HANDBOOK

to accompany
“An Australian Standard for Valuing Commercial Forests”
Version 2

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ANNEX 1: Code of Forest Mensuration Practice
PART I    PREAMBLE

1     Introduction

1.1     Introduction and Acknowledgements

Some years ago, the Association of Consulting Foresters of Australia (ACFA) decided to prepare a handbook to be used by members who were involved in determining estimates of the value of forest estates, but various delays were encountered. In the meantime, the New Zealand Institute of Forestry prepared “Forest Valuation Standards” (NZIF 1999), which was used by some in Australia in lieu of a recognised Australian methodology. With the adoption of the Australian Accounting Standards (AAS 35 and AASB 1037) for Self-Generating and Regenerating Assets (SGARA) it became more obvious that there was an urgent need for a more formal methodology and standard for valuing Australia’s forests.

ACFA proposed to develop a forest valuation standard as the first step. The Department of Agriculture Fisheries and Forestry, Australia (AFFA) was able to assist the project with funding support, together with Forest Enterprises Australia Ltd., Timbercorp Ltd., and Gunns Ltd. In 2002 the first draft ACFA document “An Australian Standard for Valuing Commercial Forests” was released for comment. Considerable comment was received from industry, ACFA members, staff of the Australian Accounting Standards Board (AASB), members of the Australian Property Institute (API) representing the Australian Valuation Property and Standards Board, and the Department of Agriculture Fisheries and Forestry (DAFF) Bureau of Rural Sciences (BRS).

The first version of the standard was released in May 2004 (ACFA 2004) and was made publicly available on the web site.

ACFA is greatly indebted to Ian Ferguson, then Professor of Forest Science, University of Melbourne who contributed much to the first version. His efforts as Technical Editor turned this project from a longed-for document into reality.

In mid 2004 the Australian Accounting Standards Board (AASB) decided to adopt international standards as the basis for the Australian accounting standards. It released AASB 141 “Agriculture” replacing AASB 1037 and AAS 35. Interpretation of this new standard was somewhat challenging and ACFA decided to prepare a supplement to the forest valuation standard which was released in January 2005 (ACFA 2005). This was necessary as the standard was operable for reporting periods on or after that date.

By mid 2005 ACFA realised that it was both necessary and feasible to revise the standard to meet the new requirements. ACFA members had long seen the need to also prepare a handbook to accompany the standard, providing useful information and guidance for forest valuers, and setting a sound direction for the future.

Funding was sought from the Forest and Wood Products Research and Development Corporation (FWPRDC), and ACFA is extremely grateful for their financial support which made possible the preparation of the first draft of this Handbook, and also the revised standard. The FWPRDC Project Number was PN06 1031.

Financial support was also received from:
- Forest Products Commission Western Australia,
- Department of Primary Industry Forestry Queensland, now Forestry Plantations Queensland,
- Hancock Victorian Plantations Pty.Ltd.,
- Forest Enterprises Australia Ltd.,
- Integrated Tree Cropping Ltd.,
- Timbercorp Ltd.,
- Auspine Ltd.,

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- Jaakko Pöyry Management Consulting (Asia-Pacific) Pty. Ltd.,
- Chandler, Fraser Keating Ltd.,
- Green Triangle Regional Plantation Committee Inc.,
- Gippsland Private Forestry Inc.,
- Central Victorian Farm Plantation Committee, and,
- Plantations North East Inc.

In return these organisations were provided with the first draft of this document for comment and review. Comments were also sought from ACFA members. Many other public and private forestry organizations have supported the project in principle.

In developing the forest valuation standard ACFA was very grateful to receive the cooperation of the New Zealand Institute of Foresters (NZIF) who made their “Forest Valuation Standards” (NZIF 1999) freely available for ACFA’s use.

ACFA wishes to acknowledge the continuation of this trans-Tasman cooperation and the kindness of the New Zealand Institute of Forestry (NZIF) for their permission to base the Australian forest valuation standard and this handbook on their work. We especially wish to acknowledge the assistance of Professor Bruce Manley as Convenor of the NZIF Forest Valuation Working Party. ACFA hopes that eventually, as both Australia and New Zealand adopt the international accounting standard, one document may suffice for both countries. ACFA believes however that for convenience two separate documents will be appropriate for quite a number of years.

In preparing this handbook ACFA has unashamedly utilised a lot of their good work and we are very grateful for their formal permission, provided again in December 2004, to continue to do so.

Staff of the Australian Accounting Standards Board provided considerable assistance in the development and the revision of the standard and the ACFA interpretation of AASB 141 in this Handbook owes much to their assistance and help. ACFA are especially indebted to the Technical Director, Mr Angus Thomson, and to various Project Officers including Mr Robert Keys, Mr Mark Shying, Ms Monique Leddard, Ms Aletta Boshoff and Ms Joanna Spencer.

Research Working Group No.2 (Forest Measurements and Information Systems) (RWG2), a group responsible to the Forest and Forest Products Committee (FFPC) of the Primary Industries Standing Committee and Ministerial Council, is the Australian and New Zealand Group with special technical expertise on forest mensuration and management, and also forest valuation. Its members have provided comments and assistance to ACFA in the preparation of both the standard and also this Handbook.

Dr Geoff Wood of RWG2 and the Australian National University initiated a code of good forest measurement practice that was completed by Dr Brian Turner and Dr Cris Brack. This code “Code of Forest Mensuration Practice: A guide to good tree measurement practice in Australia and New Zealand” (RWG2 1999) is an invaluable guide. It is reproduced with the kind permission of Dr Brack and RWG2 as Annex 1.

ACFA is grateful to acknowledge permission to copy and publish the Langsæter and Möller figures, and permission by Dr Cris Brack to reprint excerpts from his published works. Permission of the Centre for Agricultural and Biosciences International (CABI) to use some definitions and the accuracy figure from the book by Professor Jerome Vanclay (Vanclay 1994) is also gratefully acknowledged.

ACFA also wishes to acknowledge the contributions of its Forest Valuation Sub-committee members including Mr Hamish Crawford, Mr Gerry Cross, Mr Tony Fearnside, Mr Braden Jenkin and Mr Gerard Moore who, with their sub-committee coordinator and Technical Editor for this first version of the handbook, Dr Jerry Leech, have made this handbook become a reality.

Others who have contributed to, or have reviewed, various sections include Mr Chris Borough, Ms Maree Candish, Mr Mike Colley, Emeritus Professor Ian Ferguson, Mr Eric Keady, Mr Phil Lloyd, Professor Bruce Manley, Mr Gerard Moore, Dr John Turnbull, Dr Brian Turner, Mr David Wettenhall, Professor Jerome Vanclay and Mr Ferdinand Zito.

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The chapter on proprietary systems was prepared by ACFA and, in the case of the major systems, the major contact people noted were invited to comment. It is believed that all comments raised by them have been addressed, and ACFA is grateful for their help in describing their products. ACFA especially wish to thank Dr Kerrie Catchpoole, Mr Andrew Gordon, Mr Colin Hannah, Mr Doug Jones, Dr Marks Nester, Mr Brian Rawley, Mr Martin Strandgard, Mr Simon Walker, Mr Andrew Warner and Mr Ian Wild.

Dr Steve Candy and Dr Christopher Dean reviewed the sections on the models they developed to ensure that the ACFA interpretation is as correct as possible.

In 2007 ACFA became the Association of Consulting Foresters of Australia Division of the Institute of Foresters of Australia, still retaining the Acronym ACFA, and still retaining the overall control of the forest valuation standard and this handbook.

1.2 Procedures for control and update of this handbook

ACFA has established a subcommittee charged with the ongoing enhancement and maintenance of the Forest Valuation Standard and also this Handbook.

The subcommittee will comprise the President of ACFA as Chairman, a Coordinator, and generally three members.

The procedure for adopting any changes to both the Standard and this Handbook is as follows.

- The sub-committee will discuss and agree on proposed changes, consulting as widely as it deems appropriate.
- The proposed changes will be forwarded to the Executive Committee of ACFA and any interested parties for further discussion and comment.
- If necessary the sub-committee will modify the proposed changes.
- These proposed changes will be circulated to all ACFA members for comment, unless they are minor editorial or formatting changes.
- Comments will, of course, be considered, but under the constitution of ACFA it is the Executive Committee which has the responsibility of approving any changes. If the changes are considered by the Executive Committee to be of such moment or importance then the Executive Committee may deem it appropriate that the proposed changes be put to a General Meeting of ACFA.

When the Executive Committee has approved the proposed changes that version will be placed on the web site and all members will be informed of its replacement by the President and/or Business Manager.

The version on the web site at any stage will be date stamped.

One has only to look at the Forestry Handbook (Society of American Foresters 1955) to see how dramatically a professional subject can change over half a century and to see that it is necessary for any handbook, and also any standard, to be continually updated and maintained.

1.3 Scope of the Handbook

This Handbook is designed to be read in conjunction with the forest valuation standard developed by the Association of Consulting Foresters of Australia (ACFA 2004) “An Australian Standard for Valuing Commercial Forests” as revised as part of this project in conjunction with FWPRDC as (ACFA 2007) “An Australian Standard for Valuing Commercial Forests: Version 2”. It is not designed to be a complete document in itself but rather a useful practical reference source that includes the information desirable to assist professionals who already have some skills in carrying out forest
valuations. It is aimed at assisting professional foresters. It is not a text book, nor a detailed summary of all the professional literature.

This Handbook assumes a basic knowledge of the subject.

1.3.1 Australian Forestry Standard AS4708

This interim AS4708 standard was prepared by the Australian Forestry Standard Technical Reference Committee which is constituted as a technical committee under the Standards Development Organisation.

Three supplements have been provided; for medium and large native forest ownerships, for medium and large plantation ownerships, and for small native forest and plantation ownerships.

The Australian Forestry Standard (AS4708) is available from the web site:

www.forestrystandard.org.au

and can be downloaded as Acrobat .pdf files.

The standard is also available in hard copy format from
The Australian Forestry Standard Project Office
GPO Box 858
Canberra ACT 2601
or from
Standards Australia
GPO Box 5420
Sydney NSW 2001

A check through the standard and the supplements could not find any references to forest valuation or to any methodologies and standards that should be applied.

At this stage, this Australian Forestry Standard, AS4708, does not appear to provide meaningful detailed assistance on this important topic of forest valuation.

1.4 Disclaimer

This Handbook does not purport to be and is not to be deemed professional advice given by the Association of Consulting Foresters of Australia, or any member of the association, or the Forest and Wood Products Research and Development Corporation, or any member or levy payer of that corporation.

It must not be relied on as the basis for any decision to take action on any matter including, but not limited to, those to which it refers directly and/or indirectly. Readers must make their own enquiries and obtain professional advice before making any decisions.

While every care has been taken and effort made to ensure that the contents of this Handbook are correct, neither ACFA nor its members shall be held responsible for, nor shall they accept any responsibility allegedly arising from, the use of any of the details or methods described herein. Users must either rely on their own professional judgement, or seek expert advice, about the relevance of any procedure referred to in this Handbook to any particular set of circumstances and/or generally.

Where particular example models are cited in this Handbook great care must be taken to ensure that they are correctly interpreted and/or applied in this Handbook. Even greater care must be taken by the user to determine their appropriateness for the circumstances where it is planned to use them. Models presented might be deemed appropriate for particular circumstances but inappropriate for others.
1.5 Use of this Handbook

Material from the ACFA forest valuation standard “An Australian Standard for Valuing Commercial Forests”, any Supplement issued, and also this Handbook, may be reproduced and may be freely used provided due acknowledgement is given to ACFA as the source.

The material may not be sold for any purposes whatsoever without the formal written approval of the President of the Association of Consulting Foresters of Australia.

The preferred method of citing this document is:


or


1.6 Feedback is invited

Comments on this document are welcomed and should be sent to:

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ACFA propose to maintain this document and to keep a date stamped, current version on the web site:

www.australianconsultingforesters.org

and, of course, it is not only comments that are desired, but examples of techniques, models, and data that are in the public domain, as this is the only way the Handbook can be kept current.
PART II ACRONYMS AND GLOSSARIES

2 Acronyms and Glossaries

Although this Handbook is primarily designed for Australian use there is a necessity to include some New Zealand terms for completeness. This is partly because the MARVL method of forest inventory developed in New Zealand is commonly used in Australia and partly because this may facilitate a possible longer term objective of a unified trans-Tasman approach to forest valuation. Where appropriate the differences are highlighted and explained.

2.1 General acronyms

2BT, 2bt Double Bark Thickness.
AASB Australian Accounting Standards Board.
ABS Australian Bureau of Statistics.
ACCC Australian Competition and Consumer Commission.
ACFA Association of Consulting Foresters of Australia.
AFFA Agriculture, Fisheries and Forestry Australia.
AGD Australian Geodetic Datum.
ANU Australian National University.
AMG Australian Map Grid.
API Australian Property Institute, which can generally be discriminated by the manner of its use from,
APNPI Australian Pine Log Price Index.
ASIC Australian Securities and Investments Commission.
ATO Australian Taxation Office.
AURISA The Australian Urban and Regional Information Systems Association, now replaced by SSI.
AV&PSB Australian Valuation and Property Standards Board
BAF Basal Area Factor.
BLUE Best Linear Unbiased Estimate.
CABI Centre for Agricultural and Biosciences International.
cai Current Annual Increment, more properly called periodic annual increment (pai), the average increment over a finite period.
CAPM Capital Asset Pricing Model (used to determine discounting factors).
cdf Cumulative Density Function.
CRI Continuous Forest Inventory.
CPV Certified Practising Valuer, a member of the API.
CRC Cooperative Research Centre.
CRES The Centre for Resource and Environmental Studies of the Australian National University (developer of ANUCLIM).
CSIRO          Commonwealth Scientific and Industrial Research Organisation.
CSIRO FFP      CSIRO Division of Forestry and Forest Products, changed in 2005 to ENSIS.
CPI            Consumer Price Index.
D, d           Diameter.
DAFF           Department of Agriculture, Fisheries and Forestry, formerly AFFA, Agriculture, Fisheries and Forestry Australia.
DBHOB          Diameter at Breast Height (1.3 m in Australia 1.4 m in New Zealand) Over Bark.
DBH             As for DBHOB.
DBHUB          Diameter at Breast Height (1.3 m in Australia 1.4 m in New Zealand) Under Bark.
DBHIB          Diameter at Breast Height Inside Bark (see DBHUB).
DEM            Digital Elevation Model.
DIB            Diameter Inside Bark.
DOS            Diameter Over Stubs for pruned trees.
DPIF           Department of Primary Industries, Forestry in Queensland, also DPI Forestry, now Forestry Plantations Queensland.
FASB           Financial Accounting Standards Board of the United States of America.
FFPC           Forestry and Forest Products Committee of the Primary Industries Standing Committee and Ministerial Council.
FOB            Free On Board.
FPCWA          Forest Products Commission of Western Australia.
FRNZ           Forest Research New Zealand, changed in 2005 to SCION.
FWPRDC         Forest and Wood Products Research and Development Corporation.
GIS            Geographic Information System.
GPS            Global Positioning System.
GST            Goods and Services Tax.
H&BU           Highest and Best Use
IASB           International Accounting Standards Board.
ICAA           The Institute of Chartered Accountants in Australia.
IEMSA          The Institution of Engineering and Mining Surveyors, Australia.
IFRIC          International Financial Reporting Interpretations Committee.
IFRSB         International Financial Reporting Standards Board.
ILFR           Institute of Land and Food Resources, University of Melbourne. Includes the Forestry section. Renamed the Faculty of Land and Food Resources in January 2005.
IRR            Internal Rate of Return.
ISA            The Institution of Surveyors, Australia.
IUFRO          International Union of Forest Research Organisations.
JAS            Japanese Agricultural Standard (includes a log measurement method).
LED            Large End Diameter.
LVL            Laminated Veneer Lumber, constructed from wood veneer.
mai  Mean Annual Increment, the average increment over the current life of any forest stand.
MCH  Mean Crop Height.
MDH  Mean Dominant Height, the mean height of the largest diameter trees.
MIS  Managed Investment Scheme, which can generally be discriminated by the manner of its use from,
MIS  Management Information System.
MSE  Mean Square Error, a measure of accuracy.
MSIA The Mapping Sciences Institute of Australia.
MTDBH Mean Top Dbhob.
MTH  Mean Top Height.
MV   Market Value.
NMV  Net Market Value.
NPV  Net Present Value.
NZ   New Zealand.
NZIF New Zealand Institute of Forestry.
pai  Periodic Annual Increment, the average increment of a finite period.
PC   Productivity Commission.
PMH  Predominant Mean Height.
pdf  Probability Density Function.
PDH  Predominant Height, the mean height of the tallest trees.
PII  Professional Indemnity Insurance.
PLE  Probable Limits of Error.
PLI  Public Liability Insurance.
PV   Present Value.
RSPAA The Remote Sensing and Photogrammetry Association of Australasia.
RWG2 Research Working Group No.2 (Forest Measurements and Information Systems).
RWG3 Research Working Group No.3 (Land and Water Resources, formerly Forest Soils and Nutrition).
SAF  Society of American Foresters.
SAPFOR South Australian Perpetual Forests, an early forestry investment company now incorporated into Auspine Ltd.
SED  Small End Diameter.
SEDIB Small End Diameter, Inside Bark.
SEDOK Small End Diameter, Outside (or Over) Bark.
SEDUB Small End Diameter, inside (or Under) Bark.
SFNSW State Forests New South Wales; renamed Forests NSW when merged on 1 July 2004 into the NSW Department of Primary Industries.
SFRI  Victorian Statewide Forest Resource Inventory.
2.2 Systems and organisational acronyms and names

3-PG Physiological Processes Predicting Growth (CSIRO FFP).

