by subjective means (i.e. where the assessor thinks the trees look better or where the trees are easier to measure).

Access is often easier along a plantation row. If it is practical, use a take-off point that enables you to measure the distance to the plot along the row.

Advanced level

To accurately locate a plot in the field:

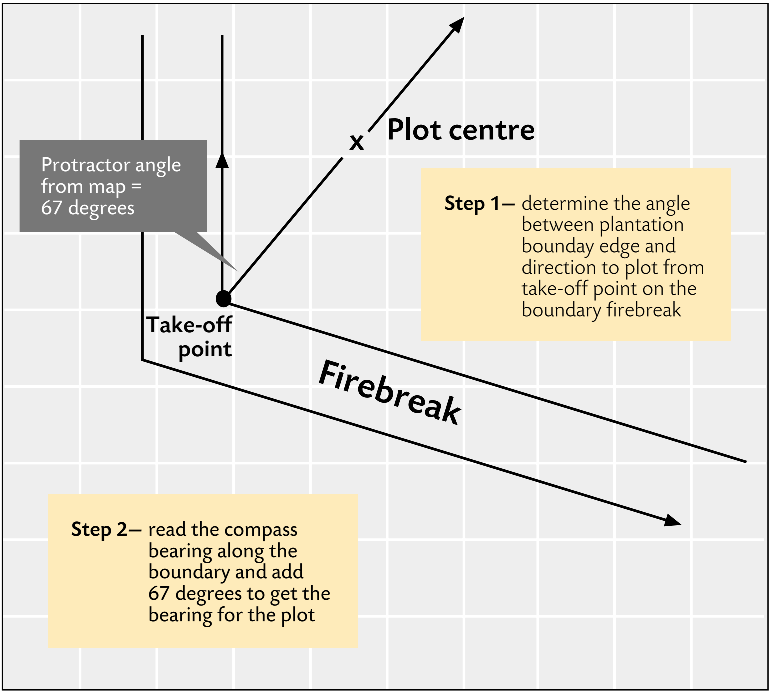
- Take a known point such as the plantation corner or road intersection.
- Use a ruler to measure how far the known point is from the ***take-off point***. The ***take-off point*** is the measured point along the road where one heads into the plantation. It should preferably be exactly north, south, east or west of the plot.
- Use a ruler to measure how far the ***take-off point*** is from the plot.
- Convert the measured map distances to ground distances (*see Table 3.1*).
- Out in the field walk the required distance from the known point to the ***take-off point*** using a measuring tape or hip chain to measure the distance.
- At the *take-off point* use a compass to determine the plot's direction and a measuring tape or hip chain to walk the required distance.
- If the terrain has a slope greater than 10 degrees, then slope corrections are required on the measured distance (*see section 3.2, which covers slope correction*).

EXAMPLE:

If the map scale is 1:5,000 and the measurement we get off the map from the known point to the *take-off point* is 20 mm, then that distance on the ground is 100 m (*see Table 3.1*).

Remember to correct for the magnetic declination if using a map orientated to true north. To avoid adjusting for magnetic declination, calculate the map angle from the edge of the plantation and in the field adjust the compass bearing along the edge of the plantation by this amount—*see Figure 4.4*.

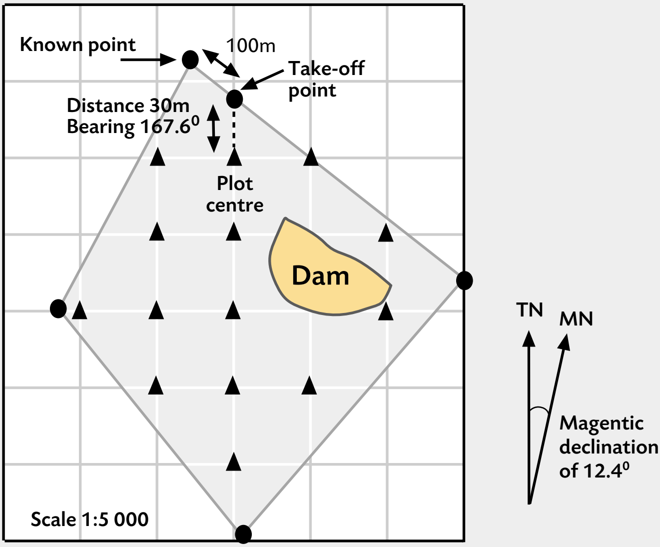
FIGURE 4.4: HOW TO AUTOMATICALLY ACCOUNT FOR MAGNETIC DECLINATION



EXAMPLE:

Purpose: to locate a plot in the plantation.

The map of the plantation is orientated to true north and has a scale of 1:5,000. Magnetic declination in the area is 12.4 degrees. First choose a boundary corner as a known point and measure the distance with a ruler to the take-off point, which is 20 mm on the map or 100 m on the ground (see the above example for the conversion). Using a 50 m tape, measure the required distance to the take-off point. The plot is due south of the take-off point and 30 m away. Using a compass, go in the direction of 167.6 degrees (i.e. 180-12.4).



4.7 Setting up the plot

Plots can be either temporary (a one-off measure) or permanent (i.e. measured over time). It would be preferable to set up several permanent plots so they can be measured over time to determine growth rates and allow the grower to become familiar with tree growth. The size of a permanent plot should be determined by the expected final stocking.

When setting up a permanent plot remember to mark it out in such a way that anyone can easily find the plot, identify plot trees and their re-measurement points in future years.

Circular plots

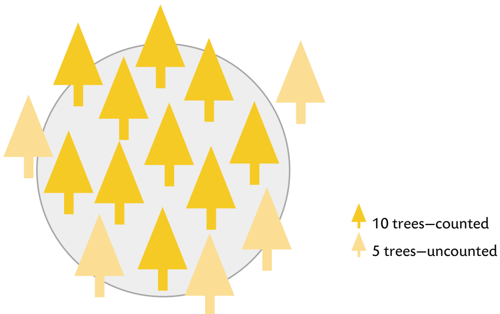
Circular plots are preferred in mature stands where ***stocking*** rates are lower due to thinning and original planting rows are harder to identify.

To set up a circular plot:

- Mark the plot centre with a peg. The measured distance to the plot becomes its plot centre—*see section 4.6*. Locate the plot centre at the measured distance. Locating the plot centre at a more convenient point nearby may bias the result
- Using a measuring tape, identify the trees that are within the predetermined radius (see Table 4.1 to work out radius) and mark the boundary trees with spray paint. For a tree to be included within the plot, the centre of the tree (usually where the diameter at breast height over bark (DBHOB) is measured) must be within the plot radius.
- The tree nearest to the plot centre should have the plot number marked on it and underlined.

When marking out the plot boundary it is important to account for slope when measuring the distance from the plot centre. On moderate slopes it is possible to adjust for slope by holding up the measuring tape horizontally from the plot centre—*see Figure 3.2.* For slopes of 5 degrees or more, the table in Appendix 4 can be used to determine the distance that must be measured down the slope to get a specified horizontal distance.

FIGURE 4.5: A CIRCULAR PLOT



Rectangular plot

Rectangular plots are preferred in stands where plantings rows are well defined, for example in unthinned stands.

To set up a rectangular plot:

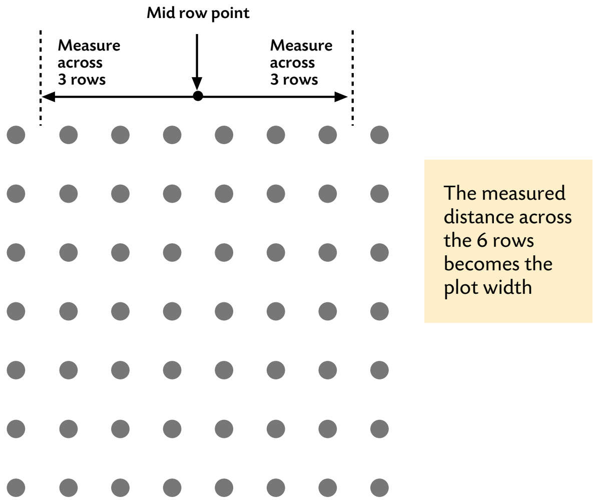
- Identify the mid row point, which is the measured distance to the plot–*see section 4.6*.
- From the mid row point, measure across three rows to the mid row in either direction. This distance becomes the plot width–*see Figure 4.6*.
- Calculate the plot length by using appendix 7, which gives plot length for a measured width where the plot area is 0.04 ***hectares***, or use the formula below:

$$\textbf{Plot length (m)} = \frac{\textbf{plot area (ha)}}{\textbf{plot width (m)} \times 10{,}000}$$

For slopes of 5 degrees or more, the table in Appendix 4 can be used to determine the distance that must be measured down the slope to get a specified horizontal distance.

- At each end of the plot determine whether border trees are in or out by estimating the right angle to the row direction.

FIGURE 4.6: MEASURING OUT THE RECTANGULAR PLOT'S BOUNDARIES



You may adjust the number of rows in a plot to provide a reasonable plot length. Six rows are suggested for regularly stocked plantations with about 1,000 trees per hectare and a plot area of about 0.04 hectares.

4.8 Plots near stand edges

A plot located near the edge of a plantation may extend beyond the plantation boundary. It will contain edge trees which are larger in stem diameter, have larger branches and may be shorter with greater stem ***sweep***. A plot is only established if the measured distance to the plot is within the plantation boundary.

Basic level

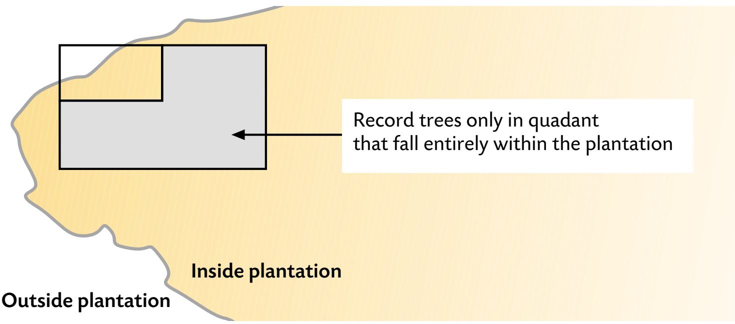
If part of the plot extends beyond the boundary, then move the plot further into the plantation.