Acrobat A very general text formatting package, with a reader freely downloadable from Adobe. The .pdf format provides a way text and other files can be freely transmitted while preserving original integrity.

ANUCLIM A spatial bio-climatic modelling package (Australian National University).

Atlas A suite of software products developed by Forest Research New Zealand for all aspects of forest management, including:
- Atlas FieldMan for inventory data entry,
- Atlas Cruiser for inventory, replacing MARVL,
- PSPDC for field data entry of permanent plot information,
- PSP for management of permanent plot information,
- Atlas GeoMaster for interfacing to spatial information,
- Atlas Yield Table Manager for managing the yield tables,
- Atlas ForeCaster for stand predictions, replacing Standpak,
- Atlas SilviQC for quality control of silvicultural operations,
- Atlas MarketSupply for 1-8 week operational harvesting management and planning,
- Atlas HarvestPlan for up to 3 year operational planning,
- Atlas TactiPlan for up to ca 9 year tactical planning,
- Atlas StratiPlan for up to ca 50-90 year strategic planning,
and a number of other products for roading, harvesting, contracting, and sawmill simulation.

BIOCLIM A component of ANUCLIM.

CSP Carbon Sequestration Predictor (Forests NSW).

C-WHIZ A general purpose linear simplex optimiser (Ketron Management Science).

FFT Farm Forestry Toolbox (Private Forests Tasmania).
FOLPI  Forestry Oriented Linear Programming Interface (Forest Research New Zealand) to be replaced by Atlas.

FORPLAN  Forestry Planning system (USDA Forest Service).

FORSIGHT  Forestry optimisation system.

FullCAM  Full Carbon Accounting Model (Australian Greenhouse Office, Department of Heritage and Environment).

IFS  Interactive Forest Simulator (Forest Research New Zealand, now Scion) to be replaced by Atlas.

LINDO  Optimisation software that can solve linear programming, integer programming and non-linear programming models, and also has an Excel add-in (Lindo Systems Inc.)

MARVL  Methodology of Assessment of Recoverable Volume by Logs (Forest Research New Zealand, now Scion). Variously the methodology of the inventory or the system to process that inventory.

MOSEK  An optimisation system that can interface with many other packages and systems (Mosek Aps).

PLYRS  Plantation Yield Regulation System (ILFR, University of Melbourne).

PROPHECY  Blue gum plantation planning and management tool (ILFR, University of Melbourne).

Standpak  Stand evaluation package (Forest Research New Zealand, now Scion).

STEPS  Software Tools for Evaluating Plantation scenarios (Forestry Plantations Queensland).

YTGen  Yield Table Generator (Silmetra, New Zealand).

2.3  Glossary of forestry terms

A number of these terms have been adapted from the NZIF Forest Valuation Standard (NZIF 1999). ACFA acknowledges the kind permission of the NZIF to use their work as a base and acknowledges that the NZIF is in no way responsible for any of the definitions presented here.

Abbreviations  See sections 2.1 General Acronyms, 2.2 Systems and organisational acronyms and names, and 2.6 IUFRO Symbols.

Appearance grades  Grades of wood, the major value of which is in its appearance as distinguished from its structural value. Commonly from clearwood and higher quality logs.

Area  The geographical or geo-spatial extent of a forest. Generally measured in hectare (ha) and generally measured as the projection on a flat un-tilted plane facilitating mapping. Area is two dimensional.

Arisings  Logs which are by-products to the major value components of the tree stem. Generally used for the production of pulp or reconstituted board products. The term is more commonly used in New Zealand.

Basal area  The sum of the stem cross sectional area at breast height over bark of all trees growing on one hectare. A parameter used in inventory, and growth and yield estimation and expressed in square metres per hectare. A simple formula for the i'th tree is
$BA \, (m^2/ha) = 0.00007854 \times DBH^2 \, (cm)$

where 0.0007854 is based on $\pi/40000$, and for a stand this is summed across all trees

$BA = \sum (BA)$

or $BA = BA \times SPH$.

Bark thickness

The radial distance from the cambium to the outer bark. Generally referred to as double bark thickness (2bt), to facilitate conversion from over bark to under bark diameter.

Breast height

Refers to the usual point of measurement of standing tree or stem diameter (1.3 m in Australia, 1.4 m in New Zealand) above ground on the uphill side of the tree.

Butt log

The log directly above the stump. This is the biggest diameter log and usually has the greatest unit value of all the logs in a tree. If the tree has been pruned this log will contain most of the available clearwood in the tree.

Chips

Wood in the form of small fragments and generated either in a whole tree chip mill or as a by-product of the manufacture of lumber or plywood and used in the manufacture of pulp and paper and various composite panel products such as medium density fibreboard, particle board and hardboard.

Clear felling

The practice of felling all the trees in a given area.

Clearwood

Wood showing no (or negligible) defects caused by knots, resin pockets or mechanical damage and usually displaying straight and even grain patterns. Clearwood is usually found in all trees in small amounts. Pruning aims to enable the growth of additional amounts, especially in longer lengths.

Clonal forestry

The practice of plantation forestry using tested clones as the planting stock. The clones are selected to meet predefined forest management objectives.

Clone

A group of individuals having identical genetic characteristics. Typically produced by cuttings or tissue culture.

Compartment

A generally contiguous area within a forest defined or recorded on a map. Used as the basic unit of forest record or description. Usually contains stands which are referenced with respect to the compartment.

Coppice

Multiple stems growing from a stump after felling the main bole of the tree. Commonly a method of regenerating some Eucalyptus species.

Crop tree

Any tree harvested for the production of wood fibre.

Croptype

An aggregation of stands; typically for the purpose of recording, analysis, and forest management. The aggregation parameters will vary depending on the purpose of the groupings, but single croptypes will generally be composed of trees of identical species that have similar growth and yield patterns and will have experienced similar silvicultural treatment. More commonly, but not solely, a New Zealand term.

Cubic metre (m$^3$)

A measure of volume; generally true volume under bark.
Cull tree
A tree which because of some major defect or defects will be selectively removed (usually to waste) at some point during the rotation.

Cuttings
Small trees grown from small twigs in a nursery for planting out to establish a plantation. See also Seedlings.

Dbh, Dbhob
Diameter at breast height over bark and commonly used in acronym form. Usually expressed over bark, hence Dbh and Dbhob are commonly equivalent terms.

Defect core
The central core of a pruned tree outside of which the clearwood is laid down and which contains pith, branch stubs and occlusion defects. Defined in terms of DOS, diameter over stubs.

Diameter breast height
See Dbh, Dbhob, also may be abbreviated to d.

Diameter over stubs (DOS)
The diameter over the largest diameter whorl of branch stubs left on a tree stem immediately after pruning (the largest diameter circle of stubs is also called the ‘largest pruned whorl’). Usually occurs at the first pruning operation and therefore is in the butt log.

DOS height
The distance (generally to the nearest 0.1 m) from ground level to the largest pruned whorl in a pruned log.

Dump
See skid site.

Epicormic
A shoot coming from the tree, too small to be classified as a branch and not within a whorl. Common in Eucalyptus species after a fire. It can also occur in pines when needles grow directly from the stem, generally at very early ages but it can also occur at late ages.

Even aged
Forest stands composed of trees of equal age. In native forest generally defined as approximately equal age.

Exotic
A species not endemic to an area (but more generally a region or country). See the antonym indigenous.

Final crop tree
A tree expected to remain in the stand until the stand is clear felled.

Forest
An area of land fully or partially occupied with growing trees. Often it is more rigidly defined. One common (but not universal) definition is an area that is dominated by trees, usually single stems, and a mature or potentially mature dominant height of over 5 m, and which has a projected foliage cover greater than 30%.

Forestry right
A term to describe the right granted by the owner or lessee of land to another person enabling that other person to establish, manage, protect and harvest, or simply to manage, protect and harvest, trees on the land. A number of Australian states have developed legislation on forestry rights and it may be necessary to consider the relevant state legislation.

Framing lumber
Grades of lumber suitable for structural purposes in buildings and for other load bearing applications. Appearance is not a prime consideration and accordingly, subject to adequate or
specified strength and stiffness requirements, framing lumber may show knots and other grain imperfections.

**Freehold**
An estate in fee simple in land.

**Girth**
The measurement around the stem of a tree or log. A diameter tape measures girth and converts this to the equivalent diameter assuming the tree or stem is circular. Synonymous with the term circumference.

**Ground level**
In forestry this is the surface of firm, mineral soil (underneath the litter) but when the surface is sloping refers to the soil level on the uphill side of the stem of the tree.

**Hardwood**
Tree species which are angiosperms (flowering plants) and whose wood structure contains vessels and tracheids. Often refers to broad-leafed species. Also used for the wood from such species. It does not mean that the wood is necessarily hard. See softwood for comparison.

**Harvesting**
The processes of felling, in-forest processing, and transport of logs to either a skid site or ay extend to the loading and cartage of logs to any site outside the forest: also called logging.

**Hectare (ha)**
The most common forestry measure of area. Defined as 10 000 square metres (approximately 2.471 acres).

**Hog fuel**
Residues from sawmills and other production units, usually containing a high proportion of bark and not able to be used in any other process, used as boiler fuel. Sometimes subject to a mechanical breakdown process (called hogging in New Zealand especially) before use.

**Increment**
The arithmetic difference between a forest, tree or stand characteristic at different points in time. The time differences are usually annualised.

**Indigenous**
Naturally occurring or native to a particular area or region. In a more strict botanical sense it generally relates to species occurring in that particular natural situation prior to any human influence. In Australia it is often used in a mildly confusing sense in that a species can be indigenous to south west Western Australia (for example karri) but is strictly speaking exotic if planted in eastern Australia, although it is commonly referred to as a plantation of an indigenous species as it is found naturally in Australia.

**Indigenous forest**
See natural forest.

**Laminated veneer lumber (LVL)**
Equivalent product to lumber but constructed from veneers in which the direction of each layer is generally along the product. It contrasts with plywood where alternative layers are generally at right angles to one another.

**Landing**
An area of land in the forest, often specially prepared and surfaced, where logs or tree lengths extracted from the forest are accumulated and further processed by trimming, cutting to length (sometimes called bucking), sorting, marking and stacking, and thereafter loaded onto trucks for removal. The term landing
is more commonly used for conventional harvesting systems and skid site for cable logging systems.

Large end diameter (LED)
Used in log measurement to measure the large end of a log. Usually refers to an under bark measurement.

Leasehold
An estate in land granted by the owner of the freehold to another person or organisation which usually gives the right of exclusive possession and use of the land to that person or organisation for a specific number of years.

Log
Merchantable lengths of the tree stem to be selected at harvesting. The raw material from which lumber, plywood, pulp wood or other wood products are prepared. Always refers to produce after felling.

Logging
See Harvesting.

Lumber
Any wood reduced by sawing or other mechanical means, generally to a square or rectangular section and frequently dried, planed or given treatment against borer, insect and/or fungal attack.

Mean crop height (MCH)
The mean height of the crop trees. More commonly used in New Zealand.

Mean dominant height (MDH)
The mean height of largest diameter trees per hectare. Commonly defined as the mean height of the largest 40, 50, 75 or 100 trees/ha. In Australia the definition of selection criteria may differ between forest enterprises but the various definitions generally provide close to compatible estimates of upper stand height. See predominant height (PDH).

Mean top dbh (MTDBH)
More commonly used in New Zealand than Australia and used in MARVL inventory. The quadratic mean of the largest 100 trees (by diameter or dbhob) per hectare. If the stocking is less than 100 trees per hectare then the mean is of all trees. See quadratic mean diameter. The base number of 100 may be varied in Australian use.

Mean top height (MTH)
More commonly used in New Zealand than Australia. The height is generally predicted by reading from the Pettersen curve (a model of tree height plotted against tree diameter) for a Dbhob corresponding to the mean top dbh (MTDBH). In Australia this term is used in what is commonly called a MARVL inventory but the number of trees may not necessarily be set at 100.

Mensuration
The theory and practice of measuring standing trees and logs to determine yields and other parameters.

Merchantable
Defines forest products for which there is a commercial market. A product may be merchantable even if its optimum sales value has not been reached.

Merchantable volume
See merchantable yield.

Merchantable yield
The total quantity of merchantable wood (usually expressed in volume and subdivided into various log products present in the total) recovered (or expected to be recovered) from an area of trees.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi aged</td>
<td>Stands that include trees of different ages.</td>
</tr>
<tr>
<td>Natural areas</td>
<td>Areas of land with a predominant cover of indigenous tree species.</td>
</tr>
<tr>
<td>Natural forest</td>
<td>Areas of land which are predominantly covered in indigenous tree species that are usually naturally established, including managed indigenous forest areas where regeneration may be supplemented by planting indigenous species. Contrast with plantation forest.</td>
</tr>
<tr>
<td>Natural regeneration</td>
<td>Usually this means trees or tree seedlings that have naturally regrown from seed deposited by trees (which may have been clear felled) or regrown by other vegetative means such as suckering or coppice.</td>
</tr>
<tr>
<td>Net stocked area</td>
<td>The area of land currently occupied by the tree crop.</td>
</tr>
<tr>
<td>Outturn</td>
<td>The ratio or quantum of forest produce derived from a process.</td>
</tr>
<tr>
<td>Occlusion</td>
<td>The process in a tree stem whereby new healthy tissue grows over and covers stem wounds, branch stubs, etc. This process may also enclose small bark or resin pockets associated with the wound and called occlusion defect.</td>
</tr>
<tr>
<td>Peeler log</td>
<td>A log suitable for production of wood veneers by rotary peeling on a lathe or by slicing. See also veneer log.</td>
</tr>
<tr>
<td>Piece size</td>
<td>The size parameters (volume weight or dimension) of a single log. Average piece size is a useful parameter to indicate the size and power of equipment required for harvesting or sawmilling or any aspect of utilisation.</td>
</tr>
<tr>
<td>Plantation forest</td>
<td>Areas of land predominantly covered in trees grown for cropping and managed for commercial purposes. There may be specific, more detailed, and more rigidly defined definitions appropriate under specific circumstances.</td>
</tr>
<tr>
<td>Planting stock</td>
<td>The plant material used for planting, including seedlings and plantlets. See tree stock.</td>
</tr>
<tr>
<td>Plantlets</td>
<td>A plant produced by micropropagation.</td>
</tr>
<tr>
<td>Plywood</td>
<td>A flat panel made up of thin sheets or veneers in which the direction of each layer is generally at right angles to the one adjacent to it.</td>
</tr>
<tr>
<td>Point sample</td>
<td>A form of sampling with probability of selection being proportional to size using a horizontal various radius plot defined by a central point and an angle gauge.</td>
</tr>
<tr>
<td>Predominant height (PDH)</td>
<td>The mean height of tallest trees per hectare. Commonly defined as the mean height of the tallest 40, 50, 75 or 100 trees per hectare. In New Zealand the predominant tree is the tallest tree on an area of 0.01 ha and the mean is the mean height of at least 4 predominant trees. In Australia the definition of selection criteria may differ between forest enterprises but the various definitions generally provide close to compatible estimates of upper stand height. See mean dominant height (MDH). Called predominant mean height (PMH) in New Zealand.</td>
</tr>
</tbody>
</table>
Prescription
The specification for the treatment of a growing forest (for example silvicultural or harvesting prescription) with particular reference to tree sizes, or ages, and treatments to be applied.

Pruned height
The height above ground level of the lowest remaining whorl of branches remaining after the last pruning operation.

Pruned log
A large higher quality log containing substantial proportions of clearwood. Used primarily in the veneer and plywood industries and in the production of clearwood lumber for furniture and higher value end uses of sawn product.

Pruned log quality
See the NZ Forest Valuation Standards for a more detailed description of specific measures of pruned log quality in New Zealand.

Pruning
The silvicultural practice of removing the lower branches of a tree by mechanical means while the tree is still young to eliminate or prevent the formulation of knots and the deformation of the grain of the wood subsequently grown. A silvicultural strategy to grow clearwood.

Pruning intensity
Defined as the ratio of mean pruned height to mean crop height and is generally expressed as a percentage:

\[
\frac{\text{mean pruned height}}{\text{mean crop height}} \times 100.
\]

Pulp log
A generally lower grade log used as fibre input for the production of pulp and paper and reconstituted wood products.

Quadratic mean diameter
The statistic mean tree diameter is only very rarely used in forestry. Instead the quadratic mean diameter is used. This is the diameter corresponding to mean basal area, the square root of the mean of the tree basal areas. Thus

\[
d = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}}
\]

Recoverable yield
The amount of wood, usually expressed as volume of round logs, produced from a stand during a harvesting operation.

Regime
A complete programme of silvicultural operations covering the stand rotation, directed towards the creation of a specific mix of forest products.

Relative spacing index
An expression of the average distance between trees in a stand relative to the mean tree crop height. Relative spacing is generally expressed as a percentage. Defined as

\[
\text{RS\%}=\frac{100000}{\text{MTH(m)} \times \sqrt{\text{Stocking(SPH)}}}
\]

The term is more commonly used in New Zealand than Australia.

Residue
The amount of wood left on the ground after harvesting. Some residue is simply waste that cannot be recovered, some because economic conditions preclude sale at the current time, and some because of poor harvesting practice. Sometimes residue includes wood harvested as fuel wood, sometimes it does not. When the term is used it generally needs to be rigorously defined.

Roundwood
All wood in log form, but more specifically used as a general term for posts and poles.
Rotation
The span of years in which a stand of trees grows from planting through to clear felling. Usually has an economic connotation in that the rotation length is commonly optimised to a set of economic criteria.

Sawlog
A log used in the sawmilling industry to produce a range of products.

Seedlings
Small trees grown from seed in a nursery for planting out to establish a plantation. See cuttings.

Selection ratio
The ratio of the number of trees available for selection for an operation to the number of trees to be selected.

Silviculture
The practice of cultivating and tending forest crops based on the knowledge of forestry; more particularly managing all aspects of the establishment, composition and growth of forests, but excluding harvesting and subsequent operations.

Site class
An objective classification of site productivity into several classes.

Site Index (SI)
A measure of the productivity of a forest site expressed in terms of the height attained by a base age. See site potential, site quality.

Site potential
A measure of the productivity of a forest site. See site index, site quality.

Site Quality (SQ)
A measure of the productivity of a forest site expressed in terms of the volume attained by a base age. See site potential, site index.

Skid site
An area of land in the forest, often specially prepared and surfaced, where logs or tree lengths extracted from the forest are accumulated and further processed by trimming, cutting to length (sometimes called bucking), sorting, marking and stacking, and thereafter loaded onto trucks for removal. The word skid refers to the (now generally discontinued) practice of pushing or rolling logs up an inclined plane for loading onto trucks, or to the dragging (skidding) of logs to the skid site. The term landing is more commonly used for conventional harvesting systems and skid site for cable logging systems. Dump is also a widely used term but it can have many other implications.

Softwood
Usually refers to the wood from the botanical groupings including coniferous trees, gymnosperms (non flowering plants), usually with needles or scale like leaves, and including pines, firs, spruces, and similar genera. See Hardwood for comparison.

Solid wood
Wood (usually sawn, sliced or peeled) which is used in its natural form and not reconstituted by pulping, chipping or other processes.

Species
A group of animals or plants subordinate in classification to genus and generally having some members that can interbreed and that differ only in relatively minor detail.

Stand
An area of trees (generally contiguous but not necessarily so) and, if plantation, generally of the same age, species and stand
Stem
The major vertical structural member of a tree, the trunk or bole of the tree.

Stocking
See also stems per hectare (SPH). Generally the number of living trees on a hectare of forest. Sometimes defined in terms of basal area or volume but more commonly in terms of number of trees.

Stems per hectare (SPH)
The number of live trees existing on one hectare. May also be compounded as in Crop SPH, Pruned SPH or SPH > 20cm dbhob.

Stratum
A subdivision of a population which is more homogeneous with respect to the variable of interest than the population as a whole. The basic spatial entity for stratified random sampling. The plural is strata.

Stumpage
The value of the standing tree when at the stump. Usually expressed in value per cubic metre (or tonne). Generally derived by the sale value of the logs at the sale point (for example ‘Mill Door’ or ‘at Wharf gate’ or ‘on Skid’ by deduction of all the costs incurred in getting then tree off the stump to that point of sale. Compares with Royalty which may be the same value but is the value as sold at the stump.

Sustainable management
The management of a forest in a sustainable manner. Specific detailed definitions may apply in various different circumstances and may even be somewhat contradictory. See also the NZIF Forestry Valuation Standards for their explicit definition under the New Zealand’s Resource Management Act (1991). Different states in Australia have slightly different environmental sustainable forest management principles and definitions and it may be necessary to determine exactly what definition to use.

Sustainable yield
The annual yield of merchantable forest produce that may be taken from a forest area whilst sustaining long term productive capacity of the forest area. In practice the term may be defined by reference to maintaining a minimum clear felling age and/or meeting other requirements over periods of time, and this may include the concept of non-declining wood flows.

Sweep
A measure of the bend in a log. Generally calculated as the maximum distance of the centre of each log from a straight line joining the centre of the log at each end. Sweep is generally expressed as a proportion of the small end diameter of the log and may also be based on a per unit log length as well.

Tending
A collective term for silvicultural operations that are directly applied to the growing trees within a stand.

Terrain
Similar to topography but also generally has the connotation of the effect of the soil, water, rock and vegetation coverage conditions on the ability to traverse the country.

Thinning
The practice of selecting certain trees for felling and leaving other trees to grow. A thinning ‘from below’ implies that the smaller trees are removed to enhance growth on the remaining trees.
Thinning intensity

The degree of intensity of a thinning. Commonly expressed by the residual stand density (number of trees, basal area or volume) but can be expressed as the proportion removed. It has sometimes been expressed as the proportion removed divided by the thinning interval.

Thinning interval

The number of years between successive thinning operations. Also sometimes called a thinning cycle.

Thinning type

The description of the types of trees removed in thinning compared with the trees left behind after thinning. Commonly the ratio of the mean tree diameter of trees thinned to the mean diameter before thinning, but the ratio can be average tree basal area or average tree volume.

Thinnings

The logs produced by thinning.

Timber

See lumber.

Topography

The vertical form of the land surface; usually expressed by contours in mapping systems.

Tree stock

The plant material used for planting, including seedlings and plantlets. Commonly called planting stock.

Variable lift pruning

A pruning technique where each tree is considered individually. The height to which each tree in a stand is pruned is determined by a chosen factor. Factors commonly in use include; a percentage of tree height, a proportion of the crown to be left or removed, or the diameter at the base of the remaining crown.

Veneer

A thin sheet of wood produced from a log by rotary peeling in a lathe or by slicing. Used in the production of plywood and laminated veneer lumber.

Veneer log

A log, usually of large diameter and/or high quality used for making veneer. Also called peeler when used for rotary peeling.

Volume

The solid bulk of any entity.

Whorl

A group of branches growing radially around a tree. A typical branching habit of softwoods but not hardwoods.

Yield

The quantity of forest produce that is, or is expected to be, recovered from a unit area of land. Net yield generally means the same as merchantable yield.

2.4 Glossary of economic and forest valuation terms

Accrual accounting

Accrual accounting involves recognition of revenues and expenses (and assets, liabilities and equity) in the financial year in which they occur, irrespective of when cash has been received or paid.

Amortisation

The procedure for writing off the cost of an asset over a period of time.

Articulation

The way concepts, treatments and definitions relate to one another in a (supposedly) logical system. The objective of articulation in a system of valuation is to make the parts of the subject of the forest valuation (for example the forest
enterprise) susceptible to the general propositions of mathematics and simple logic. For example, that the parts add up to the whole, that the ‘real’ rate of return when adjusted for rate of inflation equals the nominal rate of return. Lack of articulation is *prima facie* evidence that the valuation is flawed. Because of the long time spans involved in forestry and the complexity of the data, lack of articulation that would be immaterial for other valuations may be material in the valuation of a forest.

**Beta (β)**

A measure of the risk in a capital investment and used as a multiplier of the premium rate of return on capital (i.e. above the risk free rate) required in the overall analysis.

**Biological asset**

In the strict sense that is applied in the accounting standards a biological asset is defined by the living trees living at the point of time of the forest valuation. It has also been called ‘Living Trees’ in the ACFA (2004) valuation standard. It specifically excludes any costs or returns applicable to fallow land and to future crops, also called ‘Subsequent Rotations’ in the ACFA forest valuation standard. See also Living Trees and SGARA.

**Capital (economic sense)**

The wealth used in the forms of land, plant, equipment and labour with a view to producing a surplus.

**Capital (accounting sense)**

A quantum of wealth, measured in monetary terms and owned by an investor, committed to the enterprise and which is risk dependent on the success of the enterprise. The many categories of capital have different rights, obligations and risks attached to them.

**Cash flow**

The movement of cash resulting from transactions with parties external to the forest enterprise. Costs may be regarded as negative cash flows and revenues as positive cash flows. Usually transaction based.

**Consideration**

In simple terms the price paid for goods. Usually expressed in money terms. A consideration is always related to a transaction.

**Consumer Price Index (CPI)**

An index that enables values in different years to be related. CPI is in essence a measure of inflation.

**Contingency**

An allowance for the occurrence of an event or events to the enterprise. Generally cannot be assessed quantitatively but a quantitative allowance is made. See also risk.

**Control of an asset**

The capacity of an enterprise or entity to benefit from an asset in pursuit of the entities objectives and to deny or regulate the access of others to that benefit.

**Cost**

The price of a good as viewed from the purchaser’s viewpoint.

**Cost benefit analysis**

An economic analysis technique which aims to evaluate a project in terms of the relevant costs and benefits associated with it, including imputed social costs and benefits not otherwise recognised as cash flows.

**Currency**

The units and legal framework given to money issued within a country.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflation</td>
<td>Is the same effect as inflation but with decreasing price levels and increased purchasing power.</td>
</tr>
<tr>
<td>Director’s valuation</td>
<td>A Director’s valuation is a valuation which is not an independent valuation.</td>
</tr>
<tr>
<td>Discount point</td>
<td>The point in time at which interest is deemed to be added in a compounding calculation or deducted in a discounting calculation.</td>
</tr>
<tr>
<td>Discount rate</td>
<td>The annualised rate at which projected costs and revenues are discounted to reduce them to Present Value (PV). This term is always used with reference to projected future events. See also interest rate.</td>
</tr>
<tr>
<td>Discounted cash flow (DCF)</td>
<td>Projected costs and revenues multiplied by the discount factor at the given discount rate appropriate to the future year.</td>
</tr>
<tr>
<td>Enterprise</td>
<td>The scope of the economic venture considered by the analysis. Commonly also called an entity.</td>
</tr>
<tr>
<td>Equity</td>
<td>The residual interest in the assets of an entity after deduction of its liabilities.</td>
</tr>
<tr>
<td>Exchange rate</td>
<td>The ratio at which the currencies of two countries are exchanged at a particular time.</td>
</tr>
<tr>
<td>Fixed costs (FC)</td>
<td>Costs which are short run, and do not vary in total with the level of output or the level of activity. Therefore in unit terms they vary inversely with output.</td>
</tr>
<tr>
<td>GST</td>
<td>Goods and Services Tax.</td>
</tr>
<tr>
<td>Independent valuation</td>
<td>An independent valuation is defined as a valuation made by a person or an organisation which is an expert in relation to valuations of that type of asset and whose pecuniary or other interests could not be regarded as affecting the firm’s ability to give an unbiased valuation.</td>
</tr>
<tr>
<td>Inflation</td>
<td>A measure of the increase in price levels over time as measured by money. Hence, inversely, a means of decreasing purchasing power of unit money measures over time. Usually expressed as an interest rate (i% or a multiplier, commonly stated as 1.0i although if i ≥10 it should more properly be stated as 1.1i).</td>
</tr>
<tr>
<td>Interest rate</td>
<td>The proportion of a capital sum, usually expressed as a percentage (i%) or as a multiplier (1.0i), charged by a lender (either actually or notionally) to the borrower for the use of that capital sum over unit time (commonly one year). See discount rate, and inflation.</td>
</tr>
<tr>
<td>Internal Rate of Return (IRR)</td>
<td>The discount rate at which the investment and future returns equate in a calculation of Present Value (PV).</td>
</tr>
<tr>
<td>Investment</td>
<td>The initial capital sum and generally any future sums laid out as capital.</td>
</tr>
<tr>
<td>Land Expectation Value (LEV)</td>
<td>The price that can be imputed to land so that all positive and negative cash flows (including the price imputed to the land) associated with the forestry enterprise when discounted at the required rate (%) indicate a zero capital value for the enterprise.</td>
</tr>
</tbody>
</table>
Simply, the maximum that can be paid for land to achieve a given rate of project return.

**Life**

The span of time over which the economic enterprise starts and concludes. In forestry the life is often defined by reference to tree age or, for a stand or stands, rotation length.

**Living Trees**

Are those trees that are biologically alive, whether prostrate, or with broken boles. This replaces the traditional “standing crop” or “standing trees” in valuation as those terms no longer conform with the accounting definitions. In the strict sense that is applied in the accounting standards they are the biological asset. The term specifically excludes any costs or returns applicable to fallow land and of future crops, also called ‘Subsequent Rotations’ in the ACFA forest valuation standard. See also Biological Asset and SGARA.