Advanced level

A statistically more reliable method for a plot extending beyond the boundary is to measure only plot quadrants that fall entirely within the boundary—*Figure 4.7*. Then weight the results by:

$$\text{Plot volume} = \left(\frac{\text{Summed volume of recorded trees}}{\text{Number of quadrants x 0.25}} \right)$$

FIGURE 4.7: MEASURING QUADRANTS OF A PLOT THAT FALL ENTIRELY WITHIN THE BOUNDARY



4.9 What to measure in the plot

Now that the plot has been set up, the next step is to measure the trees within the plot. There are two main parameters for tree measurement: diameter and height. Generally all trees within the plot are measured for DBHOB. This is covered further in section 5.2, 'How to measure diameter'. The number of trees measured for height depends on the chosen volume method:

Form factor method– requires measuring the heights of at least five trees with diameter about the average for the stand.

Tree volume table method–requires the heights of all trees in the plot to be measured

The volume to basal ratio (VBAR) method–requires an absolute minimum of five pilot trees for heights, with the preference of 25 height trees for a more accurate result.

Determining the height of a tree is covered in more detail in section 5.5.

Laying out plots and measuring trees can take considerable time. You should ensure that you allow the time and resources to do the job properly. Generally it takes two people up to an hour to locate, lay out and measure a plot with about 15–20 trees where access is reasonable.

5 Measuring trees—field procedures

Objective: To accurately measure diameter and height, as these provide the basic information to calculate tree and stand volume.

Essential equipment: Diameter tape, measuring tape, inventory forms in Appendix, and ruler.

Desirable equipment: Vertex hypsometer or clinometer.

5.1 Diameter

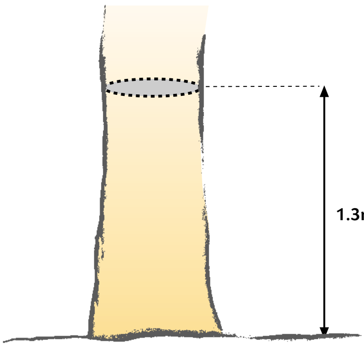
Tree diameter is the most common and important measurement made on commercial trees. By convention, the diameter of a tree is measured in centimetres at 1.3 m above the ground on the uphill side and is termed the 'diameter at breast height' (DBH). Because trees are measured with the bark on this is also called the diameter at breast height over bark (DBHOB). When measuring live trees most information is presented as over bark dimensions and volume models include a correction to provide the under bark volume used to describe most high-value products.

5.2 How to Measure Diameter

DBHOB is usually measured using a converted linear tape (called a ***diameter*** or ***'di tape'***), which allows diameter to be measured by wrapping the tape around the circumference (girth) of the tree.

To measure DBHOB:

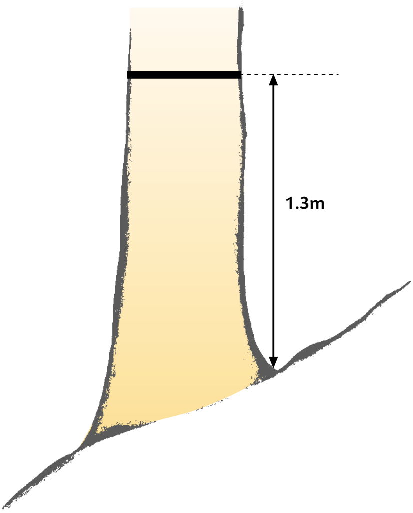
1. Determine where 'breast height' or 1.3 m is on you or use a stick 1.3 m long.

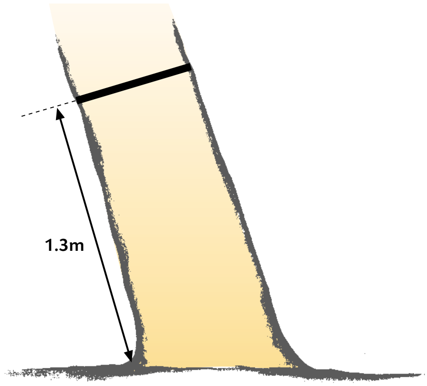


2. Remove any loose or flaking bark, especially on eucalypts.

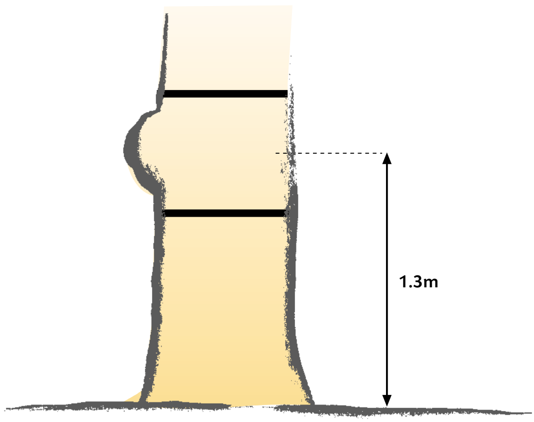
3. Stand on the up-slope side of the tree, wrap the tape around the tree at 1.3 m with the diameter measurements showing, being careful not to twist the tape.

4. Measure at right angles to the lean of the ***bole***.

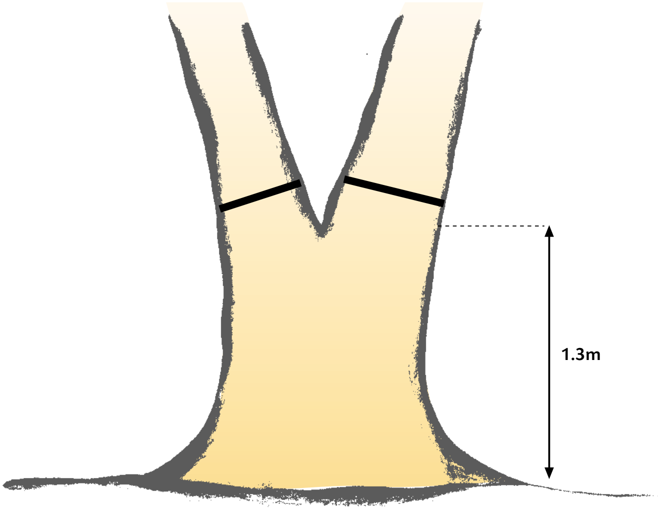




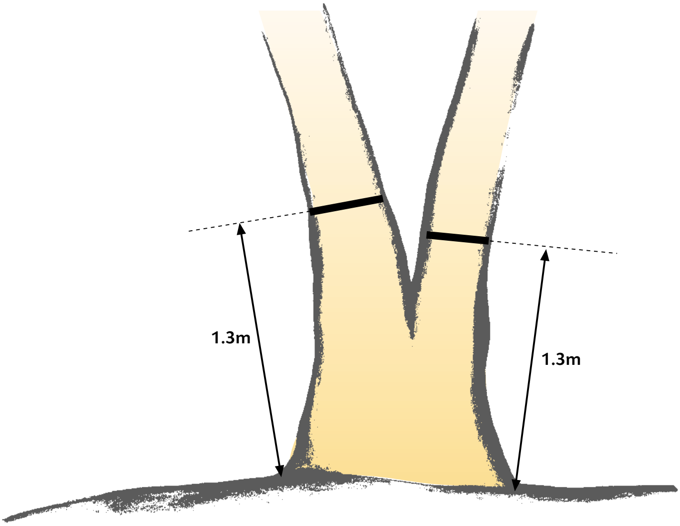
5. Read the diameter measurement from where the diameter scale starts, as the gradations on the tape do not commence from the very end (*see Figure 5.1*).



6. When swellings, bumps or branches occur at 1.3 m, diameter should be measured at an equal distance above and below 1.3 m and the two measurements averaged.



7. For trees forking at or just above 1.3 m, measure both stems above the fork.



8. For trees forking below 1.3 m, measure each stem and treat as two trees.

FIGURE 5.1: MEASURING DBHOB –THIS TREE'S DBHOB IS 11.1 CM.

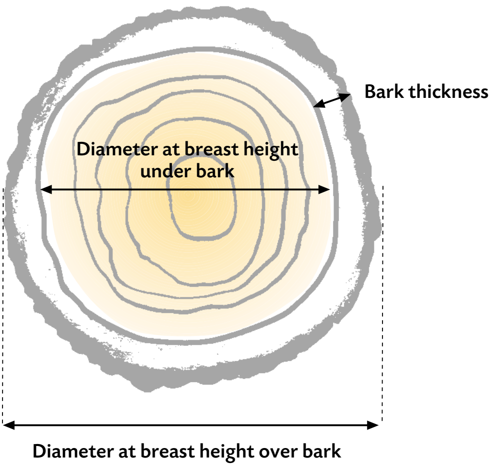
5.3 Bark thickness

Where we are interested in the wood volume under the bark layer or are measuring species with markedly varying bark thickness, it is important to measure the thickness of the bark.

DBHOB can be converted to the diameter at breast height under bark (DBHUB) using the formula:

DBHUB = DBHOB – (Bark Thickness x 2)

FIGURE 5.2: CROSS SECTION OF A TREE STEM SHOWING OVER BARK AND UNDER BARK DIMENSIONS



Once the DBHUB has been calculated it can be inserted into a ratio and used to reduce the over bark volume to an approximate under bark volume. The ratio is:

$$\text{Ratio} = \frac{(\text{DBHUB})^2}{(\text{DBHOB})^2}$$

Basic level

The depth of the bark can be estimated by cutting through the bark to the wood or observing the bark of at least five recently felled trees.

Advanced level

Bark thickness can also be measured with a specifically designed bark gauge to an accuracy of one millimetre. It relies heavily on feel; so to minimise error the following guidelines are suggested:

- If the tree has rough or fissured bark, take measurements on the ridges of the bark.
- Take three to four measurements around the stem and average, as bark thickness may vary from one side of the tree to the other.
- Feel the change in pressure while pushing the chisel into the bark. Avoid pushing too hard or it might go into the wood.

5.4 Height

Total height of a tree (h) is most commonly used. However, a range of other estimates using some form of height measurement has been developed. These include ***merchantable height, stand height*** and ***mean top height***.

5.5 How to measure total height

The total height of a standing tree can be measured in a number of ways, using a range of instruments. The method you use will depend on the size of the tree and resources you have available.

Stick or pencil method

1 Take a straight stick of known length (30–40 cm long preferably)

2 Place a mark on the stick at a point 1/10th of its length from the bottom. For example, if the stick is 30 cm long, place the mark at 3 cm from the bottom.