**Market**

A series of transactions in goods and services of a similar nature carried out by individuals assumed to have a reasonable knowledge of the nature of the goods and services traded, the past history of prices and a reasonable appreciation of the factors influencing the prices.

**Money**

A measure of wealth having universal acceptance in (typically) one country or a group of countries.

**Net Market Value (NMV)**

The net market value (or Market Value in New Zealand) is the amount for which the defined good or service should exchange; on the date of the valuation, between a willing buyer and a willing seller, in arm’s length transactions, after proper marketing, and, where each party has acted knowledgeably, prudently and without compulsion. Sometimes called market price or market cost. May be applied to a good not yet the subject of a transaction in order to give a market based valuation. Interpreted as being equivalent to ‘fair value’ in the AASB accounting standards.

The Society of American Foresters (1955) state that “Market value is based on the evidence of transactions, similar in time and place, in which similar property was exchanged. The current market value of a property is the amount which a seller, who is willing and able but not compelled to sell, will accept for the property from a purchaser who is willing and able but not compelled to buy.”

**Net Present Value (NPV)**

See Present Value.

**Non current asset**

A non current asset is a future economic benefit controlled by the entity as a result of past transactions or other past events which, in the ordinary course of business, would not be consumed or converted into cash, or would be due or payable, within twelve months of the end of the financial year to which the financial report relates or reporting date involved. A biological asset or SGARA may be a class of non current asset.

**Non living produce**

Non living produce represents the potentially commercial saleable produce derived from a biological asset or SGARA but is not a biological asset or SGARA itself because it is not living. In
the case of forests this includes, logs, pulpwood, firewood, turpentine, un-germinated seed, severed foliage and floral parts.

Opportunity cost
The opportunity cost of a decision is the value of the next best alternative which has to be given up because of that decision. It is the value foregone.

Present Value (PV)
The sum of all discounted cash flows appropriate to the item being measured. The PV is a measure of the contribution of a project to wealth. The term present generally means the beginning of the first time period of the calculation, and not the date at which the calculation is performed. Also called Net Present Value (NPV).

Price
The quantum of money (or money’s worth expressed in current money’s terms) used as the consideration in an economic transaction. Price always has the connotation of occurrence at a defined point in time.

Price point
A geographic point where the commercial transaction is assumed to take place. This is also a point in the time sequence from tree to product so there is a time dimension as well. Differs from point of sale in that in fact no transactions as described may actually take place at that point. Price point is a convenient point at which costs and prices may be adjusted to bring all transactions in an area to a common base.

Profit
The return due to the owner of investment capital through the operation of the enterprise. Profit may be viewed as return on the owners capital for the entrepreneurial ability which appears as a cost to the purchaser of the enterprise’s products.

Rational
A rational outcome, action or conclusion is based on the rules and processes of reason. Rationality, being based on culturally, personally, or organisationally held postulates, precepts and perceptions of facts, will produce different outcomes for different entities from the same situation. In the economic arena market participants may therefore consider the actions of other participants irrational. A market outcome of price, market, volume etc. is, by extension, reckoned to result from the average postulates, precepts, perceptions held by participants in a market rationally assembled. It is generally held that a market will tend to impose a common rationality on participants in the medium to long term. Economic rationality is generally considered able to be represented by mathematical constructs but this does not imply that market participants will always proceed from a pre-existing rational model.

Real
With reference to cash flows and calculated PVs, refers to a calculation and a result in which future (or past) inflation or deflation has been excluded from the included money quanta and the interest rates. The underlying postulate is that value concepts can only be comprehended by reference to the present prices of goods and service and value impacts of present interest rates.

Revenue
Any net positive cash flow not being the extraction of capital. In essence the value of a good from the seller’s viewpoint.
Risk  The likelihood of an occurrence of an event to the enterprise. Usually expressed as a percentage of the capital of the enterprise exposed to future adverse events. Can be assessed quantitatively.

SGARA  A Self Generating and Regenerating Asset is a non-human living asset and the term is intended to apply to all living assets regardless of production cycle, or how they were created. Produce from a SGARA that continues to undergo changes after extraction from a SGARA for example wine or timber is not a SGARA because it does not undergo biological change. The term is expected to become redundant and has been replaced in the Accounting Standards by the term “biological asset”.

Social costs  Costs which may not feature in financial accounts in the short term, for example costs of air and water pollution, but which are real costs to the society as a whole.

Tax  Any contribution levied on a person or organisation by law for the support of national, state or local government. See also GST.

Testator  One who makes a will, or who has died leaving a valid will. Also legator.

Time preference  The subjective phenomenon in which present enjoyment of a quantum of resource is preferable to the future enjoyment of the same quantum of resource. Measured by discount rate in the absence of inflation or deflation.

Transaction  A transfer of goods and/or services from a seller to a buyer in return for a consideration transferred to the seller from the buyer. A transaction is the best evidence of value in that two separate individuals are agreeing at a definable point in time with respect to definable goods or services and a specific and universal measure of value. At the point of the transaction the price and buyer’s cost and value are an equal quantum of wealth.

Valuation event  An expected occurrence relevant to a valuation process and its associated cash flows.

Value  The quantum of moneys worth placed on a defined good or service by an individual, enterprise or market at a particular time. Two people or enterprises may well hold that the same good has different value at the same point in time. A transaction in a good or service can only take place in a free market if each prospective party separately holds that their personally held value for the good or service is either, below the transaction value (in the case of a seller) or above it (in the case of a buyer). Value is always subjective and remains largely immeasurable until a completed transaction places a price or exchange value on the good or service in that instance. It follows that each party to a transaction will receive a surplus of personal value from the transaction. The sub-categories of personally held value are extensive and include: need, sentimental, ecological, aesthetic, compensation, spiritual, cultural, time preference and loss minimisation. Articulate analysis of the personal value
components plus the personal surplus back to price is rarely possible. See market value.

2.5 Glossary of other terms

Accuracy
How close an estimate is to the true value, thus implying both precision and freedom from bias. The term implies both concepts.

Allometric
A relationship which maintains constant proportions.

Bias
The difference between the expectation of a sample estimator and the true population value, systematically distorting results. Bias may arise in a number of ways.

Anamorphic curves
A series of curves or equations scaled so that each is a simple proportion of a base curve. See polymorphic curves.

Confidence limits
The confidence limits of a sample indicate the range of values within which a true mean of a population is likely to be found. They are normally expressed as the estimated mean plus or minus (±) some interval. For forest management purposes it is common to adopt the 95% probability level for sampling (p=0.05). This implies that there is a 1 in 20 chance of the true mean lying outside these limits.

Continuous variable
A variable that can take a complete range of values. See also qualitative variable.

Dependent variable
A variable to be predicted using other independent variables. Sometimes called the response variable.

Deterministic model
A mathematical model involving no chance or probability in the prediction of future states. Contrasts with stochastic model.

Extrapolation
Prediction beyond the range of the calibration data.

Heterogeneous
Implies that members of a sample or population differ to a considerable extent in respect to some or all parameters of interest. See also homogeneous.

Heteroscedastic
Generally restricted to heterogeneous variances.

Homogeneous
Implies that all members of a sample or population are similar to one another with respect to some or all parameters of interest. See also heterogeneous.

Independent variables
Variables used to predict the dependent variable. Sometimes called an explanatory variable.

Interpolation
Prediction within the range of the calibration data.

Mean
Also average, the sum of the values of a particular attribute for an item divided by the number of items.

Mean Square Error (MSE)
A measure of accuracy. The sum of the squares of precision and bias.

Model
A simplified representation of some aspect of reality. Specifically in the statistical sense a model is a formalised expression of a theory and may include a series of mathematical equations, the
numbers embedded in those equations and the means of linking them all together in a meaningful way.

Parameter
A quantitative characteristic of an individual or population. For example the mean or variance of a population or the constants describing and equation fitted to data. An equation consists of parameters and variables.

Polymorphic curves
A series of curves or equations of different shape. Typically the curves do not cross. See anamorphic curves.

Precision/precise
The degree to which estimates are clustered about their own average. The repeatability of a measurement or estimate.

Probable limit of error (PLE)
The confidence limits expressed as a percentage of the estimated mean.

Qualitative variable
A variable that is not continuous and which may take a number of discrete values. See also continuous variable.

Serial correlation
Generally the correlation between successive observations on the same sample unit.

Stochastic model
A mathematical model involving chance or probability, so that there is some indeterminacy in the predictions by that model. Contrasts with deterministic model.

Variable
A characteristic that may vary from one individual in a population to another and which relates to some property of the individual or population, for example dbhob, height, basal area.

Variance
The statistical measure of variability within a sample or population.

For formal definitions of statistical terms see an appropriate statistical text book.

2.6 IUFRO Symbols

An inventory of standard forest terminology symbols has been prepared by the International Union of Forest Research Organisations (IUFRO) (Soest et al. 1959). Although the document has not been widely used in Australia and New Zealand it does provide one sound, consistent and widely accepted set of symbols. These originated during the type-writer period, and pre-date the common availability of Greek symbols and italics on modern word processors. In the IUFRO convention a lower case variable generally means a tree variable, and an upper case means a stand variable.

c circumference
d diameter
f form factor
g basal area
h height
i increment
k form quotient
n number (generally of stems, but also of years)
p increment per cent	
age
In Australia “t” is the standard symbol for tonne, but there is rarely confusion between age and tonnes in practice.

2.7 Species

This handbook generally uses common names rather than botanical names. The objective was to use whichever is simplest and is least subject to possible confusion. The objective was also to use the cited species.

In some cases it is easier to refer to the botanical name. For example, swamp gum can refer to either *Eucalyptus regnans* or *E. ovata* depending on the state where the name is being used and so, to avoid confusion, the use of the botanical name is preferable.

In other cases it is easier to refer to the common name or names, for example *E. regnans* is known as swamp gum in Tasmania and mountain ash in Victoria.

Some species formerly in the genus *Eucalyptus* have now been placed in the genus *Corymbia*. Spotted gum is now generally considered to be *Corymbia maculata*, formerly *Eucalyptus maculata* but it could be *Corymbia citriodora*, formerly *Eucalyptus citriodora*.

Published papers may use various botanical name conventions depending on when the paper was published.

The more commonly used species names referred to in this Handbook are included here for convenience.

<table>
<thead>
<tr>
<th>Botanical name</th>
<th>Common name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cupressus macrocarpa</em> Hart.</td>
<td>cypress</td>
</tr>
<tr>
<td><em>Eucalyptus botryoides</em> Smith</td>
<td>southern mahogany</td>
</tr>
<tr>
<td><em>Eucalyptus camaldulensis</em> Dehnh.</td>
<td>river red gum, red gum</td>
</tr>
<tr>
<td><em>Eucalyptus citriodora</em> Hook.</td>
<td>lemon scented gum, sometimes called spotted gum, and renamed as <em>Corymbia citriodora</em> (Hook.) K.D.Hill and L.A.S.Johnson</td>
</tr>
<tr>
<td><em>Eucalyptus delegatensis</em> F.Muell.</td>
<td>alpine ash, woollybutt</td>
</tr>
<tr>
<td><em>Eucalyptus diversicolor</em> F.Muell.</td>
<td>karri</td>
</tr>
<tr>
<td><em>Eucalyptus fastigata</em> Deane &amp; Maiden.</td>
<td>brown barrel</td>
</tr>
<tr>
<td><em>Eucalyptus globulus</em> Labill.</td>
<td>blue gum</td>
</tr>
<tr>
<td><em>Eucalyptus grandis</em> Hill ex Maiden</td>
<td>flooded gum</td>
</tr>
<tr>
<td><em>Eucalyptus maculata</em> Hook.</td>
<td>spotted gum, renamed as</td>
</tr>
<tr>
<td><em>Corymbia maculata</em> (Hook.) K.D.Hill and L.A.S.Johnson</td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus marginata</em> Donn ex Smith</td>
<td>jarrah</td>
</tr>
<tr>
<td><em>Eucalyptus obliqua</em> L’Hér.</td>
<td>messmate, stringybark</td>
</tr>
<tr>
<td><em>Eucalyptus ovata</em> Labill.</td>
<td>swamp gum</td>
</tr>
<tr>
<td><em>Eucalyptus nitens</em> (Deane &amp; Maiden) Maiden</td>
<td>shining gum</td>
</tr>
<tr>
<td><em>Eucalyptus pilularis</em> Smith</td>
<td>blackbutt</td>
</tr>
<tr>
<td><em>Eucalyptus regnans</em> F.Muell.</td>
<td>swamp gum (Tasmania)</td>
</tr>
<tr>
<td></td>
<td>mountain ash (Victoria)</td>
</tr>
<tr>
<td><em>Eucalyptus saligna</em> Smith</td>
<td>Sydney blue gum</td>
</tr>
</tbody>
</table>
Eucalyptus viminalis Labill.  manna gum, ribbon gum and white gum
Pinus radiata D.Don.  radiata pine
Pinus pinaster Ait.  maritime pine
Lophostemon confertus (R.Br.) Peter G.Wilson and J.T.Waterhouse  brush box, formerly
Tristania conferta R.Br.

### 2.8 Multilingual Terminologies

The United Nations Food and Agriculture Organization provides a FAO Terminology Web Site that facilitates multilingual support for various forestry and economic terms. The site at 2005 was:


and provides translations of subjects from any of the source languages, English, French, Spanish, Arabic, Chinese and Latin into any of these target languages.

The site also provides a “names of countries” data base to facilitate standardisation for publications.

Another site within the European Union web site;

[http://glossary.eea.eu.int/EEAGlossary](http://glossary.eea.eu.int/EEAGlossary)

provides a multilingual environmental glossary and can be used in all official European Union languages, although the site did not appear to be complete for all the minor languages as at early 2005.

### 2.9 World Wide Web Search Engines

This Handbook frequently refers to web sites as the base for obtaining further information. Every attempt has been made to date stamp each such entry as URLs and domain names or addresses do tend to change over time.

#### 2.9.1 Google

For searching across the World Wide Web the most commonly used search engines are those developed by Google. Given their aggressive ongoing development there are likely to be other products released. The main search engine, as at mid 2007, is:

[http://www.google.com](http://www.google.com)

There is also Google Scholar;

[http://scholar.google.com](http://scholar.google.com)

that is restricted to academic text and enables searching for scholarly literature including peer-reviewed papers, theses, books, preprints, abstracts and technical reports.

There is also the more general Google Print or Google Books;

[http://books.google.com](http://books.google.com)

As at 2007, reformatted 2012 but no textural changes
For satellite images there is Google Earth;

http://earth.google.com

### 2.9.2 Other search engines

Other search engines that may be useful for scientific searches include the following;

http://www.mamma.com
http://www.northernlight.com
http://www.scirus.com

Each has their own strengths and weaknesses and users may find that changing search engines for different purposes provides advantages.

Another site was redlightgreen, available in 2007 from;

http://worldcat.org

which allows searches of parts of authors, names, titles, and also ISBN numbers of over 1 billion books. The site also links to on-line book sellers and a number of libraries around the world to assist determining the availability of each book. Although obviously incomplete this may however be a useful point of reference.
PART III  FOREST DESCRIPTION

Part III of this Handbook covers all aspects of forest data collection, calculation, modelling and processing of data that are necessary to carry out forest valuations.

The depth of treatment is not uniform as some areas are well documented in standard text books but other areas are only covered in references which may or may not be readily available.

One useful web site that covers this subject, and provides some simple models for situations where no other information was available in mid 2005 at;

www.fao.org/forestry/fra-knowledgeref

and was prepared by a group of eminent forest managers.

3  Forest measurements

The basis of all forest valuation is the sound measurement of the forest entity. Any measurement made must be reproducible, accurate and useful, and should be carried out in a manner that meets generally acceptable standards.