3 Holding the stick vertically at full arms length, walk backwards from the tree you wish to measure, until the top and bottom of the stick match with the top and bottom of the tree.

4 Note where your mark lines up with the tree trunk and have your assistant, standing at the tree, put their hand up to this point on the tree trunk. Then measure the distance from the ground to this point on the tree—call this the 'tree mark height'.

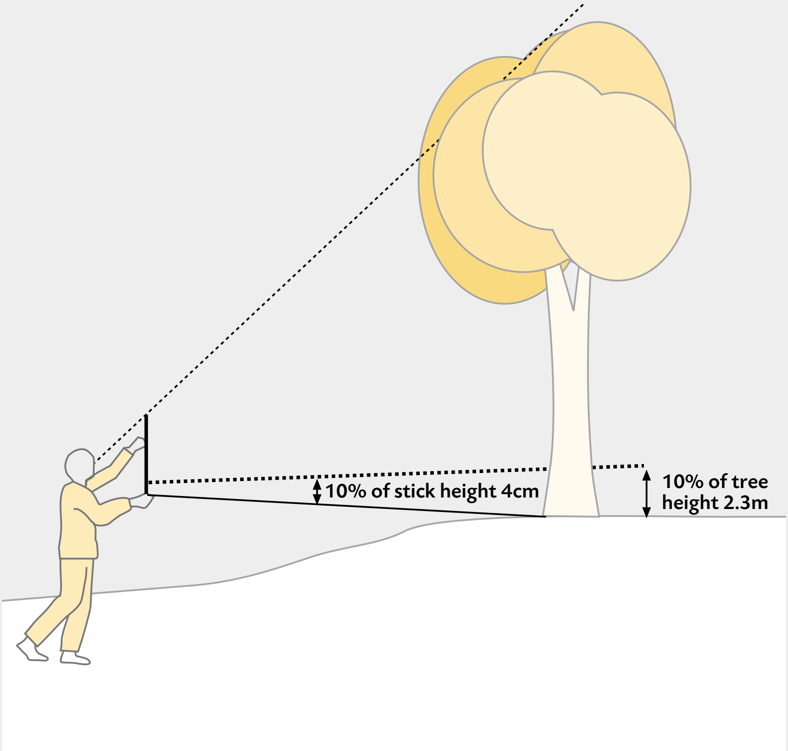
5 As the mark on the stick was 1/10th of its total length, the mark on the tree is also at 1/10th of the total tree height. Therefore multiply the tree mark height by 10 to get the total tree height.

Depending on the height of the trees you may need a longer or shorter stick. Alternatively a tape measure or ruler can be used instead of a stick.

The stick or pencil method has the disadvantage of having a high level of error and being very time-consuming. Be careful to sight on the base of the tree at ground level and on the highest point of the tree, rather than on the side of the crown. It is recommended that, if possible, a vertex hypsometer or clinometer should be borrowed to determine tree height.

EXAMPLE:

A straight stick can be used to estimate the height of a tree. Cut the stick to 40 cm length. Place a mark at 10% of its length, that is, 4 cm from the end. One person stands at the base of the tree. Another person walks backwards away from the tree holding the stick at arms length until the top and bottom of the stick are in line with the top and bottom of the tree. Line up the 10% mark on the tree and mark that point on the trunk. Measure the distance from the base of the tree to the 10% mark. For example, if the 10% mark is at 2.3 m height, then multiply 2.3 by 10 to estimate the tree height.



Advanced level

CLINOMETERS

The Suunto Clinometer (clino) is a tool commonly used by foresters to measure tree heights and also slope angles. At the rear of the clino is a peephole, which shows a percentage scale and a horizontal line (*see Figure 5.3*).

1. First measure the horizontal distance between the base of the tree and the operator.
2. Looking through the peephole, line up the horizontal line with the top of the tree and read off the corresponding number from the percentage scale, which is on the right hand side. The scale on the left is in degrees and should not be used!
3. Line up the horizontal line with the base of the tree and again read off the corresponding number from the percentage scale.
4. If the base of the tree is above you (i.e. you're on the downward slope) then subtract the number from Step 3 from the number from Step 2 and multiply by the horizontal distance to get a total tree height.
5. If the base of the tree is level with you or below you (i.e. you're on the upward slope) then add the numbers together and multiply by the horizontal distance to get a total tree height.
6. If the tree is leaning, stand at right angles to the lean so the tree isn't leaning towards or away from you.

Be careful to sight on the base of the tree at ground level and on the highest point of the tree, rather than on the side of the crown. If you can't see the bottom of the tree because of branches or understorey, sight to a point up the stem that can be seen and treat this as the base of the tree and continue with the procedure as described above. Then add the height from the base to the point you could see to get your estimate of total tree height.

Clinometers have two scales. The scale on the left-hand side is in degrees, while the right-hand side is a percentage scale —*see Figure 5.3*

FIGURE 5.3: LOOKING THROUGH A CLINOMETER

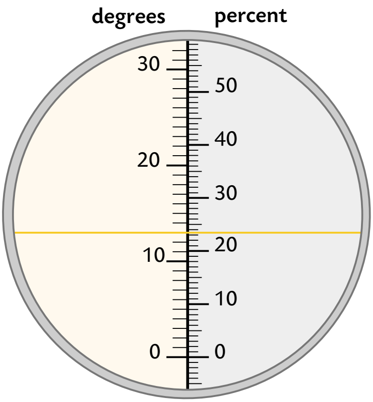


FIGURE 5.4: USING A CLINOMETER

EXAMPLE:

Purpose: to determine the height of two trees. The base of one of the trees is slightly below you. The base of the other tree is slightly above you.

Measure the distance to the first tree, which is 25 metres away. Using the clinometer, sight to the top of the tree: the horizontal line aligns with the percentage number 64. Then sight to the base of the tree: the horizontal line aligns with minus 6, that is, it is 6% below you. Add both percentages and multiply by the distance:

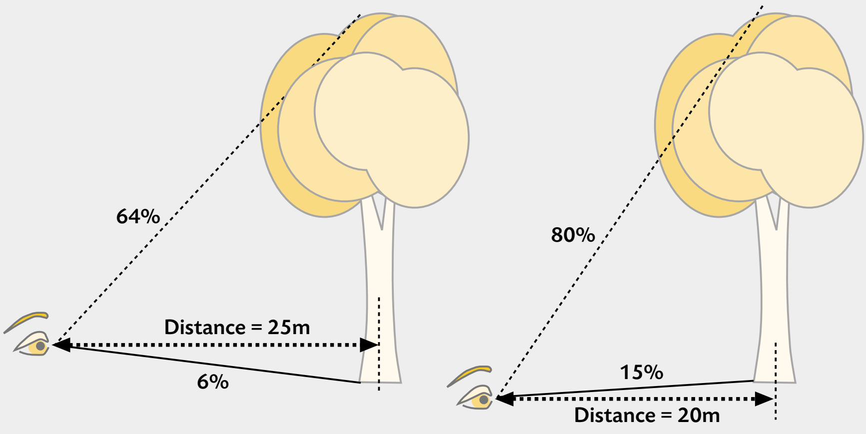
Tree height = 25 x (0.64 + 0.06)

= 17.5 m.

Repeat the procedure for the second tree, which is 20 metres away from you. The percentage to the top of the tree is 80. The percentage to the bottom of the tree is plus 15, that is, the base of the tree is above you. Therefore, the height of the second tree is

Tree height = 20 x (0.80 – 0.15)

= 13.0 m.



Advanced level

VERTEX HYPSOMETER

The vertex hypsometer is a small instrument, which uses an ultrasonic beam to estimate the height of a tree. It is quick and easy to use and requires no calculations as heights are displayed on liquid crystal screens.

The vertex hypsometer consists of a transponder and a vertex. The transponder is pinned to the tree and faces the direction of the operator. The vertex is then pointed at the transponder and at the top of the tree. Tree height is then shown on the display. Refer to the user's manual on the exact operation of the device or seek assistance from your local farm forestry expert—*see chapter 12*.

5.6 Other factors

Some specialised models dealing with growth or volume may require additional measurements such as crown height and crown width, etc. These are not covered by the manual.

6 Calculating volumes for stands greater than three hectares

Objective: **To provide an accurate estimate of tree and *stand volume* for stands greater than three *hectares*.**

Essential equipment: Calculator.

Desirable equipment: angle gauge (diameter tape), and volume table.

6.1 Tree Volume.

The amount of wood in a single tree or stand of trees is the most important measure of a commercial forest. Indeed the main aim of a commercial tree grower is to maximise the amount of wood grown, on as few individual trees as possible, given the inherent productivity of the site. Although weight (measured in tonnes) is being used more often to sell wood, most assessments of forest crops are based on volume (measured in cubic metres).

Usually volume is expressed inside bark and according to different specifications:

Gross total volume: volume of the main stem/s of trees or stands including the stump and top and also including defective or decaying wood

Gross merchantable volume: volume of the main stem/s of trees or stands excluding the stump and top but including defective or decaying wood.

Net merchantable volume: volume of the main stem/s of trees or stands excluding the stump and top and also excluding defective or decaying wood.

The volume of a tree is determined by how tall it is (its height), how fat it is (its diameter), and how its shape changes along the length of the stem (taper form).

Calculating volume for stands greater than three ***hectares*** requires height and diameter information collected from plots. The basis of all volume calculations is the generic formula:

Volume = basal area x height x form factor

The form factor (also called form coefficient; refer glossary) describes the shape of the tree bole. A form factor of one-third, which is commonly used if measured values are unavailable, assumes the tree is perfectly conical. A tree with substantial taper has a lower form factor and a tree with little taper has a higher form factor.