3.1  RWG2 “Code of Forest Measurement Practice”

Research Working Group No.2 (Forest Measurements and Information Systems) (RWG2), is a group responsible through the Research Priorities Coordinating Committee (RPCC) to the Forest and Forest Products Committee (FFPC) of the Primary Industries Standing Committee and Ministerial Council. It is the Australian and New Zealand Group with special technical expertise on forest mensuration and thus also forest valuation.

In 1999 RWG2 published the “Code of Forest Mensuration Practice: A guide to good tree measurement practice in Australia and New Zealand”. Dr Geoff Wood was the prime mover for the preparation of the document and when he retired from the group Drs Brian Turner and Cris Brack completed the editing of the document.

Further References


3.2  Getting Assistance

The Association of Consulting Foresters of Australia has a web site

www.australianconsultingforesters.org

that includes a register of all members in good standing and also includes their special areas of expertise.

It is planned that both the ACFA (2007) forest valuation standard, and this Handbook will be posted on this web site as Adobe Acrobat .pdf files, available for free download.

Forest owners, managers and others interested in determining an estimate of the value of a forested property are invited and encouraged to contact a member of ACFA who is in good standing, perhaps via the ACFA web site.

For smaller scale operations it may also be useful to consult one of the many Private Forest Development Committees around Australia. In 2007 the listing of contact details for these committees was found by logging onto the DAFF website and searching for “PFDC”.


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http://www.daffa.gov.au/forestry/plantation-farm-forestry/pfdc
4 Ownership and measurement of forest area

The measurement of a forest requires knowledge about the area of the forest, the spatial information, as well as the other attribute, or non spatial, information about that forest.

Valuations of the land on which forests or plantations are grown need to be based on a secure knowledge of the legal basis of ownership of the land.

4.1 Land title

Appropriate checks on the location and condition of, and assets on, that land need to be carried out as an initial part of the valuation of the forest or plantation.

The starting point for the determination of the forest area is to inspect the land title. Each state has differently named Government departments responsible for maintaining the register of land titles, and each state has different procedures for accessing that information.

The easiest way to get information is probably to use a conveyancer or surveyor, as both professions generally know the mechanisms for confirming land title and for obtaining survey plan information.

In 2005 the relevant Government Departments or organisations were as follows. The information is believed to be an appropriate first point of contact.

New South Wales
   Department of Lands, Lands and Property Information Division
   1 Prince Albert Road Queens Square
   PO Box 15 Sydney NSW 2000
   Tel (02) 9228 6666

Victoria
   Land Victoria
   Level 14, 570 Bourke Street
   Melbourne VIC 3000
   Tel (03) 8636 2010 or 136 186

Queensland
   Department of Natural Resources, Mines and Energy
   Mineral House
   41 George Street
   Brisbane QLD 4000
   Tel (07) 3405 6900

South Australia
   Land Services Group (Lands Titles Office)
   101 Grenfell Street
   Adelaide SA 5000
   Tel (08) 8226 3983 or 1800 648 176

Western Australia
   Department of Land Information
   1 Midland Square Morrison Road (cnr Gt Northern Hwy)
   PO Box 2222 Midland WA 6936
   Midland WA 6936

As at 2007, reformatted 2012 but no textural changes
In 2005 a useful web site to find any appropriate governmental body was:
a private site which provides links to Australian, state and local government sites. In some cases it is easier to use this site than to try to navigate within the official sites.

In some states it is possible to deal direct with the land title body while in others it is necessary to either become an agent or to deal through an appropriate search agent, variously called reseller and approved information broker, or to work through a licensed conveyancer or surveyor.

Each state provides slightly different services. In Victoria, for example, the Vicmap series of 1:30,000 topographic maps are available for Land Victoria for the whole state in A4 format at a cost in 2004 of ca $1.50 per map sheet, downloadable in .pdf format. They also provide an online service for downloading title and property certificates.

4.2 Confirm title matches land area

It is generally necessary to ensure that the land area recorded on the title matches the area on the ground. Errors in the titles are not unknown and in one large section in South Australia an error of 5 chains (ca 60 m) was found in a map, presumably because they had miscounted the number of 5 chain steel band lengths along a traverse in the early survey.

However, early surveys were generally remarkably precise given the terrain, the equipment available and the methods of calculation. Errors are often known to exist but that knowledge may not be available to the forest valuer. It is therefore necessary to confirm that the area to be surveyed matches the title.

Any differences between the survey and the title will need to be at least noted in any valuation report.

Global Positioning Systems (GPS) provide one good method for verifying location and survey dimensions. Techniques such as differential GPS can provide the appropriate accuracy.

Older manual survey techniques may still be appropriate under certain circumstances.

Air photos can also provide a quick visual check that the shape of the area matches the shape on the title and cases are known where this simple and quick check has highlighted errors in fence alignments.
It may also be appropriate to use a Licensed Surveyor. Surveyors are licensed by State Boards and it will be necessary to check whether a surveyor has the appropriate registration to perform cadastral surveys in that state or territory. In the past, most surveyors were also members of the Institute of Surveyors, Australia, which (for most states) in 2003 amalgamated with other professional bodies into the newly formed Spatial Sciences Institute (SSI). Membership of SSI does not imply that a surveyor is necessarily licensed to perform the necessary cadastral survey, but licensed surveyors are generally members of SSI.

### 4.2.1 Surveying

#### Surveying handbooks

There are a number of general surveying texts available and the most commonly used would seem to be that of Elfick (Elfick et al. 1994) but others are also used as students texts (for example Bannister, Baker and Raymond 1998, Richard, Wolf and Ghilani 2001).

Each state operates under the relevant Surveyors Licensing Boards and so requirements and methods differ a little between states.

The Victorian Board provides a Survey Practice Handbook which in 2007 was available in downloadable .pdf files from:


There are three parts to their Handbook; Part 1 Drawing Practice, Part 2 Surveying Procedures and Part 3 Land Surveying Law and Administration. The 40 files total to about 8 Mb but provide a detailed and useful free source of information that is of more general use as well as being strictly appropriate for Victoria.

The equivalent South Australian site in 2007 was:


(note underlines to separate words, not blanks), there being two volumes to the manual. Volume 1 is titled Plan Presentation Guidelines, and Volume 2 is titled Cadastral Survey Principles. The download site provides a large consolidated updated version of the second manual. This manual also contains very useful information.

Abed and Stephens (2003) provide information appropriate for farm forestry at a relatively elementary level.

#### International Standards

International standards exist and could be accessed in 2007 from

http://www.isotc211.org

the web site for the International Standards Organisation (ITO) Technical Committee 211, “Geographic Information / Geomatics”. Their objective is standardization in the field of digital geographic information, aims to develop structured standards for spatial objects, and the standards may include geographic information, methods, tools and services for data management, data acquisition, processing, analysing, accessing, presenting and transferring such data in digital/electronic form between different users, systems and locations.

#### Further References

Abed, T. and Stephens, N.C. (2003) [A measurement manual for farm forestry, useful for simple surveying only]

4.2.2 Global Positioning Systems

Global Positioning Systems (GPS) are commonly used to determine the location of a particular title area and to determine the exact spatial dimensions.

The operating manuals of the various manufacturers generally provide the necessary information to operate the devices.

A useful reference on GPS systems was available in 2007 from Land Victoria (Milner and Hale 2004) and downloadable in 2007 from:

http://www.land.vic.gov.au

and then following the links (Professions > Geodesy > Reference Library) to reach the Global Positioning Handbook. This 54 page .pdf file provides both general and detailed information to support the GPS manufacturer’s manual, describes types of GPS receivers, and presents a tutorial that is practically oriented. It also contains a comprehensive glossary.

Land Victoria is responsible for GPSnet which can provide centimetre accuracy (depending of the equipment and techniques used). See their web site for a brochure. A useful reference paper from the same organisation is that of Retimana, Kealy and Hale (2004) who discuss repeatability and location repeatability, the datum to be used, differential GPS, how GPSnet can be used. It provides a useful reference for users.

This is only one of the many possible sources of information.

4.3 Reporting

Any forest valuation report should include full details of the description of the land, its characteristics and climate, and any other matters that affect its potential commercial yields.

A valuation report should declare or disclose the following.

- The legal basis of the property rights to both the living trees or biological asset and the land.
- The boundaries and gross areas of land involved.
- Any ambiguity or differences observed between the surveyed area and the land title.
- The boundaries and net effective areas of plantation or forest by age class or structural classes, site productivity, stocking, and condition.
- The sources of area data, maps, and methods used to develop the area statements.
- A statement as to the reliability of the area estimates.

The ownership can be established through inspection of the legal title. Note should be taken of any rights of neighbours, covenants, encumbrances, or easements thereon.

Most States have legislation relating to Forestry Rights that enable the tree asset to be legally separated from the land, without necessarily requiring registration of that assignment of ownership on the title. Under these conditions, written assurance should be sought from the registered owner of the ownership status of the trees. Separate or related rights are, in some states, extended to Carbon Rights and global warming issues.
4.4 Stratification

The identification and mapping of net effective areas of forest or plantation is vital as it distinguishes those areas from others which are either carrying no trees or whose trees are, or will be when mature, of such low aggregate volume, average stem size, or quality as to be uneconomic to harvest.

Stratification divides an area of land into different strata in an attempt to gain more uniformity with each stratum. The stratification is generally mapped and is often a very convenient forest management tool. The gross area of a plantation forest can be stratified into:

- planted area and non-planted area,
- the planted area can be stratified based on planting year,
- each major plantation unit may be stratified into compartments or coups and it is necessary to identify fire breaks and tracks, swamps, stone outcrops and other physical features, and,
- each compartment may be further stratified into areas of approximately equal productivity.

Forest inventory will generally be applied to the net effective area only, which is a stratum of the gross area.

The primary objective of stratifying the forest is to reduce heterogeneity and so facilitate improvement in sampling efficiency. It is possible to sample gross area but this is recognised as inefficient sampling statistically, and is generally also cost inefficient.

Having first stratified the area into forested and non-forested land, or net effective area and other, it is generally advantageous to further stratify the area that is to be sampled by forest inventory.

Overall the objective is to provide a forest valuation of the highest precision for a given cost or to meet a target sampling precision at the least cost. This means that the cost of obtaining a particular stratification of the area must be balanced against the likely gain in sampling efficiency. The levels of precision that can be achieved for various cost alternatives should be matched against the outcomes required and this should be discussed with the client.

Various stratifications are often available on maps held by the forest owner and may therefore be relatively easily obtained. Such stratifications might include productivity class, site index, soil type, geology, original vegetation and silvicultural history, including establishment methods, pruning, thinning history and fertiliser application.

Other sources of stratification include air photos and remote sensing such as Landsat™ TM satellite images.

4.5 Surveying software

There are many commercially available software packages that can be used to take surveying data, correct any traverses, plot maps from that data, calculate areas of any polygons of interest, and provide data in a suitable format for input into a Geographic Information System (GIS).

Because most surveyors already have a suitable package it is not proposed to review the various packages that are available.

In April 2003, the members of the Australian Urban and Regional Information Systems Association (AURISA); the Institution of Engineering and Mining Surveyors, Australia (IEMSA), the Institution of Surveyors, Australia (ISA), the Mapping Sciences Institute of Australia (MSIA), and the Remote Sensing and Photogrammetry Association of Australasia (RSPAA) voted to become founding members of the Spatial Sciences Institute (SSI). The web site in mid 2007 was:


SSI provides members with a magazine “Position” published by:

South Pacific Science Press International Pty.Ltd.
50 Alexander Street

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The October/November 2004 edition, No.13, provided the “2004 Surveying Software Listing” including brief descriptions, the names of the manufacturer and distributor, and email, web and contact information. Some 37 packages are described. They include packages such as hand held Hewlett Packard calculator packages to facilitate the closing of traverses in the field, packages to process GPS data, packages to handle specific file formats, packages that can link to GIS packages, and complete field-to-finish systems. Some require CAD (computer assisted/aided design/drafting) packages, others include CAD components as part of a total suite.

The December 2006 / January 2007 edition, No.26, provided a “Products and Services Directory 2007” including contact details for imagery, hardware, software and services. Many of the organizations provided advertisements describing their products and services.

The magazine provides regular summaries of new products that are being marketed.

ACFA does not endorse any software package but suggests that this magazine may provide a useful starting point for anyone wanting to acquire surveying software, or hardware, imagery or services.
5 Stand history

It is necessary to record the stand history. Environmental factors are the main determinants of growth but the silvicultural history may also affect future growth.

5.1 Environmental history

The environmental history of a forest site may or may not be readily available. Soil and geological surveys cover much of the forested area of Australia and general rainfall maps are also available.

The most commonly used environmental factor is the soil. Soil maps may be available for an area of interest, and it is common to carry out a soil survey before establishing a plantation forest in order to be better able to predict future yields. Similarly, soil maps can assist improve the stratification of native forests and also improve future yield predictions.

In 1987 RWG 3 produced a technical classification of soils for pine plantations (Turvey 1987) that provides a sound method for describing forest soils that is commonly far more appropriate for forestry purposes than other more general soil classifications.

A useful software package that can provide bio-climatic parameters useful for modelling and for comparison between sites is ANUCLIM available from the Australian National University (ANU) Centre for Resource and Environmental Studies (CRES). This requires basic spatial attribute information that can be acquired with the package. See the chapter on proprietary planning systems, other possibly useful systems, for more details.

Examples of information that may be readily available, generally in spatial form, include;

- soil maps and soil descriptions (generally including soil type, depth to water retentive layer, the depth and type of any impermeable layer, possibly general profile descriptions and nutrient assays),
- geological maps,
- ANUCLIM information,
- maps of the original vegetation or, if formerly farm land, the status of the land at establishment,
- maps of average rainfall, and,
- maps of topography and terrain.

5.2 Stand history

In the past it was generally satisfactory to start from a forest inventory and work forward without the necessity to know how the stand had got to that particular state. This was because the silviculture practiced was similar between sites and so the data used to develop prediction models had a similar silvicultural history to the data that represented the stands to be predicted by those models.

This is no longer the general case. In plantations especially, site specific silviculture has become the norm and it is necessary not only to know the current status of each stand but to know the silvicultural history that produced that stand. Prediction models have for some organisations become more complicated and sophisticated so that they require the knowledge of historical treatments as well as the current state and expected future silvicultural treatments. Similarly, it may be necessary to know the history of past silvicultural treatment in native forests.

For example, if two plantation stands have the same current status in terms of stocking, basal area and volume at a particular age, but one had received intensive early aged silvicultural treatments (weedicide, fertiliser and site preparation), and the other was planted on a better soil type, but had received little fertiliser, then subsequent growth rates may well be quite different. This is also true
for different planting stock from different seed sources. Fertiliser application within the few years prior to inventory can also affect future growth as the growth effects of fertiliser can generally last about 6-8 years. Late age fertiliser application prior to clear felling harvest can also affect tree growth and change the number of trees that are in the larger and more valuable size classes.

Even if the information is not necessary for currently available models it may be necessary for future models so it is highly desirable to record the stand history even if it is only believed that it may be useful in the future.

Two relatively early examples of papers that indicate this need are those of Boardman (1988) and Horne (1988).

Site survey
Aspects of site survey are generally unlikely to change over time, and might include;

- boundary survey, including tracks and roads,
- soil surveys, including soil type, soil depth, and possibly soil nutritional status,
- geological surveys,
- topographic surveys that identify sensitive areas of land including stream side buffer zones, water courses, unplantable land and assets, for example sheds and fencing, and,
- any survey of the original native forest vegetation, or if former farmland, the pasture or crop status.

Site preparation
Aspects of site preparation that may affect future growth might include;

- soil or other nutrient analysis to determine the nutritional status of the site,
- planting site preparation including ripping, ploughing and mounding treatments,
- pre-planting weedicide applications and a record of their effectiveness,
- animal control measures carried out, and,
- any erosion mitigation measures carried out.

Establishment
Aspects of plantation establishment that might be desirable to record include;

- planting dates,
- meteorological conditions,
- genus and species,
- seed stock, including the expected potential of any seed orchard stock,
- if the site was previously planted, the length of any fallow period,
- method of planting,
- tree spacing within the rows,
- row spacing, and,
- knowledge of any heaps or wind rows within the block that may impede future access.
Early aged silviculture

This could include;

- establishment survey to record any initial mortality, including whether general or in patches,
- replanting if required,
- the timing of any wind throw soon after planting that may have required remedial action,
- post establishment weedicide application, including any pre-application weed surveys, especially for bracken control, chemical used including active ingredients and surfactant, coverage and application rate, timing of the application(s), assessment of control, and any post application surveys,
- pruning history, the age of each operation, lift height, and method of pruning,
- any foliar, soil or other nutrient analysis to determine the nutritional status of the forest,
- any foliar, soil or other nutrient analysis to determine the nutritional status of the trees and forest,
- fertiliser applications to enhance growth, including fertiliser mixture, dose level, application method, the timing of application, and area treated, and,
- remedial fertiliser application to correct deficiencies, for example copper, zinc, boron.

Thinning history

In plantation silviculture thinning is generally described in terms of;

- the age of the first commercial thinning,
- the frequency of extraction rows, or in some steep country it may be necessary to prepare a map of extraction tracks,
- the interval between thinnings (or the years in which subsequent thinnings occurred),
- the thinning intensity, both the target and actual stockings after each thinning (and in this case stocking may be trees per area or residual basal area after thinning),
- the thinning type for each thinning (a row thinning, thinning from below or above, or it may be defined by the ratio of the mean diameter of thinnings to that before thinning $TT = (d_t / d_{bt})$ although the ratio may also be based on tree basal area or volume, or thinning type may be defined in terms of a diameter distribution, and,
- the age of clear felling.

If a stand has been replanted then this information should be recorded for each previous rotation, and as well the interval between clear felling and replanting should also be recorded and may be recorded as the fallow period under establishment.

For other forest the thinning treatment may be described in terms of;

- year of treatment,
- frequency between treatments,
- prescription for treatment, for example, trees greater than a specified diameter limit, or thinned to leave a specific residual basal area or stocking (N/ha), and,
- any environmental constraints that were imposed, and the basis for the imposition, including such constraints as stream buffer widths, the provision of nesting hollows, preservation of specific target species, and topographic and soil limitations.
Any salvage operation should also be recorded, including:

- the reason for the salvage (for example insect, pathogen, wind, hail, snow),
- the stocking recovered,
- the volumes recovered, including the volumes of various log products,
- any volume that could not be recovered, and,
- any other information that may possibly be desirable in the future to explain why the forest has attained the then current state.

**Other historical factors**

Other factors could include:

- any roading survey to determine future roading requirements,
- any control burning or other fire history that may be relevant,
- any browsing survey (for example rabbits, wallabies),
- any pathological or insect attack, the extent, and the treatments applied, if any,
- fire history, and,
- any unusual periods of flooding or drought, especially in the first year or so after establishment.

**Recording**

It may not be sensible to include all this information in a valuation report but at the very least the report should note what information was used, and where it is currently being stored. Brief descriptions and the location of the information may suffice. Records may include reports, computer files, and maps.
6 Forest inventory

One definition of forest inventory is that of Husch et al. (1982):
“...the procedure for obtaining information on the quantity and quality of a forest resource and the many characteristics of the land area on which the trees are growing.”

The text also provide the following check list of items which may need to be considered in planning an inventory.

1. Purpose of the inventory.
2. Background information (past surveys, maps, reports etc).
3. Description of the area (location, size, terrain, accessibility).
4. Information required for the final report (tables, graphs, maps, narrative report).
5. Inventory design (estimation of area, determination of timber quantity, size and shape of sampling units, sampling method, precision).
7. Procedures for field work (location and establishment of sampling units, current stand information, recording of observations, data conversion, and editing).
8. Compilation and calculation procedures (instructions for reduction of field measurements).
10. Maintenance (storage and retrieval of data).

Although obviously now dated, for example limiting stratification to aerial photography, the underlying points remain very relevant to modern forest inventory.

A very useful Australian web site provides access to the lecture notes of Dr Cris Brack of the Australian National University. These notes provide more basic forest mensuration detail that is useful for forest inventory than is provided in this Handbook. These notes were available in 2007 at:

Dr Brack also maintains the RWG2 (1999) Code of Forest Measurement Practice, available in 2007 at:

and also available as an Annex to this Handbook.

These two sites provide sound mensuration advice.

Further References for simple forest inventory

Farm Forestry Toolbox version 4.7, available in 2007 from:


Further References

Assman, E. (1970)
Bonnor, G.M. (Ed) (1978) [A guide to Canadian inventory terminology.]
Loetsch, F. and Haller, K.E. (1973)
Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)
Spurr, S.H. (1951)

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6.1 Purpose

The field work component of forest inventory can be expensive and historically much effort has been spent on developing cost efficient sampling and measurement strategies.

However before any forest inventory is designed it is necessary to know what the purpose of the inventory is, or more generally, what the purposes are, as there are generally multiple objectives even though they are often interrelated.

Some of the most common objectives of forest inventory are to;

- determine what is there for sale,
- prepare short term operational plans for harvesting,
- develop longer term strategic plans, and,
- determine the value of the forest for accounting purposes.

It is common to design a forest inventory so that it can meet all these needs if required.

Often a forest inventory is designed to meet a particular set of circumstances, and then subsequently it is used for purposes not originally intended. It may or it may not still be appropriate.

It is essential that the purpose of the inventory be recorded.

6.2 Design

Forest inventory field work is extremely costly and so it is generally well worth the effort to spend time ensuring that the design of the inventory is as efficient as possible, and so gain maximum accuracy at minimal cost.

Sample points should be located on a map and copies of the map should be used in the field to locate the sampling points. Although not necessary for strict statistical reasons it is generally considered desirable to ensure that the samples cover the complete area of interest.

6.2.1 Stratification

The most commonly used sampling design is a stratified random design where plots or points are located at random within strata. The advantages of stratification are primarily twofold.

First, the stratification into approximately homogeneous strata reduces the number of samples that are required to meet an overall precision target for sampling precision.

Second, if the forest is very heterogeneous then it is possible to use variable probability sampling and to concentrate the samples in the strata with greatest volume (or basal area). This also is a cost efficient strategy if, for example, the objective of the forest valuation is to meet an overall target precision for say total volume of wood.

This approach may also assist future practical management of the forest as it may be sensible to treat each stratum, or perhaps a group of strata, separately, in order to best meet harvesting or other silvicultural objectives.

It is possible, and indeed common, to have a stratum that has no effective timber on it, and it may be decided not to sample this stratum at all, the manager being happy to consider that this sample has nil or negligible volume. This needs to be considered carefully if there is the possibility that an alternative stratification may be superimposed over the samples at a later stage as it can create gaps in information. The implied original stratum with no plots and no volume may mistakenly be ignored.

If strata differ widely in terms of a variable of interest (generally basal area or volume) then it is possible to adjust the sampling level accordingly and so reduce the number of samples required to achieve a desired precision. This works well if pre-stratification (stratification prior to sampling) is...
used but may cause some computational challenges if post sampling stratification is used as the weights for each point or plot have to be based on the first stratification and then those weights carried over to the second stratification, post sampling. This can be done but it is easy to make a mistake and there is a need to be careful with potentially aberrant observations.

Some inventory specialists prefer to use equal probability sampling between strata even though it is more expensive as it makes computation easier and, more importantly, it is easier to explain what is happening to managers and clients. This may be a very important consideration if there is any possibility of subsequent litigation that uses the inventory information as evidence. It is important that managers and clients understand the possible implications and determine the most appropriate strategy to adopt.

It is also possible to use Bayesian approaches if the variation within a sampling stratum is known. By adjusting the number of plots based on this known variation it is possible to improve overall efficiency considerably. A Bayesian approach (Bayes 1763 (1958)) combines information available prior to an inventory and data obtained from the inventory in the statistical analysis. The prior information assists by improving the posterior estimate. Or in the simple inventory context, the prior information can enable better determination of the number of samples to be measured. Bayesian approaches are often derided because they can be based on arbitrary judgements but this is not always the case for, as in this example, the prior information can be based on an objective study. One forest inventory discussion is that of Ek and Issos (1976, 1978).

However generally “n” plots/ha or “a” hectare per plot sampling intensity, statistically inefficient though it is, is often used as a sampling framework as it at least maintains coverage, facilitates post sampling stratification, and is easy to explain.

### 6.2.2 Systematic or random sampling

Statistically there is no doubt that simple random sampling, or stratified random sampling, are the most appropriate sampling designs.

Sampling prescriptions for forest inventory generally ensure that samples do not overlap although this is not a requirement of the statistical theory.

Systematic sampling has frequently been used in forest inventory with the generally accepted advantage that systematic sampling ensures that the area is well covered. This compares with random sampling where there is a small probability that the samples may all be grouped together and that some of the area may have few or no samples. Systematic sampling theoretically has only one degree of freedom statistically, whereas random sampling has (n-1) degrees of freedom where n is the number of plots, and some have argued that it is not possible to compute the sampling error for a systematic sample.

It must be noted that systematic sampling can fail to provide unbiased estimates if there is some underlying systematic variation in the area that matches the frequency of the samples. Given the nature of forests this is unlikely to be an issue, but it must at least be considered. For example if a plantation was planted with exactly 2.5 m row spacing and then first thinned with every fifth row removed as an extraction row, then point sampling on a grid of say 25x25 or 50x50 m could see all the samples taken in the extraction rows with no trees, an obvious source of bias.

If adequate care is taken not to introduce a systematic bias then systematic sampling may, in some inventories, be quite appropriate.

### 6.2.3 Equal or variable probability sampling by area

Another issue that must be addressed is whether plots or points should be located with equal probability between the strata or with variable probability.
In principle variable probability is more efficient as the strata with higher timber yields can be sampled at greater intensity and this will improve the overall precision of the inventory. It is efficient both statistically and economically. The weight should be approximately proportional to the expected strata per hectare volumes (or the variable of interest).

If there is the possibility of a change to a post sampling stratification then this can create computational complexities that may not be considered warranted. The weight applied to each sample should be based on the pre-sampling stratification, not the new post sampling stratification.

In one example (Jerry Leech pers. comm.) a forest was stratified into three high yield class strata and a low yield class stratum. Sampling of the lower class, which was by far the greatest area, was at a per area rate of only 5% of that used for the three higher yield classes. When an improved alternative post sampling stratification was adopted one new stratum had ten plots from former higher yield strata and one plot from the low yield strata. Because of the excessive difference in the strata weighting adopted this plot had twice the weight in the analysis of the other ten plots combined and it significantly impacted the result. Statistically the analysis was perfectly correct as the Central Limit Theorem should be operating and taking effect, but in practice the result was untenable to the forest manager.

The problem really arose because of the relatively small number of samples, but unfortunately that problem commonly occurs in forest inventory.

### 6.2.4 Complex or simple

Complex inventory designs can offer considerable cost savings in terms of field work but generally this is associated with more complex processing and the complexity may have some disadvantages.

The more complex the design the more difficult it is to explain the design to the owners and/or managers of the forest.

A complex design may be satisfactory for the current use but if the inventory is to be used for determining growth by remeasuring some or all the inventory plots and if the stratification changes between the two measurements then great care needs to be taken to ensure that any growth is correctly calculated.

Examples are known where the calculations were incorrect because the two stratifications were assumed to be equivalent when they were not. There was nothing wrong with the field design but there were problems with the calculation methodology. If complex designs are used then great care should be used and it may be desirable to get expert assistance in the analysis stages.

Some of the more complex designs such as cluster sampling may enable within and between cluster variances to be computed. This can provide an indication of patchiness. Cluster sampling designs may be economically efficient as they can keep between cluster transit costs at a minimum.

More complicated cluster designs, and some other complicated designs, may be able to provide sensible estimates of the mean values but the statistical procedures to calculate sampling precision may not always be readily available. In practice this may or may not be a problem as the mean values are generally readily calculable.

Complexity may gain significant cost savings but that may come at the cost of user understanding, which in turn can affect user acceptance. It is a matter for the inventory designer to consider when deciding to adopt a complex design that saves field measurement expense.

**Further References**

Loetsch, F. and Haller, K.E. (1973)

Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)

Spurr, S.H. (1951)
6.2.5 Multi-phase, multi-stage sampling

The differentiation between multi-phase and multi-stage sampling is often clouded.

These sampling procedures occur more generally in large national forest inventories than in the forest inventories generally used for valuing smaller forests.

The idea is to start from a complete area and to stratify that, selecting sample areas, such as forest reserves, watersheds, or bio-geographic regions. This provides the first stage samples and a number of these are selected, but not all. Then for each first stage sample the area is stratified in more detail and second stage samples are selected from this level. The procedure can be repeated to any depth. This is the multi part of the names.

The separation into multi-phase or multi-stage is generally based on the methods of stratification. If the stratification at each level is basically the same, only increasing in depth, then it is commonly called multi-stage. If the stratification is based on quite different bases, for example the first stage being administrative regions, the second Landsat TM or other remote sensing imagery, and the third on aerial photography, or more intensive but different remote sensing imagery, then the procedure is generally called multi-phase.

For most forest valuation work it is often considered more appropriate to ensure that all first stage and generally all second stage strata are sampled. In this case the sampling is just stratified random sampling. Calculation procedures for these styles of multi-phase and multi-stage sampling designs are available in statistical texts and in the general forest inventory literature.

Further References
Loetsch, F. and Haller, K.E. (1973)
Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)

6.2.6 Using experience

One way of extending the multi-phase approach is reported by Brack (1996) who used experienced forestry staff to visually estimate the commercial sawlog volumes in each compartment in a northern New South Wales forest. In essence the experienced staff provided experienced guesses. These estimates were then stored. A sample of all the compartments was then sampled using standard inventory techniques. A linear regression model was then developed to predict the measured sampled volumes from the estimated volumes and this regression model was then used to correct the estimates for all the compartments.

The approach is basically a Bayesian (Bayes 1763 (1958)) approach in that prior information (the guesses or subjective estimates being the prior information) have an information content that can be used to refine the predictions. This approach can either be used to improve the precision of an inventory or, if previous experience is available to suggest how good the estimates are, then the number of compartments that need to be sampled to meet a desired sampling precision level can be reduced.

In essence, if the guesses are by inexperienced and/or incompetent operators then the gain through the method will be nil, but with experienced staff then the gain can be quite considerable. Because the second stage sample is soundly based the overall predictions will be unbiased and quite satisfactory.

The technique is sound and has a lot of potential, but it seems that it is rarely used.
6.3 Plots or point samples

One of the first decisions that must be made in designing an inventory is whether to use plots or point samples. Point samples or angle count sampling use angle gauges the best known of which are the Spiegel Relaskop or the simple optical wedge prism.

Point samples have some definite advantages in that they give a higher priority to the larger trees which are generally the more important, and there are generally less of them in the forest. On the other hand it is more difficult to address problems near the boundary of the forest or the stratum and quite sophisticated procedures have been developed to account for this. If point samples are used to determine growth then there is generally an increase in sampling error as trees that were considered “out” during the first measurement may now be considered “in”. Point samples do have their place in forest inventory. The mathematics are now well determined and the conceptual challenge some find in thinking about sampling a point rather than an area is more a myth and lack of understanding than a real difficulty.

The choice of BAF (Basal Area Factor) is critical and the general rule is to choose a BAF that will provide approximately 10 trees for each sample. If the BAF is numerically too high then the number of trees will be too few, and if numerically too low then it may be almost impossible (for example in tropical moist forest) to obtain an unbiased estimate as large trees a long way from the point may be missed.