TABLE 6.1: EXAMPLE OF FORM FACTORS

FORM FACTOR	DESCRIPTION
0.25	HEALTHY DOMINANT TREE IN OPEN LOCATION, TOP 50% TOO SMALL TO USE OR DEFECTIVE
0.4	HEALTHY, DOMINANT TREE GROWING IN OPEN LOCATION WITH NO DEFECTS
0.45	CODOMINANT TREE, USEFUL ALL THE WAY UP
0.6	SUBDOMINANT TREE TO BE REMOVED IN PULP OPERATION

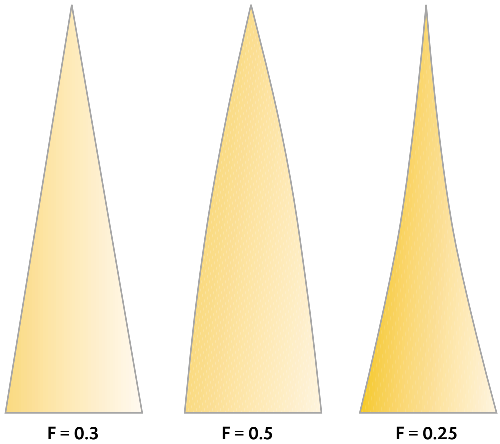
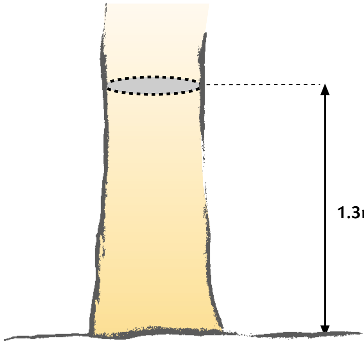


FIGURE 6.1: EXAMPLES OF FORM FACTOR OF A TREE BOLE.

6.2 Basal Area

Basal area is used in formulas to estimate volume and can be easily measured over time to determine stand growth. Basal area can refer to a single tree or the whole stand. Tree basal area (TBA) is the cross-sectional area (over bark) of a single tree at breast height (1.3 m), measured in square metres, which is the common unit for describing basal area. TBA can be described as the area you would see visible if you cut horizontally through a tree at 1.3 metres. TBA can be useful in estimating the volume of a tree.

FIGURE 6.2: TREE BASAL AREA AT 1.3 M



How to measure Tree Basal area

To determine tree basal area, simply measure the diameter at breast height in centimetres (DBHOB) and calculate the basal area (m^2) using the formula below, which is adapted from the simple formula for the area of a circle (area= πr^2), where π is approximately 3.142. This formula converts the diameter in centimetres to the basal area in metres squared (m^2).

$$\textbf{Tree basal area } (m^2) = \left(\frac{DBHOB}{200}\right)^2 \times 3.142$$

where DBHOB is the diameter at breast height over bark (cm).

The same technique can be used to calculate the cross-sectional area of the tree at any point. When measuring log volume, for example, the cross-sectional area at the centre of the log is often calculated.

Normally we use the term ***basal area*** to represent the whole stand, not a single tree, and so use the unit m^2/ha. Stand basal area (SBA) is simply the basal area of all the trees at breast height per ***hectare*** of forest or plantation (m^2/ha). Stand basal area can be used to estimate ***stand volume*** or as a useful measure of the degree of competition in the stand. SBA is often quoted when planning thinning prescriptions.

How to measure stand basal area

Stand basal area can be determined by summing the tree basal areas or by using a basal area sweep.

Sum of tree basal areas

The most accurate method of assessing stand basal area is to measure all tree diameters in a plot, calculate the individual tree basal areas using the formula above and add these up, then divide by the plot area.

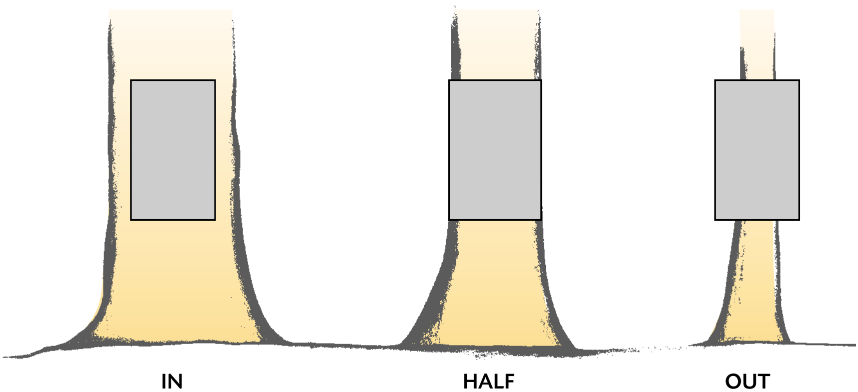
$$\text{SBA } (m^2/ha) = \frac{\text{(Sum of the basal area of each tree in the plot)}}{\text{(area of the plot)}}$$

Diameters of each tree can be entered onto a computer, and processed easily using spreadsheets.

Basal area sweeps

Basal area sweeps estimate the stand basal area by using a very simple optical method. Using a gauge of a known width, the assessor rotates around the centre point of the plot, observing each tree at breast height and counting the number of trees that appear wider than the width of the gauge (called an 'IN' tree). Trees that are exactly covered by the gauge are counted as a half (called a 'HALF' tree). Trees that are smaller than the gauge are ignored ('OUT' tree)–*see Figure 6.3.*

FIGURE 6.3: ANGLE GAUGE USED TO ASSESS 'IN' 'HALF' AND 'OUT' TREES



The total number of IN trees and borderline trees (i.e. counted as a half) is then multiplied by the basal area factor (BAF) of the gauge, to give the basal area per ***hectare***.

Stand basal area (m^2/ha) = BAF x count

where BAF is the basal area factor. It is important to select a gauge factor that is suitable for the forest being assessed. The aim should be to count 5 to 10 trees. Using a gauge that is too narrow (small BAF) in a dense stand will lead to counting many trees. Using a gauge that is too wide (large BAF) in a sparse stand will lead to counting few trees, so that the effect of variation in stocking and errors in reading the gauge will be large.

EXAMPLE:

If the gauge has a factor of 5 and counts 6 IN trees and 2 HALF trees then:

Stand basal area **= 5 x [6 + 2(1/2)]**

= 35 m^2/ha

Remember:

- View each tree at breast height (1.3 m).
- The gauge must stay at the plot centre and your eye must pivot around the gauge.
- View at right angles to the stem of leaning trees.
- View trees hidden by undergrowth or other stems.
- Use a gauge that counts 5 to 10 trees.
- Check the accuracy of half trees to confirm their status.

Checking HALF trees:

Including too many HALF trees leads to less reliable results, so their status needs to be confirmed. Measure the horizontal distance to the central axis of the tree and its DBHOB. Then using the table in appendix 6, determine the marginal distance. If the marginal distance is shorter than the horizontal distance then the tree is not counted.

EXAMPLE:

A basal area sweep using a gauge with a factor of 3 finds two half trees. Their diameters are 20 cm and 35 cm and their horizontal distances from the plot centre are 6 m and 10.1 m, respectively. From the table in Appendix 6, their marginal distances are 5.8 m and 10.1 m. The first tree is therefore out, because it is further from the plot centre than the marginal distance. The second tree would be counted as half because it is the same distance from the plot centre as the marginal distance..

Using the diameter tape as a basal area gauge

The metal plate at the end of the plastic diameter tapes supplied by The Master TreeGrower Program can be used as a basal area gauge. It is 16 mm wide and is longer on the white side. Hold the metal plate between the forefinger and thumb of your left hand, with the white side of the tape facing up. The distance you hold the metal plate from your eye will determine the basal area factor. For a basal area factor of two, hold the tape at the 49 cm mark on the yellow side with your right hand. For a basal area factor of four, hold the tape at the 32.5 cm mark on the yellow side with your right hand.

Remember to:

- pull the tape tight and look along the white side towards the metal plate
- hold the tape against your cheekbone at the appropriate point.

FIGURE 6.4: USING THE METAL PLATE AT THE END OF A DIAMETER TAPE TO UNDERTAKE A BASAL AREA SWEEP

6.3 Calculating volumes

There are a variety of methods to determine total volume of a stand depending on the amount of data collected and level of accuracy required.

Basic level

FORM FACTOR

A quick way to estimate over bark ***stand volume*** is to use the following formula. It assumes that all the trees in the stand are uniform and are cone-shaped,that is, the form factor is one-third.

$$\textbf{Standing over bark volume (m}^2\textbf{/ha)} = \frac{\textbf{(SBA x MTH)}}{\textbf{3}}$$

where SBA = stand basal area (m^2/ha)—for measurements of stand basal area see section 6.2.

MTH = ***Mean Top height*** (the average height of the three fattest trees in the plot).

The effect of using different form factors is discussed in Section 6.1.

Intermediate level

TREE VOLUME TABLE

Tree volume tables enable the estimation of a tree's volume by inputting one, two or three dimensions of the tree. Accuracy is improved by applying restrictions to the populations it refers to. Restrictions can involve the type of species, age and locality. The number of dimensions put into the table determines the type of table:

- One-way table—normally DBHOB or basal area
- Two-way table—DBHOB and height (standard table)
- Three-way table—DBHOB and height, then bark thickness or ***taper***.

If deciding to use a tree volume table it is important to find one for your locality and same age and species as your plantation.

Once the volume of each individual tree has been determined for a plot, they can be summed then divided by the plot area to derive the ***stand volume***.

$$\textbf{Stand volume } (m^3/ha) = \frac{\textbf{Plot volume } (m^3)}{\textbf{Plot area (ha)}}$$

EXAMPLE:

Heights and diameters have been measured from several 0.005 ha plots. The following dimensions were collected from one of the plots:

DBHOB – 17 cm, ht – 16 m

DBHOB – 15 cm, ht – 12 m

DBHOB – 16 cm, ht – 14 m

DBHOB – 17 cm, ht – 14 m

DBHOB – 16 cm, ht – 16 m

DBHOB – 15 cm, ht – 10 m

VOLUME TO 7 CM DIAMETER OVER BARK, M³				
	TOTAL HEIGHT (M)			
DBHOB (CM)	10	12	14	16
15	0.10	0.12	0.13	0.15
16	0.11	0.13	0.14	0.16
17	0.12	0.14	0.16	0.18

Using the above volume table, the tree volumes are 0.18m³, 0.16m³, 0.12m³, 0.16m³, 0.14m³, and 0.10m³. By summing the volumes, the plot volume is 0.86m³. The volume per hectare is therefore 0.86/0.005 = 172m³/ha. Repeat the process for the other plots and calculate the average volume per hectare.

The major drawback in using a tree volume table is finding one similar in species, locality, age, and stocking to your stand. The less compatible the volume table the greater the error.

Volume tables provide a volume estimate under bark based on DBHOB and tree height. Check with local farm forestry experts to see whether any tables are available for your area. See Chapter 12 for your local farm forestry expert or download the Farm Forestry Toolbox http://www.privateforests.tas.gov.au/downloadindex.htm, which has an electronic tool that may be used to approximate tree volumes for your region.