Plots on the other hand can be kept within the stratum or forest boundary more easily and do provide a consistent area base for determining growth. However because they sample a fixed area they may not provide as good an estimate for the largest tree diameter classes, and commonly over sample the smaller diameter classes.

One method of avoiding this over and under sampling problem is to use different fixed diameter concentric circular plots radiating from a point but this can cause similar discontinuities to point samples if used for growth.

A commonly adopted rule of thumb is to use plots if re-measurement is expected, point samples if it is not. There is no hard and fast rule.

Whether plots or point samples are used it is necessary to apply the procedures properly. Whichever method is used it is necessary to have a good understanding of the strengths and weaknesses of the approach used and it may be desirable to consult an appropriate specialist if in doubt.

Determining just what measurements should be carried out at each sampling unit is not necessarily a simple task. The objective is to achieve a desired accuracy and that can generally be achieved in a number of different ways. Commonly there are different measurement strategies that can achieve the stated objective but there may be other secondary objectives that are better achieved by one strategy than another. Like all forest mensuration it is a matter of balance.

Further References

Loetsch, F. and Haller, K.E. (1973)
Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)
Spurr, S.H. (1951)

6.4 Point sample measurements

The theory and practice of point samples, or angle count samples, including details of how to control errors in measurement is detailed on two web sites. The first is the RWG2 (1999) Code of Forest Mensuration Practice available in the annex to this Handbook and also in 2007 at:

This is maintained by Dr Cris Brack whose Forest Mensuration lecture notes are also available on http://sres.anu.edu.au/associated/mensuration/

Anyone wanting to use point sampling should consult one or other of these sites.

The following is a brief and incomplete summary of the main points.

- Choose a BAF that will provide about 10 (7-12) trees.
- If the basal area (g) is known approximately then the BAF is (g/10).
- Take care not to bias point location. It can be within a tree!
- Walk around the point, not turn around with your back to the point, as the distance to trees of interest will vary.
- Measure the distance to doubtful trees or boundary trees. This is possible using the formula
  \[ LD = \frac{50d}{\sqrt{BAF}} \]
  where LD is limiting distance and d is dbhob.
  If (measured distance > LD) then the tree is out.
  If (measured distance < LD) then the tree is in.
- Count every tree that is obviously an ‘in’ tree.
- Correct for the slope.
- Take care to measure all trees and not to duplicate trees (i.e. only measure the 360° of the circle).
- Overlap between point samples is statistically quite satisfactory but it is commonly considered prudent not to allow overlap.
- Be careful to assess trees that are obscured by other trees.
- Be careful not to get too close to the boundary of the stratum or forest. Have procedures in place to cover such circumstances.
- For example, if a full 360° sweep is not possible then it may be possible to either use a 90° or 180° sweep and weight the estimate accordingly.
- Be alert for dead trees which are normally excluded from any assessment.
- The procedures may need to consider damaged trees with broken tops or severe butt damage. Sometimes it may be appropriate to exclude them completely, and at other times it may be necessary to consider them as a separate category and measure them separately.
- Document the procedures, ensure that they are consistent and complete. Get the procedures checked and, if appropriate, discuss them with the client and gain his acceptance and approval.

An approximate guide to the number of sample points required for a stratum is:

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of sample points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 – 2.0 ha</td>
<td>8</td>
</tr>
<tr>
<td>2.0 – 10.0 ha</td>
<td>12</td>
</tr>
<tr>
<td>Over 10.0 ha</td>
<td>16</td>
</tr>
</tbody>
</table>

Stocking cannot calculated directly but can be calculated from:

\[ N = \text{BAF} \sum_{i=1}^{n} \left( \frac{1}{g_i} \right) \]

where \( g_i \) is the basal area of the i’th tree.

It should be remembered that if there are say 10 trees in sweep then stocking is ±10%, if 5 trees on average then ±20%. The question needs to be asked about how precise an estimate of stocking is required, not just basal area.
6.5 Plot measurements; general

Determining just what measurements should be carried out at each sample point is not necessarily a simple task.

The objective is to achieve a desired accuracy and that can generally be achieved in a number of quite different ways. Commonly there are different measurement strategies that can achieve the stated desired objective but there may be other secondary objectives that are better achieved by one strategy than another. Like all forest mensuration it is a matter of balance.

6.5.1 Balancing costs

Just as sampling design is a matter of balancing costs in an effort to achieve maximum precision for a fixed cost, or to achieve a target precision at lower cost, so too it is necessary to balance the costs of alternative measurements that in turn impinge on the overall precision. Two examples may help clarify this issue.

If the MARVL inventory methodology is adopted a decision must be made whether to use a standard taper function that may be available and risk possible bias, or whether it is better to measure trees to create a local taper function, at the cost of measuring fewer inventory plots. This can be considered a trade off between precision and possible bias.

Another example is in South Australia where if Predominant Height (PDH) is measured only 4-5 inventory plots can be measured by a crew in a day, whereas if an upper stand height measure based on the mean heights of the largest diameter trees is used, and a relationship used to estimate PDH then perhaps 6-10 plots can be measured. If the PDH is estimated from known site quality and age relationships then some 15-25 plots can be measured. There is a trade off between gains in sampling precision by measuring more samples against the possibility of introducing bias in the estimate of PDH.

Cluster sampling may be adopted in an effort to save measurement costs by reducing the number of clusters so as to lessen travel time and cost between samples.

Balancing the number of first and second (and subsequent) stage samples in a multi-stage sampling protocol is really just another way of balancing precision and cost.

6.5.2 Quantifying measurement error

It is common to use contractors to carry out inventory field work but in-house staff to measure research and other plots. This may be quite satisfactory if the contractors are well trained and experienced in the measurement methodology adopted but the pressure to complete an inventory quickly in order to meet contracted obligations or profit imperatives may lead to short cuts being taken and measurement errors may be made.

One way of controlling measurement error is to remeasure a small number of samples again. This may be carried out to ensure that contractors or in-house staff meet defined accuracy targets and may impinge on contractor payments and/or staff bonuses. It does provide a mechanism for determining just what the measurement errors are and it is then possible to assess the effect of measurement error on overall precision of the inventory.

6.6 Plot measurements; area

Fixed area plots are generally either rectangular or circular. The area should be selected so as to provide an objective number of trees but commonly it is determined quite arbitrarily.
6.6.1 Surveying in to the plot

The location of the plots should be determined by random selection of a fixed point which can be the plot centre for a circular plot or a fixed corner of the plot for a rectangular plot.

Surveying into the location of the plot may be difficult in natural forest and even in some plantations. To avoid selection bias when the surveyed distance and bearing may be known to be inaccurate it is desirable to survey as accurately as possible the last 50-100 m. In plantations it is common to survey along the fire break or known, mapped, track, and then to survey along the rows to the appropriate point for starting plot establishment.

6.6.2 Rectangular plots

For rectangular plots common plot areas are 0.04, 0.05 and 0.10 ha. In plantations plots are best established with the corners in the midpoint between the rows as this minimises any chance of bias.

It is also best to allow for plot area not to be exactly the nominated size in case it is not possible to get a reasonably clear line of sight across the ends of the plot.

Length to width ratios of 1:1 to 2:1 are commonly used.

In plantations that have been thinned it is generally advantageous to make the plot width, across the rows, match a multiple of the distance in rows of the extraction row frequency.

Survey accuracy should be to 0.1 m and the plot area should be recorded to four decimal places in hectare, i.e. 0.nnnn ha, although sometimes it is recorded to three decimal places.

6.6.3 Circular plots

Circular plots are preferable in natural forest and are used in some plantations.

Circular plots are generally defined in terms of the radius in metres required to achieve the desired plot area. For example a radius of 17.84 m would provide a plot of 0.1 ha.

It is necessary to ensure that there is no bias in the selection of the plot centre and it is therefore possible for the plot centre to fall within a tree making it difficult to establish the plot. Care must also be taken to measure accurately any doubtful trees at the edge of the plot. This is not such an issue for rectangular plots which is why some consider it preferable to use rectangular plots in plantations where rows can be used to assist plot survey.

Circular plots are advantageous when also measuring regeneration as locating one point allows variable radius plots to be established so as to best sample the trees, poles, saplings and seedlings.

6.7 Plot measurements; tree diameters (basal area)

Tree diameter should be measured at 1.3 m above ground on the high side of the stem.

Tree diameters should generally be recorded to the nearest 0.1 cm although some research organisations prefer to use mm. Tree diameter was one of the few approved uses of centimetre, or cm, by the Australian Metric Conversion Board in the early 1970’s.

The objective is to measure a single mark at 1.3 m but this may be affected by branch stubs, or swellings, or other malformation. In these cases most practitioners prefer to measure, in decreasing order of priority:

- a true mean, equidistant above and below 1.3 m,
- a best available mean measurement, not symmetric about 1.3 m but as close to it as possible,
- a best available single measurement.
See the RWG2 (1999) measurement procedures in the Annex for more detail.

It may be necessary to account for buttress effects. The most convenient method is to measure at 1.3 m until that point is no longer representative and is affected by buttressing and then to measure for at least one more time at the old height and also at a new height sufficiently higher to not be affected by the buttressing. The height that the new measurement is taken should also be recorded. This method enables basal area and diameter increments to be determined sensibly although there is a discontinuity in the trend over time. The importance of this issue may need to be considered before deciding whether to use the data for increment trends or yield trends.

**6.8 Plot measurements; height**

Compared with tree diameters, the measurement of tree or stand height is much more complex and more prone to error.

The RWG2 (1999) manual (see the annex) provides a sound base for tree and stand height measurement.

Tree height is defined as the vertical distance from ground level to its uppermost point. In the case of forest where tree lean is common it may be preferable to adopt the definition to the length of the tree bole or standing volume may be underestimated.

**6.8.1 Tree height measurement**

The most commonly used methods are described in detail in the RWG2 (1999) manual. They include;

- height sticks,
- hypsometers (Suunto clinometer, Forester Vertex, Haga, Relaskop, and less commonly Abney level and Blume Leiss),
- laser dendrometers, which basically rely on the same geometric principles as the hypsometers.

There are many companies that can provide tree height measuring equipment include (as at mid 2007) Forestry Tools at:


the Ben Meadows Co. at


and Forestry Supplies at


ACFA makes no recommendation about these or any other suppliers, the web sites are provided as a possible starting point.

The more important points made in the RWG2 manual include;

- the necessity to observe safety procedures and wear required safety equipment,
- the tip should be plumbed in so as to ensure that lean is corrected for,
- taking care to adjust for sloping ground,
- the need to ensure that there is no parallax error between the tip of the tree and the tip of height sticks,
- taking care to ensure that if hypsometers are used on trees with umbrageous crowns then the operators are on either side of the tree and that they sight on the same tip,
- that hypsometers are checked regularly against a known height (for example a radio mast) to ensure that they do not become maladjusted,
- taking care to ensure that the correct scale is used (for some hypsometers), and,
- the need for careful training of operators.

_As at 2007, reformatted 2012 but no textural changes_
If a Criterion Laser, or other complex measuring device, is to be used then care should be taken to
ensure that the operators are well trained and their measurements maintain consistency and
accuracy. This can be assisted by checking against known heights, as previously mentioned.

Because tree height estimation is difficult, time consuming and costly, as well as being error prone, it
is common to measure only a sample of tree heights and to use statistical procedures to determine
estimates for all the other trees in a stand (if such estimates are required).

### 6.8.2 Tree height estimation

Because tree height measurement is costly it is common to measure all trees for diameter but to
measure only a sample of trees for height and then to use a model based on these data to predict
tree height for all trees.

This is necessary as tree volume \(V\) is commonly derived from a function of diameter, dbh or \(D\)
and tree height \(H\), i.e. \(V = f[D,H]\).

Tree height generally increases as tree diameter increases with the rate of increase decreasing with
increasing diameter. Tree height often approaches an asymptote.

A range of models have been used in the past. The following incomplete list is compiled from a
number of sources including Arabatzis and Burkhart (1992) and Brack, see


The models include the following.

\[
\begin{align*}
H &= b_0 + b_1 D \quad \text{Linear} \\
H &= 1.3 + b_1 D + b_2 D^2 \quad \text{Quadratic} \\
H &= b_0 + b_1 \log(D) \quad \text{Log linear} \\
H &= b_0 + b_1 / D^{b_2} \quad \text{Inverse linear} \\
H &= b_0 * D^{b_1} \quad \text{Power} \\
\ln(H) &= b_0 + b_1 \ln(D) \quad \text{Log - log} \\
\ln(H) &= b_0 + b_1 / D \quad \text{Log inverse linear} \\
1/((H-1.3)^{0.4}) &= b_0 + b_1 / D \quad \text{Pettersen curve} \\
D/((H-1.3)^{0.4}) &= b_0 + b_1 D \quad \text{Alternative Pettersen curve}
\end{align*}
\]

It can be argued that it is important to see which function best suits a particular species and region,
and that the best curve may also change during the life of a plantation.

Of the models presented the four latter models will produce biased predictors as the model is fitted
to a transformed dependent variable and so when the predictor is transformed back to predict
height a small bias is introduced. This is generally ignored as it is small relative to the errors in the
basic measurements. However it may need to be considered.

Pettersen’s curve (Schmidt 1967) is commonly used in MARVL inventory for radiata pine in order to
predict tree heights from a sample of tree heights, and also to predict Mean Top Height. One user
suggests using the simpler alternative Pettersen curve form although also suggesting that the
reciprocal form should be used where the number of sample trees is too small or includes extreme
points.

Because the Pettersen model has a transformed dependent variable an unbiased model estimated
for a particular data set will be biased as a predictor but the extent of the bias is generally considered
negligible and acceptable. In a simple study, a bias of -0.05% resulted in the prediction of mean tree
height when the variation about the trend line had a standard error of 5%. Users may care to consider the extent of the bias in their particular circumstances. Although small it may be worth correcting for.

### 6.8.3 Upper stand height

There are many measures of stand height, generally of upper stand height, and arguments abound about the usefulness of each.

The reasons for the differences generally lie long ago in history and although there were often good cogent reasons for choosing the particular definition in an organisation the differences between the measures are more in the definitions than in the relative usefulness of the variables.

It makes good sense to stay with a definition, even if a marginally superior definition may be suggested, simply to avoid inconsistencies within the various data bases, especially over time.

The following are typical of the main definitions of upper stand height in use.

- **Mean crop height.** The mean height of the crop trees. More commonly used in New Zealand than Australia where a measure of upper stand height is generally preferred. Mean crop height is affected by thinning more than the other measures as thinning is generally from below.

- **Mean dominant height (MDH).** The mean height of the largest diameter trees per hectare, commonly the largest 40, 50, 75 or 100 trees/ha. The definition of selection criteria may differ between forest enterprises. Care should be taken not to include trees that have severely malformed tips that render them atypical.

- **Mean top height (MTH).** More commonly used in New Zealand than Australia. The height predicted by reading from a height – diameter curve (commonly the Pettersen curve (see above)) for a Dbhob corresponding to the mean top dbh (MTDBH). In Australia this is generally only used in MARVL inventory. The base number of trees may vary.

- **Predominant height (PDH).** The mean height of the tallest trees per hectare, commonly the tallest 40, 50, 75 or 100 trees per hectare. In New Zealand the predominant tree is the tallest tree on an area of 0.01 ha and the mean is the mean height of at least 4 predominant trees. In Australia the definition of selection criteria may differ between forest enterprises. For example, in South Australia as close to an equal number of trees are selected from each quarter of a plot. Also called predominant mean height (PMH) in New Zealand.

And the ancillary definition.

- **Mean top dbh (MTDBH).** Defined as the quadratic mean of the largest 100 trees (by diameter or dbhob) per hectare. If the stocking is less than 100 trees per hectare then the mean is across all trees. The base number of 100 may be varied in Australian use.