Intermediate level

VBAR

The VBAR (Volume/Basal Area Ratio) method allows the assessor to accurately measure several pilot trees, then quickly measure numerous trees with a reasonable level of accuracy. The VBAR method involves:

1. Calculating the basal area and volume of several pilot trees
2. Using the values from the pilot trees to calculate the VBAR coefficient
3. Estimating the basal area, by undertaking a basal area sweep
4. Using the VBAR value and several basal area sweeps to estimate volume.

Step 1—Calculate the volume and basal area of several pilot trees

Determine the volume and basal area of several pilot trees. Form factor, volume tables or centroid sampling can be used to determine volume. An absolute minimum of five pilot trees is required, with the preference of 25 trees for a more accurate calculation.

Step 2—Determine the VBAR

The VBAR value is calculated by dividing the tree volume by the basal area for each pilot tree, then averaging for all pilot trees:

$$\mathbf{VBAR} = \frac{\mathbf{Volume}}{\mathbf{Basal\ area}}$$

Step 3—Basal area using a basal gauge

Undertake a basal area sweep as described in section 6.2.

Step 4—Calculate stand volume

Stand volume is then calculated by using the VBAR value and a basal area sweep, into the following formula:

Volume (m^3/ha) = VBAR x BAF x number of IN trees
where BAF = basal area factor.

Repeat this process for several other basal area sweeps and average. Each basal area sweep is a plot and the number of sweeps should be determined in the same way as mentioned in section 4.4.

The VBAR method has the advantage of being very quick and fairly accurate once the volume of the pilot trees has been calculated.

7 Sampling and volume calculations for stands under three hectares

Objective: To provide an estimate of tree and *stand volume* for stands of less than three *hectares*.

Essential equipment required: Diameter tape, measuring tape, spray paint, and calculator.

7.1 Sampling

To undertake sampling in small stands, it is best to walk through the whole stand, counting every tree and systematically select individual trees to measure.

Method

1. Walk through the stand in a systematic manner and count every tree using a tally counter. If you already have an accurate figure of how many trees there are go to step 2.

2. Determine the number of DBHOB and height measurement trees according to Table 7.1.

TABLE 7.1: SELECTION OF TREES FOR DBHOB AND HEIGHT MEASUREMENT

1 TOTAL NUMBER OF TREES IN STAND	2 TOTAL NUMBER OF TREES TO MEASURE DBHOB AND HEIGHT	3 WHICH TREES TO MEASURE DBHOB AND HEIGHT
LESS THAN 200	MEASURE ALL TREES	MEASURE EVERY TREE
200 – 400	50 – 100	EVERY 4TH TREE
400 – 600	66 – 100	EVERY 6TH TREE
600 – 800	75 – 100	EVERY 8TH TREE
800 – 1000	80 – 100	EVERY 10TH TREE
1000 – 1500	100 – 150	EVERY 10TH TREE
1500 – 2000	100 – 133	EVERY 15TH TREE
2000 – 4000	100 – 200	EVERY 10TH TREE, EVERY 2ND ROW
4000 – 6000	133 – 200	EVERY 10TH TREE, EVERY 3RD ROW

7.2 Volume calculations

Use Table 7.1 to determine which trees to measure DBHOB and height. Then use the following formula to estimate the volume of each measured tree. It assumes that the tree is uniform and cone-shaped, that is, the formm factor is one-third. Forestry people working in your area may be able to advise a more suitable form factor.

$$\textbf{Tree volume (m}^3\textbf{)} = \frac{\textbf{(TBA x HT)}}{\textbf{3}}$$

where TBA = tree basal area (m^2) – for measurements of tree basal area *see section 6.2.*
HT = tree height.

Sum the volume of each measured tree to get the sample volume. The results for the sample can then be multiplied to get the total stand results.

$$\textbf{Stand vol.} = \left(\frac{\textbf{Total number of trees}}{\textbf{Number of trees measured}}\right) \textbf{x sample volume}$$

EXAMPLE:

The number of trees in a plantation is counted and found to be 1,500. Using Table 7.1, a suitable sample would be 133 trees located by selecting every 15th tree. Measure their heights and diametres and use the form factor equation to estimate their bolumes. If the sum of their volumes were found to be 24 m^3, the stand volume would be: (1,500/133) x 24 = 271 m^3.

Intermediate level

TREE VOLUME TABLE

See section 6.1 on how to use a tree volume table. Once the volume of each individual tree has been determined, sum the volumes to get a sample volume, and then multiply to get the total stand results.

$$\textbf{Stand vol.} = \left(\frac{\textbf{Total number of trees}}{\textbf{Number of trees measured}}\right) \textbf{x sample volume}$$

7.3 Shelterbelts

Shelterbelts are usually long strips of trees often only one to three rows wide. To establish a plot, divide the shelterbelt into at least five even sections and place a plot in each section. The results for the sample can then be multiplied to get the total shelterbelt results.

$$\textbf{Shelterbelt vol.} = \left(\frac{\textbf{Total number of trees}}{\textbf{Number of trees measured}}\right) \textbf{x sample volume}$$

EXAMPLE:

Purpose: to measure a shelterbelt that is 1,000 trees long and 3 rows wide (3,000 trees).

The minimum number of plots required is five, which means establishing a plot every 200 trees. Each plot is five trees long, so there are approximately 15 trees per plot. Measure the height and diameter of each tree in the plot and use the volume table to derive each tree's individual volume. For each plot, the individual tree volumes are summed to get a plot volume. The plot volumes are averaged resulting in 2.7 m^3. So the shelterbelt volume is

Shelterbelt vol. = (3000/15) x 2.7
= 540 m^3.

7

8 Estimating Growth

Objective: To determine the growth of a stand.

Growth varies from year to year depending on the age of a stand and environmental variables such as rainfall. Determining the annual growth or increment of a stand allows the owner to forecast volume and productivity.

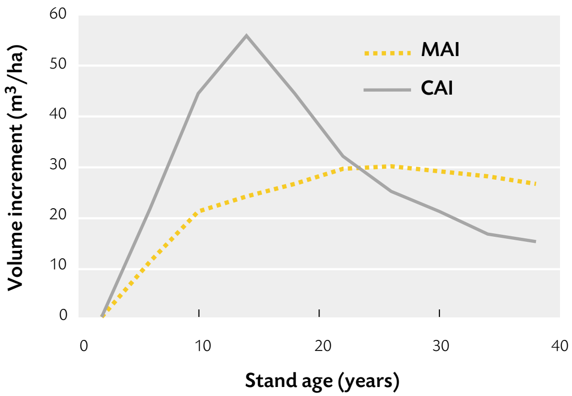
Growth can be expressed as either the current annual increment (CAI) or the mean annual increment (MAI). CAI is the increase in volume at a particular age and is determined by measuring a stand annually over successive years. MAI is the average volume production per year of a stand of known age. It does not need measurements over successive years unless the point of maximum MAI is required. For growth rate to be determined, volume must be measured and put into the following formulas.

$$\text{MAI} = \frac{\text{Volume of stand } (m^3/ha)}{\text{Age of stand (yrs)}}$$

CAI at age X = (Volume at age X) – (Volume at age X-1)

e.g. CAI at age 25 = Volume at age 25 – Volume at age 24

FIGURE 8.1: EXAMPLE OF THE CAI AND MAI OVER TIME OF A FAST GROWING PLANTATION



8

EXAMPLE:

Stand volume data collected annually can be used to determine how fast a plantation is growing. For the ages and measured volumes shown below and using the formulae above, the MAI and CAI are:

AGE	VOLUME (M^3/HA)	MAI	CAI
25	525	21	NA
26	620	23	95
27	705	26	85
28	755	27	50
29	790	27.2	35

Generalised MAI figures for some species and available for some areas (check with your local farm forestry network or private forestry development committee). These figures are usually based on data from particular stands. When relating them to other stands it is important to make allowances for differences in soils, rainfall, silviculture and other factors that affect growth.

9 Quantity Versus Quality

Objective: To understand products and defects

The above methods give you a final figure of total volume (m^3) per ***hectare***, in your farm forest. This figure is the quantity of wood you have currently standing in your plantation and if you know the current market price per m^3, it can be converted into a value. Appendix 8 shows the ***stumpage*** price range that you could receive per cubic metre of wood for each State in 2001.

However, quantity is different to quality. Price per cubic metre is strongly influenced by:

- The suitability of the species and the log for different end uses.
- ***Bole*** straightness which is important for minimal wastage during sawing. It's usually assessed by the amount of ***sweep*** in the ***bole***.
- ***Multiple leaders***. A single leading stem is preferred as it has more volume in the one log than multiple stems on a tree of a similar age.
- Branch size, number and distribution. Branches create knots in the wood which can affect the strength of the timber as well as its appearance. A premium is paid for ***clearwood***. Pruning must be undertaken to produce clearwood and should be verified by an independent auditor to certify the quality of pruned logs. Australian Forest Growers (AFG) have developed a system for pruned stand certification.
- ***Bole*** roundness which includes the stem being oval or having ***fluting***. This increases the amount of wastage during sawing and makes the log unacceptable as a ***peeler***.
- Defects such as decay, hollows, broken tops.

Price is also affected by the diameter and length of the logs. Table 9.1 shows the log specifications for a specific softwood mill in Tasmania. Specifications vary from region to region and from mill to mill. They usually involve limits of maximum and minimum log lengths, a minimum small end diameter (SED) and a maximum large end diameter. Figure 9.1 shows the possible products you can get from a log.

Other factors affecting price include distance to the mill, road access to the stand, slope and soils. In some States, if you are intending to harvest timber for sale you or the harvester, will need to submit a timber harvesting plan. Consult local extension officers for advice.

Check with local farm forestry experts on the log grade specification relevant for your region, as there may be considerable variation.

FIGURE 9.1: POSSIBLE PRODUCTS FROM A LOG

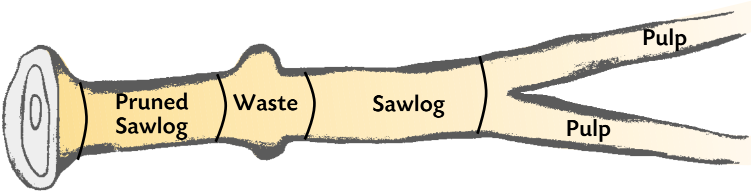


TABLE 9.1: TASMANIAN SOFTWOOD SPECIFICATIONS

	PRUNED SAWLOG	SAWLOG	PULPLOG
MIN. LENGTH	3.7 M	3.7 M	2.4 M
MAX. LENGTH	6.1 M	6.1 M	6.1 M
MIN. SED	35 CM	20 CM	10 CM
WOBBLE	NOT ALLOWED	NOT ALLOWED	MAX DEVIATION TO BE LESS THAN THE SED
ROUNDNESS	MAX. 150%	MAX. 150%	N/A
KINK	NOT ALLOWED	NOT ALLOWED	MAX. DEVIATION TO BE LESS THAN THE SED
NODAL SWELLING	MAX. 4 CM	MAX. 4 CM	UNRESTRICTED
FLUTING	MAX. 8 CM	MAX. 8 CM	UNRESTRICTED
BUTT FLAIR	TRIMMED FLUSH	TRIMMED FLUSH	N/A
SCARS	NOT ALLOWED	NOT ALLOWED	DEAD WOOD NOT ALLOWED
SPLITS	NOT ALLOWED	NOT ALLOWED	UNRESTRICTED
CONE HOLES	N/A	NO MORE THAN 2 WHORLS PER METRE	N/A
SIDE TEARS	NOT ALLOWED	NOT ALLOWED	UNRESTRICTED
KNOT SIZES	N/A	MAX. KNOT SIZE 7 CM WITH NO MORE THAN 5-7 CM KNOT PER 2.5 M OF LOG	UNRESTRICTED IF TRIMMED FLUSH
BLUE STAIN	NOT ALLOWED	BY NEGOTIATION	BY NEGOTIATION

10 Conclusion

A greater understanding of a plantation can be gained through measuring a few trees properly. This manual goes through each step of determining plantation area, selecting appropriate trees (sampling), measuring the trees and using that data to calculate standing wood volume.

Estimates in standing wood volume are always subject to error. This manual provides a choice of techniques to allow for a ball park figure or a more accurate figure. The volume provides an idea of its value although value is strongly influenced by the quality of the timber.

11 Glossary of terms

AMG/AGD (Australian Map Grid/Australian Geodetic Datum)	If using the AMG, coordinates are given in metres, while latitude/longitude uses degrees. When recording AMG coordinates, the Easting (X-axis) is read first, followed by the Northing (Y-axis). An easting is 6 digits long (e.g. 580 330 m) to specify a location to the nearest metre, while the northing is 7 digits long (e.g. 5 379 680 m).
bark thickness	the radial distance between the cambium (solid wood) and the outside of the bark
basal area (of the stand)	the sum of the basal areas of all the trees, measured in m^2/ha
basal area (of a tree)	the cross-sectional area (over bark) at breast height (1.3 m) measured in m^2
bole	the main stem or trunk of the tree
clearwood	the knot free part of the tree that grows after pruning off branches–it is considered to be of higher value, especially for sawlog and veneer use timber
clinometer	an instrument used to measure the percentage or degree of angle, can be used to calculate tree height
di tape/diameter tape	short for diameter tape–similar to a measuring tape except it is calibrated to measure diameter rather than the tree's circumference, when placed around the tree's stem
fluting	indentations in the log, usually worse closer to the ground
form factor	Also called "form coefficient", this is a measure of the form, or shape, of a tree bole. It is determined by dividing the volume of the tree by the volume of a cylinder with the same diameter and height as the tree. (Refer Figure 6.1).
hectare	10,000 m^3 or 100 m by 100 m or approximately 2.471 acres
kink	relating to stem straightness where a sudden change in angle occurs along the stem

log specifications	certain log characteristics prescribed by the buyer such as maximum and minimum log lengths, diameter, branch size and sweep—desirable and non-desirable features can also be included
mean top height	the average height of the three fattest trees in a plot
merchantable height	the distance from ground level to the saleable part of the tree, i.e. to the highest point on the bole where the diameter is not less than some specified value (e.g. 10 cm)
multiple leaders	where there is more than a single main stem
net merchantable volume	volume of the main stem of the tree excluding the stump and top as well as defective or decaying wood
net stocked area	an estimation of the area actually occupied by trees—it excludes roads, dams, streams, canopy gaps and failed plantings from the gross area
nodal swell	the stem diameter at a branch whorl which is usually larger than the diameter in between whorls
optical dendrometer	a variety of instruments used to measure upper stem diameter
peeler	a straight, round log used to produce veneer by rotary peeling
plots	an area of defined or undefined size where the trees are measured
projection	the mathematical transformation required to represent the earth's three-dimensional surface in two-dimensional space (i.e. flat surface of a map)
sample	a subset of the population, which is deemed to be representative of the whole—for example, a person who samples a cake can assume the portion is typical of the rest of the cake

stand height	the average height of a stand, conventionally based on the tallest trees
stand(ing) volume	the volume in cubic metres per hectare of standing trees
stocking	the number of stems per hectare. Stocking is important for managing the stand as it grows. Often thinning and pruning activities need to meet prescribed stocking rates–for example, 'thin from 1000 down to 300 stems/hectare' or 'prune the best 200 stems/hectare.
stumpage	the value of standing trees in dollars per cubic metre–it may be affected by costs of harvesting and haulage
sweep	curvature or bend in a log
systematic sampling	a grid pattern is superimposed on a map and plots are located at the grid junction
take-off point	the measured point along the road where one heads into the plantation–preferably exactly north, south, east or west of the plot
taper	the change in diameter from large to small the higher up the stem you go
total height	the vertical height from ground level to the tip of the tree
variability	the variation from individual to individual of a particular characteristic such as DBHOB, height or volume
vertex hypsometer	advanced instrument for measuring heights and distances
volume	quantity of wood in the stem of a tree, measured in cubic metres (m^3)
wobble	relating to stem straightness where a deflection occurs over a short distance in the stem

12 Links

Websites

These three sites provide additional information on tree measurement:

http://www.anu.edu.au/Forestry/mensuration/

http://sres.anu.edu.au/associated/mensuration/rwg2/code

http://www.mtg.unimelb.edu.au/log/measure.pdf

The ANU Forestry Market Reports site provides forest product and input markets in Australia, primarily for the small-scale forest grower and can be found at:

http://sres.anu.edu.au/associated/marketreport/index.html

The Farm Forestry Toolbox is a collection of user friendly programs enabling conversions, survey and mapping, volume calculations and financial analysis. It must be installed from a CD – see your local forestry expert contact below for information on obtaining a CD. To download updates of the Farm Forestry Toolbox, go to:

http://www.privateforests.tas.gov.au

For your local forestry expert contact go to the National Farm Forest Inventory site and look under Farm Forestry Regional contacts:

http://www.daff.gov.au/nffi

For a list of professional consulting foresters, go to the Australian Consulting Foresters Association site:

http://www.australianconsultingforesters.org/

Organisations

Australian Forest Growers
PO Box 318
Deakin West ACT 2600
02 6285 3833

Australian Greenhouse Office
GPO Box 621
Canberra ACT 2601
02 6274 1888

The Australian Master TreeGrower Program
Institute of Land and Food Resources
University of Melbourne
Victoria 3010
03 8344 7170

Bureau of Rural Sciences
Agriculture, Fisheries, Forestry – Australia
GPO Box 858
Canberra ACT 2601
02 6272 4680

Greening Australia
PO Box 74
Yarralumla ACT 2600
02 6281 8585

Private Forests Tasmania

Launceston
PO Box 180
Kings Meadows TAS 7249
03 6336 5300

Hobart
78 Patrick St
Hobart TAS 7000
03 6233 7448

North West Tasmania
PO Box 68
Burnie TAS 7320
03 6434 6319

Contacts for purchasing materials

Aerial photos

VICTORIA–Qasco Vic Image, 03 9682 3330

http://www.qasco.com.au

SOUTH AUSTRALIA–Environmental and Geographic Information, 1800 44 0133,
http://www.environment.sa.gov.au/mapland/aerial.html

WESTERN AUSTRALIA–DOLA, 08 9273 7209
http://www.dola.wa.gov.au/home.nsf/(FrameNames)/Aerial+Photography

NEW SOUTH WALES–Land and Property Information
02 6332 8200**, http://www.lpi.nsw.gov.au/**

TASMANIA–TASMAP 03 6233 7741
http://www.dpiwe.tas.gov.au/inter.nsf/ThemeNodes/JGAY-548VJT?open

NORTHERN TERRITORY–NT Dept of Infrastructure, Planning and Environment, 08 8999 6636 or 08 8999 6186 **http://www.lpe.nt.gov.au/airphoto/index.html**

AUSTRALIAN CAPITAL TERRITORY–ACT Land Information Centre 02 6205 0074, **http://www.palm.act.gov.au/actlic/**

Inventory Gear

Prospectors Earth Sciences–02 9838 7899
The Australian Master TreeGrower Program–supplies diameter tapes
03 8344 7170

Recommended Reading

AGO 2002, *Field measurement procedures for carbon accounting*, Bush for Greenhouse program, Australian Greenhouse Office, Canberra.

Maclaren, J.P. 2000, *How much wood has your woodlot got?* 'A practical guide to estimating the volume and value of planted trees', *Forest Research Bulletin*, No. 217, New Zealand Forest Research Institute.

Reid, R. and Stephen, P. 2001, *The Farmer's Forest: Multipurpose Forestry for Australian Farmers*, RIRDC Publication Number R01/33.

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Brack, C.L., 'Technical Note: A simple procedure for measuring single tree volume using the centroid sampling technique', *Institute of Foresters of Australia Newsletter*, 37(5):12–14.

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Maclaren, J.P. 2000, 'How much wood has your woodlot got? A practical guide to estimating the volume and value of planted trees', *Forest Research Bulletin*, No. 217, New Zealand Forest Research Institute.

Philip, M.S. 1994, 'Measuring Trees and Forests', 2nd ed., CAB International, UK.

PFT 2001, 'Tasmanian Market Information Update for Farm Forestry', No. 3, Private Forests Tasmania.

Reid, R. and Stephen, P. 1999, *The Farmer's Log 1999–Australian Master TreeGrower Manual*, Printworks Colac.

1 Appendix: Boundary log field form

FROM POINT	TO POINT	BEARING	BACK BEARING	DISTANCE

2 Appendix: Inventory form

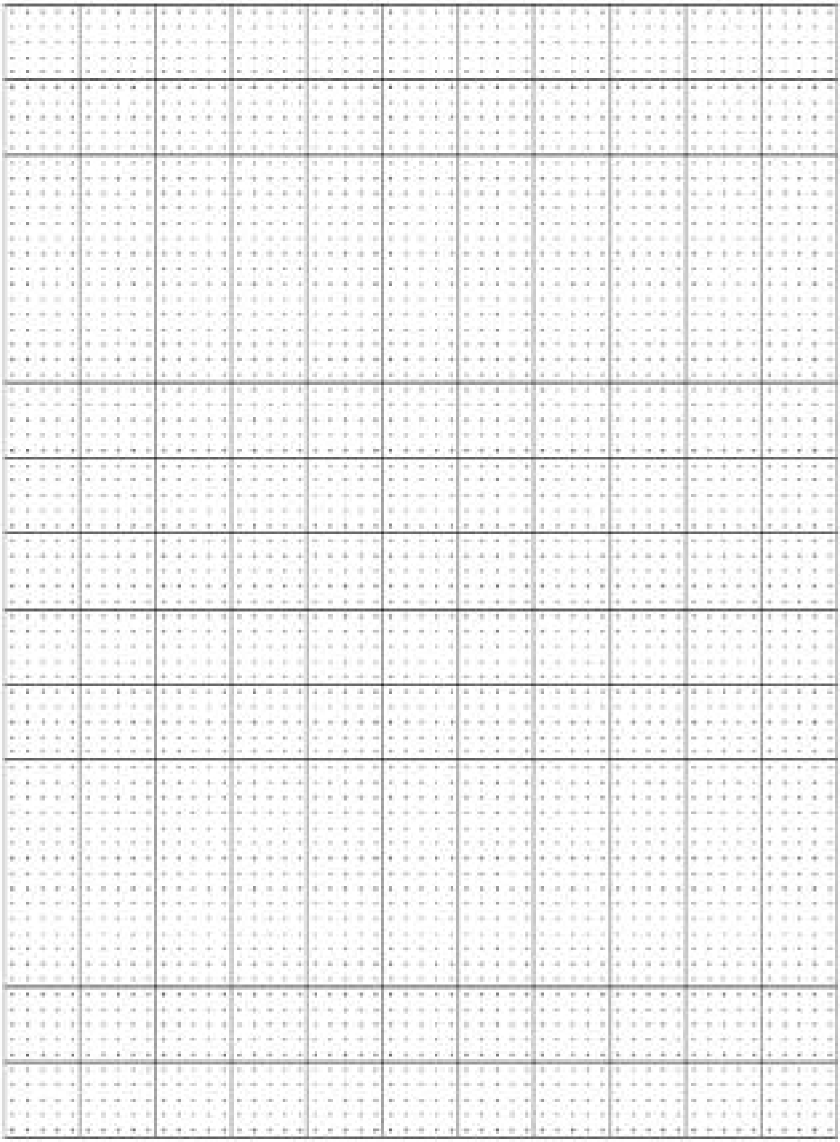
PROPERTY	PADDOCK	DATE
PLOT NUMBER	PLOT SIZE	MEASURED BY:
SPECIES	AGE	OPERATION
SLOPE	ASPECT	COORDINATES (NOTE WHETHER AMG OR GDA)

TREE NUMBER	DBHOB	TOTAL HEIGHT	COMMENTS

Legend: Dot grid for calculation of area

Area (hectares)		
Map scale	**Area/dot**	**Area/square centimetre**
1:10,000	0.04	1.00
1:15,000	0.09	2.25
1:20,000	0.16	4.00
1:25,000	0.25	6.25

3 Appendix: Dot grid for calculation of area



4 Appendix: Slope distance (metres) required to provide specified horizontal distance

SLOPE	HORIZONTAL DISTANCE SPECIFIED (METRES)								
DEGREES	5	7.5	10	12.5	15	17.5	20	22.5	25
5	5.02	7.53	10.04	12.55	15.06	17.57	20.08	22.59	25.10
6	5.03	7.54	10.06	12.57	15.08	17.60	20.11	22.62	25.14
7	5.04	7.56	10.08	12.59	15.11	17.63	20.15	22.67	25.19
8	5.05	7.57	10.10	12.62	15.15	17.67	20.20	22.72	25.25
9	5.06	7.59	10.12	12.66	15.19	17.72	20.25	22.78	25.31
10	5.08	7.62	10.15	12.69	15.23	17.77	20.31	22.85	25.39
11	5.09	7.64	10.19	12.73	15.28	17.83	20.37	22.92	25.47
12	5.11	7.67	10.22	12.78	15.34	17.89	20.45	23.00	25.56
13	5.13	7.70	10.26	12.83	15.39	17.96	20.53	23.09	25.66
14	5.15	7.73	10.31	12.88	15.46	18.04	20.61	23.19	25.77
15	5.18	7.76	10.35	12.94	15.53	18.12	20.71	23.29	25.88
16	5.20	7.80	10.40	13.00	15.60	18.21	20.81	23.41	26.01
17	5.23	7.84	10.46	13.07	15.69	18.30	20.91	23.53	26.14
18	5.26	7.89	10.51	13.14	15.77	18.40	21.03	23.66	26.29
19	5.29	7.93	10.58	13.22	15.86	18.51	21.15	23.80	26.44
20	5.32	7.98	10.64	13.30	15.96	18.62	21.28	23.94	26.60
21	5.36	8.03	10.71	13.39	16.07	18.75	21.42	24.10	26.78
22	5.39	8.09	10.79	13.48	16.18	18.87	21.57	24.27	26.96
23	5.43	8.15	10.86	13.58	16.30	19.01	21.73	24.44	27.16
24	5.47	8.21	10.95	13.68	16.42	19.16	21.89	24.63	27.37
25	5.52	8.28	11.03	13.79	16.55	19.31	22.07	24.83	27.58
26	5.56	8.34	11.13	13.91	16.69	19.47	22.25	25.03	27.82
27	5.61	8.42	11.22	14.03	16.83	19.64	22.45	25.25	28.06
28	5.66	8.49	11.33	14.16	16.99	19.82	22.65	25.48	28.31
29	5.72	8.58	11.43	14.29	17.15	20.01	22.87	25.73	28.58
30	5.77	8.66	11.55	14.43	17.32	20.21	23.09	25.98	28.87
31	5.83	8.75	11.67	14.58	17.50	20.42	23.33	26.25	29.17
32	5.90	8.84	11.79	14.74	17.69	20.64	23.58	26.53	29.48
33	5.96	8.94	11.92	14.90	17.89	20.87	23.85	26.83	29.81
34	6.03	9.05	12.06	15.08	18.09	21.11	24.12	27.14	30.16
35	6.10	9.16	12.21	15.26	18.31	21.36	24.42	27.47	30.52

5 Appendix: Conversion of slope distance to horizontal distance

SLOPE	SLOPE DISTANCE (METRES)										
DEGREES	2	5	10	15	20	25	30	35	40	45	50	100
10	2.0	4.9	9.8	14.8	19.7	24.6	29.5	34.5	39.4	44.3	49.2	98.5
11	2.0	4.9	9.8	14.7	19.6	24.5	29.4	34.4	39.3	44.2	49.1	98.2
12	2.0	4.9	9.8	14.7	19.6	24.5	29.3	34.2	39.1	44.0	48.9	97.8
13	1.9	4.9	9.7	14.6	19.5	24.4	29.2	34.1	39.0	43.8	48.7	97.4
14	1.9	4.9	9.7	14.6	19.4	24.3	29.1	34.0	38.8	43.7	48.5	97.0
15	1.9	4.8	9.7	14.5	19.3	24.1	29.0	33.8	38.6	43.5	48.3	96.6
16	1.9	4.8	9.6	14.4	19.2	24.0	28.8	33.6	38.5	43.3	48.1	96.1
17	1.9	4.8	9.6	14.3	19.1	23.9	28.7	33.5	38.3	43.0	47.8	95.6
18	1.9	4.8	9.5	14.3	19.0	23.8	28.5	33.3	38.0	42.8	47.6	95.1
19	1.9	4.7	9.5	14.2	18.9	23.6	28.4	33.1	37.8	42.5	47.3	94.6
20	1.9	4.7	9.4	14.1	18.8	23.5	28.2	32.9	37.6	42.3	47.0	94.0
21	1.9	4.7	9.3	14.0	18.7	23.3	28.0	32.7	37.3	42.0	46.7	93.4
22	1.9	4.6	9.3	13.9	18.5	23.2	27.8	32.5	37.1	41.7	46.4	92.7
23	1.8	4.6	9.2	13.8	18.4	23.0	27.6	32.2	36.8	41.4	46.0	92.1
24	1.8	4.6	9.1	13.7	18.3	22.8	27.4	32.0	36.5	41.1	45.7	91.4
25	1.8	4.5	9.1	13.6	18.1	22.7	27.2	31.7	36.3	40.8	45.3	90.6
26	1.8	4.5	9.0	13.5	18.0	22.5	27.0	31.5	36.0	40.4	44.9	89.9
27	1.8	4.5	8.9	13.4	17.8	22.3	26.7	31.2	35.6	40.1	44.6	89.1
28	1.8	4.4	8.8	13.2	17.7	22.1	26.5	30.9	35.3	39.7	44.1	88.3
29	1.7	4.4	8.7	13.1	17.5	21.9	26.2	30.6	35.0	39.4	43.7	87.5
30	1.7	4.3	8.7	13.0	17.3	21.7	26.0	30.3	34.6	39.0	43.3	86.6
31	1.7	4.3	8.6	12.9	17.1	21.4	25.7	30.0	34.3	38.6	42.9	85.7
32	1.7	4.2	8.5	12.7	17.0	21.2	25.4	29.7	33.9	38.2	42.4	84.8
33	1.7	4.2	8.4	12.6	16.8	21.0	25.2	29.4	33.5	37.7	41.9	83.9
34	1.7	4.1	8.3	12.4	16.6	20.7	24.9	29.0	33.2	37.3	41.5	82.9
35	1.6	4.1	8.2	12.3	16.4	20.5	24.6	28.7	32.8	36.9	41.0	81.9

HORIZONTAL DISTANCE = SLOPE DISTANCE X COSINE (SLOPE ANGLE)

6 Appendix: Horizontal marginal distances (m) for BAFs

	BASAL AREA FACTOR (BAF)					
DBHOB(CM)	1	2	3	5	7	10
1	0.5	0.4	0.3	0.2	0.2	0.2
2	1.0	0.7	0.6	0.4	0.4	0.3
3	1.5	1.1	0.9	0.7	0.6	0.5
4	2.0	1.4	1.2	0.9	0.8	0.6
5	2.5	1.8	1.4	1.1	0.9	0.8
6	3.0	2.1	1.7	1.3	1.1	0.9
7	3.5	2.5	2.0	1.6	1.3	1.1
8	4.0	2.8	2.3	1.8	1.5	1.3
9	4.5	3.2	2.6	2.0	1.7	1.4
10	5.0	3.5	2.9	2.2	1.9	1.6
11	5.5	3.9	3.2	2.5	2.1	1.7
12	6.0	4.2	3.5	2.7	2.3	1.9
13	6.5	4.6	3.8	2.9	2.5	2.1
14	7.0	4.9	4.0	3.1	2.6	2.2
15	7.5	5.3	4.3	3.4	2.8	2.4
16	8.0	5.7	4.6	3.6	3.0	2.5
17	8.5	6.0	4.9	3.8	3.2	2.7
18	9.0	6.4	5.2	4.0	3.4	2.8
19	9.5	6.7	5.5	4.2	3.6	3.0
20	10.0	7.1	5.8	4.5	3.8	3.2
21	10.5	7.4	6.1	4.7	4.0	3.3
22	11.0	7.8	6.4	4.9	4.2	3.5
23	11.5	8.1	6.6	5.1	4.3	3.6
24	12.0	8.5	6.9	5.4	4.5	3.8
25	12.5	8.8	7.2	5.6	4.7	4.0
26	13.0	9.2	7.5	5.8	4.9	4.1
27	13.5	9.5	7.8	6.0	5.1	4.3
28	14.0	9.9	8.1	6.3	5.3	4.4
29	14.5	10.3	8.4	6.5	5.5	4.6
30	15.0	10.6	8.7	6.7	5.7	4.7
31	15.5	11.0	8.9	6.9	5.9	4.9
32	16.0	11.3	9.2	7.2	6.0	5.1
33	16.5	11.7	9.5	7.4	6.2	5.2
34	17.0	12.0	9.8	7.6	6.4	5.4
35	17.5	12.4	10.1	7.8	6.6	5.5
36	18.0	12.7	10.4	8.0	6.8	5.7
37	18.5	13.1	10.7	8.3	7.0	5.9
38	19.0	13.4	11.0	8.5	7.2	6.0
39	19.5	13.8	11.3	8.7	7.4	6.2
40	20.0	14.1	11.5	8.9	7.6	6.3
41	20.5	14.5	11.8	9.2	7.7	6.5
42	21.0	14.8	12.1	9.4	7.9	6.6
43	21.5	15.2	12.4	9.6	8.1	6.8
44	22.0	15.6	12.7	9.8	8.3	7.0
45	22.5	15.9	13.0	10.1	8.5	7.1

	BASAL AREA FACTOR (BAF)					
DBHOB(CM)	1	2	3	5	7	10
46	23.0	16.3	13.3	10.3	8.7	7.3
47	23.5	16.6	13.6	10.5	8.9	7.4
48	24.0	17.0	13.9	10.7	9.1	7.6
49	24.5	17.3	14.1	11.0	9.3	7.7
50	25.0	17.7	14.4	11.2	9.4	7.9
51	25.5	18.0	14.7	11.4	9.6	8.1
52	26.0	18.4	15.0	11.6	9.8	8.2
53	26.5	18.7	15.3	11.9	10.0	8.4
54	27.0	19.1	15.6	12.1	10.2	8.5
55	27.5	19.4	15.9	12.3	10.4	8.7
56	28.0	19.8	16.2	12.5	10.6	8.9
57	28.5	20.2	16.5	12.7	10.8	9.0
58	29.0	20.5	16.7	13.0	11.0	9.2
59	29.5	20.9	17.0	13.2	11.1	9.3
60	30.0	21.2	17.3	13.4	11.3	9.5
61	30.5	21.6	17.6	13.6	11.5	9.6
62	31.0	21.9	17.9	13.9	11.7	9.8
63	31.5	22.3	18.2	14.1	11.9	10.0
64	32.0	22.6	18.5	14.3	12.1	10.1
65	32.5	23.0	18.8	14.5	12.3	10.3
66	33.0	23.3	19.1	14.8	12.5	10.4
67	33.5	23.7	19.3	15.0	12.7	10.6
68	34.0	24.0	19.6	15.2	12.9	10.8
69	34.5	24.4	19.9	15.4	13.0	10.9
70	35.0	24.7	20.2	15.7	13.2	11.1
71	35.5	25.1	20.5	15.9	13.4	11.2
72	36.0	25.5	20.8	16.1	13.6	11.4
73	36.5	25.8	21.1	16.3	13.8	11.5
74	37.0	26.2	21.4	16.5	14.0	11.7
75	37.5	26.5	21.7	16.8	14.2	11.9
76	38.0	26.9	21.9	17.0	14.4	12.0
77	38.5	27.2	22.2	17.2	14.6	12.2
78	39.0	27.6	22.5	17.4	14.7	12.3
79	39.5	27.9	22.8	17.7	14.9	12.5
80	40.0	28.3	23.1	17.9	15.1	12.6

$$\textbf{Marginal distance (m)} = \frac{\textbf{DBHOB}}{(2\sqrt{\textbf{BAF}})}$$

Where BAF is the basal area factor

7 Appendix: Plot Length

PLOT LENGTH (metres) required given plot width (metres) below for PLOT SIZE = 0.04 hectares

METRES	ADDITIONAL LENGTHS—PER METRES									
PLOT WIDTH	**+0m**	**+0.1m**	**+0.2m**	**+0.3m**	**+0.4m**	**+0.5m**	**+0.6m**	**+0.7m**	**+0.8m**	**+0.9m**
10	40.0	39.6	39.2	38.8	38.5	38.1	37.7	37.4	37.0	36.7
11	36.4	36.0	35.7	35.4	35.1	34.8	34.5	34.2	33.9	33.6
12	33.3	33.1	32.8	32.5	32.3	32.0	31.7	31.5	31.3	31.0
13	30.8	30.5	30.3	30.1	29.9	29.6	29.4	29.2	29.0	28.8
14	28.6	28.4	28.2	28.0	27.8	27.6	27.4	27.2	27.0	26.8
15	26.7	26.5	26.3	26.1	26.0	25.8	25.6	25.5	25.3	25.2
16	25.0	24.8	24.7	24.5	24.4	24.2	24.1	24.0	23.8	23.7
17	23.5	23.4	23.3	23.1	23.0	22.9	22.7	22.6	22.5	22.3
18	22.2	22.1	22.0	21.9	21.7	21.6	21.5	21.4	21.3	21.2
19	21.1	20.9	20.8	20.7	20.6	20.5	20.4	20.3	20.2	20.1
20	20.0	19.9	19.8	19.7	19.6	19.5	19.4	19.3	19.2	19.1
21	19.0	19.0	18.9	18.8	18.7	18.6	18.5	18.4	18.3	18.3
22	18.2	18.1	18.0	17.9	17.9	17.8	17.7	17.6	17.5	17.5
23	17.4	17.3	17.2	17.2	17.1	17.0	16.9	16.9	16.8	16.7
24	16.7	16.6	16.5	16.5	16.4	16.3	16.3	16.2	16.1	16.1
25	16.0	15.9	15.9	15.8	15.7	15.7	15.6	15.6	15.5	15.4
26	15.4	15.3	15.3	15.2	15.2	15.1	15.0	15.0	14.9	14.9
27	14.8	14.8	14.7	14.7	14.6	14.5	14.5	14.4	14.4	14.3
28	14.3	14.2	14.2	14.1	14.1	14.0	14.0	13.9	13.9	13.8
29	13.8	13.7	13.7	13.7	13.6	13.6	13.5	13.5	13.4	13.4
30	13.3	13.3	13.2	13.2	13.2	13.1	13.1	13.0	13.0	12.9

8 Appendix: Australian Stumpage Ranges

	SAWLOG VENEER $/M³		SAWLOG PRIME $/M³		SAWLOG RESIDUAL $/M³		PULP STANDARD $/T	
SW PLANTATION	**LOWER**	**UPPER**	**LOWER**	**UPPER**	**LOWER**	**UPPER**	**LOWER**	**UPPER**
NSW	50	80	40	60	5	15	1	12
QLD	75	120	40	70	12	20	3	16
SA	60	75	30	70	20	25	5	10
VIC	55	85	70	80	20	30	3	10
WA	50	75	45	68	20	45	5	10
TAS	50	85	40	75	20	30	5	10
HW NATIVE FOREST								
NSW	60	110	30	90	8	25	5	18
QLD	NA	NA	40	70	15	25	5	10
SA	NA	NA	NA	NA	NA	NA	NA	NA
VIC	60	90	30	90	10	15	5	12
WA	50	70	45	65	15	30	6	25
TAS	35	70	25	40	15	25	5	22
HW PLANTATION								
NSW	–	–	–	–	17	25	5	20
QLD	–	–	–	–	–	–	–	–
SA	–	–	–	–	–	–	23	29
VIC	–	–	–	–	–	–	4	13
WA	–	–	–	–	–	–	10	25
TAS	–	–	–	–	–	–	5	22

SOURCE: PFT (2001)

Notes

Notes

'I'm measuring the diameter of one of my 14 year old *E. nitens*. The tree is 60cm in diameter at breast height, is 25m tall and is pruned to 6.5m. The total underbark volume is approximately $2.3m^3$ and the volume of the pruned log about $1.3m^3$. I'm aiming to grow the trees out to a diameter at breast height of over 65cm so they yield over $1.5m^3$ of high value sawlog'.

'Being able to measure and monitor growth provides me with the confidence to manage my trees. It ensures that my expectations are realistic and that I am producing the product I want. Farm foresters who are serious about producing timber, or any other product, must be able to monitor performance and assess yields. This excellent manual outlines the techniques, calculations and ways of analysing data in a clear and practical way for farmers who need to know. What's your Diameter at Breast Height?'

Rowan Reid
Australian Master TreeGrower Program
The University of Melbourne

Natural Heritage Trust
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SCIENCE FOR DECISION MAKERS