In some cases the trees are selected according to the definition and then measured for height, the mean calculated and the measure of upper stand height determined.

Some organisations believe that it is necessary to use a measure based on the tallest trees and to select these trees by climbing to ensure that the correct trees are selected. This is more commonly used with remeasured permanent research plots than inventory plots.

In other cases a height – diameter curve is defined based on sample tree heights, and the estimated height obtained for each of the selected trees. This can only be used for measures based on the largest diameter trees. In MTH as defined in New Zealand and as used in the MARVL inventory methodology, the estimated individual heights are generally not used but the estimated height of the tree of MTDBH.

In other cases the upper stand height measure adopted is based on the trees of largest diameter as this can ensure that the correct trees are selected.
In almost all cases, if there are fewer trees per hectare than the number in the definition, then all trees are measured for height.

It is common for a definition to explicitly avoid the use of trees where the tip of the tree has been seriously damaged.

In uneven aged forest it can be difficult to establish a height diameter curve but it may be easier to establish a merchantable height diameter curve.

### 6.8.4 Converting from one height measure to another

Many forest management organisations use a number of different measures of upper stand height. This may be for a number of reasons, generally convenience and cost. It may also occur when plantation resources with differing mensuration methods are acquired by an organisation.

For example MARVL uses MTH defined as the height of the tree of equivalent MDH (commonly quadratic mean diameter of largest 100 trees/ha) as defined by sample tree heights and the Pettersen curve (see above).

Growth models may have been developed using a different measure such as MDH (based on say the mean height of the largest diameter 40, 50, 75 or 100 trees per ha) or PDH based on the mean height of the tallest trees.

In some cases the number of trees selected change so inventory might be based on MDH, say the mean height of the largest 40 trees /ha, but growth models may use PDH based on 75 trees /ha.

Often what is needed is a method for converting from one metric to the metric that an organisation decides is to be the base it uses.

Generally the model is a simple linear correction model. Polynomial terms should be tested to ensure that they are not required. The models relating two alternative upper stand height measures \(H_1\) and \(H_2\) are generally of the simple structure

\[
H_1 = b_0 + b_1 H_2
\]

although (Leech 1974) showed that for various South Australian radiata pine alternatives the coefficient \(b_1\) was not significantly different from 1.0 and so the simple correction model

\[
H_1 = b_0 + H_2
\]

or

\[
H_1 - H_2 = b_0
\]

was appropriate, and far simpler. Examples have been observed where the coefficient \(b_1\) was probably not significantly different from 1.0 in models that were being used in practice. This is unsound statistically.

In some circumstances other variables such as age, stand density and site potential may be useful variables.

### 6.9 Plot measurements; volume

There are a variety of methods for calculating volumes of trees and stands.

#### 6.9.1 Calculated from tree diameter and height

There is need to predict tree volume (and by summation stand volume) and one way is to develop tree volume equations that just require tree diameter and either tree or upper stand height to be measured. The biometrics of these equations is discussed elsewhere.
The most commonly used model form is:

\[ Y = b_0 + b_1 D^2 H \]

where

- \( Y \) is tree volume
- \( D \) is tree dbhob, diameter at breast height over bark
- \( H \) is tree height

although other forms are also commonly used, including:

\[ Y = b_1 D^3 H \]
\[ Y = b_0 + b_1 D^2 H + b_2 D^2 + b_3 H \]
\[ Y = b_0 + b_1 (D-b_2)^2 (H-b_3) \]
\[ Y = b_0 + b_1 (D^2-b_2) (H-b_3) \]

and even

\[ Y = b_1 D^b_2 H^b_3 \]

which can be transformed by taking logarithms into an intrinsically linear model form

\[ \ln(Y) = b_1' + b_2 \ln(D) + b_3 \ln(H) \]

Using the concept of dimensional analysis the sum \((b_2+b_3)\) in the last equation should equal 3.0 with \((b_2=2.0, b_3=1.0)\). However as trees are not cylinders but can generally be approximated by a neiloid or second degree paraboloid and then the parameter values generally fall in the ranges \((b_2 \approx 2.2-2.5, b_3 \approx 0.5-0.8)\) with the \((b_2+b_3 \approx 3)\).

### 6.9.2 Calculated from tree diameter, height and taper

If there are measurements of tree diameter (dbhob), tree height, and functions available to predict the taper up the stem and also bark thickness up the stem, then it is possible to calculate stem volume. This is done by integrating the taper function between the stump and the tip height using \(D=dbhob\) at \(H=1.3\) m as one control point, \(D=0\) at \(H=\) tree height as the other.

The inventory protocol may be extended by recording stem quality in product classes up the stem. This is commonly called a MARVL inventory after the New Zealand protocol (Deadman and Goulding 1978, Goulding and Lawrence 1992), although the calculation procedures do not have to use either the MARVL system or its replacement Atlas Cruiser.

The first advantage of this methodology is that volumes to either specific heights or specific top diameter limits can be determined. The second advantage is that volumes to different product categories can be determined, because both the taper and quality of the stem is available.

This leads to the ability to use a dynamic bucking or cross cutting algorithm to determine the most efficient and profitable use of the whole of the stem. The procedure in the MARVL (now Atlas Cruiser) and similar systems uses a variant of an optimisation algorithm to achieve this. The calculations require definitions of products (diameter and length ranges) and their prices.

The protocol is very useful for inventory prior to clear felling in that it can help achieve greater profitability.

Its use for forest valuation is based on enabling a sound determination of value by products.

The MARVL inventory protocol relies on having an appropriate taper function and in some cases this is developed for a particular stand by clear felling samples, measuring them, and defining a local taper equation. The reliance is greater if the prediction of volumes by products is a major requirement.
### 6.9.3 Sample tree measurements

The direct measurement of stem volume is generally not appropriate for forest inventory. This is because such measurements are expensive to obtain and it is generally not the most efficient way to achieve overall prediction efficiency.

Tree or stem measurements are however commonly used in research plots, including thinning research plots.

Sample tree measurements may be appropriate for a stand outside the common experience of a forest valuer, for example a different species, or a small forest that has not been inventoried before and which is distant from stands where appropriate biometrics might be available.

Sample trees are generally measured by taking measurements at intervals up the stem. Measurements are commonly both over and under bark, as under bark volume is generally what is required to be predicted. This enables over bark dbhob to be used to predict under bark volumes.

Measurement intervals vary.

- Historically 10 foot sections were commonly used as these facilitated manual calculation in the days before computers were available.
- This was converted to 3 m sections by some organisations to ensure consistency between imperial and metric measurements in long trend Permanent Sample Plots (PSPs) as 10 feet = 3.048 m ≈ 3 m.
- Some organisations consider that 2 m sections are superior.
- Some organisations measure to a particular top diameter limit that was originally set as the expected harvesting upper diameter limit. That is generally no longer appropriate but the measurement protocol is maintained for consistency within the data bases.
- The better approach is to use variable sections, measuring the stem at closer intervals at the base, in an attempt to have approximately equal volume in each section. This better accommodates measurement error than fixed length sections, and provides more measurements where the greater value is.
- One variant useful for standing trees is the four-way Regional Volume Table used in South Australia where trees are measured for dbhob, DUB at 1.5m, DUB at either 4.5 or 7.5 m, and tree height (Lewis, McIntyre and Leech 1973). This provides good estimates of stem volume and the upper stem measurement can be reached by ladders. It has been used (Dr Geoff Wood pers. comm.) to predict volume for other species in other regions and has been found to be virtually unbiased, presumably because it effectively accounts for tree shape as well as dbhob and tree height, and accounts for bark thickness.

Sample tree measurements may provide the base data for the development of appropriate tree volume equations or of taper equations.

### 6.9.4 Importance sampling

Importance sampling is a highly efficient method of deriving tree volume when volume functions are not available (Gregoire et al. 1986, Wiant et al. 1989, Wood and Wiant 1992, Wood et al. 1990 and Leech 1996) and when there is doubt about the applicability of available equations.

The technique uses measurements of tree diameter (D=dbhob at H=1.3 m), tree height (D=0.0 at H=h) and also an upper stem diameter (D=D_i at H=H_i). A proxy taper function is also required but this does not have to be known to be appropriate for the area.
Volume \( (V_e) \) is calculated from diameter, height and the proxy taper function. The proxy taper function is used to estimate the diameter \( (D_i) \) at the position \( (H=H_i) \) selected on the stem. The estimated importance sampled volume \( (V_i) \) is calculated from:

\[
V_i = V_e \left( \frac{D_i}{D_e} \right)^2
\]

The difference between the two common forms of importance sampling described below is in the selection of the third point up the tree, the height at which the extra diameter measurement is taken.

The work of Gregoire especially, but also the others referred to above, demonstrates that the proxy taper function does not have to be a terribly good one for the procedure to provide efficient estimates of volume.

**Centroid sampling**

In centroid sampling the height at which the third measurement is taken is the point at which, according to the proxy taper function, half the volume is above that point, half below. For most trees with approximately second degree paraboloid shapes this is at approximately 30% of the tree height.

The advantage of this point is that it is basically half way, in volume terms, between the other two measurements \( (D=dbhob at H=1.3 m and D=0 at H=h or tree height) \).

Centroid sampling is theoretically biased. The bias is a function of the difference between the true taper and the proxy taper function. However the bias is negligible in practice even if the proxy taper function is very simple and known to not be appropriate for the area being sampled.

**Importance sampling**

In the more commonly used definition of importance sampling the height at which the third measured point \( (D=D_i at H=h_i) \) is made is defined by a uniform random distribution of volume up the tree. This means that half the points will be below the centroid, half above, and the concentration of points is in the lower part of the tree. This approach is theoretically unbiased and still very efficient.

Professor Tim Gregoire (pers. comm.) suggests that the use of this uniform distribution is preferable because it is theoretically unbiased while recognising that centroid sampling is only minimally biased.

In practice if the selected height \( (H=h_i) \) is near either of the other two measured points then errors in diameter measurement will have a great effect and in practice this decreases the precision of the estimate.

**Generalised importance sampling**

Leech (1996) suggested that the heights selected by both centroid and importance sampling are just extreme values of heights selected from a Beta distribution of volume up the tree and that the two approaches are really just extremes of the same approach.

He demonstrated that there is a value of the dispersion parameter in the Beta distribution that is more efficient than either the centroid or importance sampling methods and that is less biased than centroid sampling and more efficient than importance sampling.

**Other variations**

Another variant is to measure two extra measurements not one, using antithetic variates. The first random number \( (n) \) is selected as for importance sampling and the other selected at the height equivalent to the random number \( (1-n) \).
6.9.5 Market application nuances

If harvesting contracts are predicated in terms of weight then it may be necessary to develop weight to volume conversion factors so that harvested weights can be converted to volume or measured forest volume can be converted to weight. Weight may be defined in a number of ways including oven dry weight and green weight although generally green weight is used for log products.

Similarly the sale of some forest products such as small logs that will be preserved and used for fencing and other similar uses may be predicated in terms of number of pieces.

Care needs to be taken to ensure that any conversions used are sensible, are unbiased and that they are recorded.

6.10 Site potential

Site potential is often used as a means of stratification and in some measurement systems it is used as the driver variable for growth.

There are basically three different ways of measuring site potential.

- It can be based on edaphic factors; including soil type, parent geology, existing or remnant native vegetation, rainfall, slope, topography, and in fact many environmental variables including information from ANUCLIM.

- Site index is based on mean upper stand height at a base age.

- Site quality is generally based on total production volume at a specified base age.

The base age is commonly about the midpoint of the rotation so as to lessen prediction errors when an height-age curve or equation is used to predict the site index at other ages based on height at that other age. Some consider that the base age should be earlier, say at about age 10 for radiata pine and about age 4 or 5 for blue gum, which approximates the age at which volume growth culminates and means that almost all projections are forward from that point in time and not backwards.

The most commonly used indices of site potential are based on site index or estimated upper stand height at an index age. The advantage of using a measure of upper stand height is that it is generally not markedly affected by thinning. Mean tree height is less useful as it affected by thinning especially when thinning is generally from below, taking the smaller trees.

For radiata pine, site index (SI) is less effective in South Australia where height growth is affected by wind and micro-topographic effects on the coastal plain. Two plots measured at age 9½ that were 100 m apart in the same compartment had the same PDH (a measure of upper stand height) and the same stocking, but one had twice the basal area and three times the volume of the other. This was considered to be partly caused by soil type differences but also topography. South Australia generally uses Site Quality (Y10) defined as the total volume production of radiata pine at age 10 for a relatively narrow range of initial stocking (Lewis et al. 1976). These authors regarded Site Quality as a better predictor of future growth of radiata pine than Site Index in that region.

Another method of referring to site potential is Yield Class, the maximum or culmination of mean annual increment, generally in terms of volume (m$^3$/ha). This refers to volume produced not volume available for harvesting.

Further References


6.11 Other plot measurements

Other measurements may be required or may be desired in order to meet particular needs.
6.11.1 Bark thickness

Sawlogs are generally measured under bark and it is often necessary to convert from over bark measurements to under bark measurements. This is easier if the end of a log can be accessed on say a log truck, but is more difficult if the measurements are required on a standing tree.

The most common form of bark gauge used to measure bark thickness on standing trees is the so-called Swedish Bark Gauge which has a handle to allow the sharpened U-shaped ferrule to be tapped through the bark until the cambium is reached. It is generally easier to push the bark gauge into the cambium in between bark plates. The T-bar slide can then be positioned so that the single bark thickness can be easily read.

This gauge is suitable for most pines and for some eucalypts.
Lewis (1953) described a simple bark gauge for thin barked trees such as in radiata pine at young ages and where fluting has not started to occur. It is still used in some places.
Care must be taken measuring bark thickness on species with dehiscent bark.
As many trees are elliptical and the bark thickness varies around the stem it is necessary to take more than one measurement, generally two or preferably four.

6.11.2 Product description

For some species, and especially for radiata pine, it is desirable to record the stem quality so that the various possible log products within a stem and be better determined. This is the base of the MARVL inventory protocol.

This requires a stem dictionary detailing the relationship between stem characteristics and possible product classification.

6.11.3 Selection of trees for future harvest operations

Most organisations is to use a computer based algorithm to determine which trees are likely to be removed in the next commercial harvesting operation.

In South Australia (Lewis et al. 1976) inventory in radiata pine is carried out soon after each commercial thinning and the information used to predict the next commercial operation. As the form of the stands varies considerably it has been found desirable to identify the trees that are expected to be removed at the next operation. This avoids the need for generalised functions of thinning type for short term prediction and the precision of the prediction of the next commercial thinning operation is considerably improved. This approach may be appropriate for other forest enterprises.

6.12 Measurement procedures

There is a great need to record the detailed measurement procedures used in forest mensuration and management field work. This is especially so for research plots where data measured up to 50 years ago may be used for current modelling, but it is also necessary for inventory plot measurement as well.

Examples are known where data can now no longer be used because the exact method of measuring those data has been lost in the fog of history.

Recording the measurement procedures would seem to be an obviously vital activity but because the work does not improve the precision of the current predictions, and because there is generally only a
limited time to produce the necessary planning reports, this task is unfortunately delayed, and often delayed indefinitely.

There is also a need to ensure that any computer data bases are appropriately backed up. This should include off site backups, ensuring that all historical archives can be read by current hardware and software, ensuring that the measurement procedures are also recorded, and generally ensuring that all information collected in the past remains useful.

Unfortunately there have too often been situations where a problem occurs and the archive backups need to be read and either the hardware to do so, or the software to do so, are not available. This loss of data can have serious implications. Cases are also known where it became desirable to either redevelop models or to justify existing models, and the base data used for that model development have been lost. This has just added to the uncertainty in forest planning, an uncertainty that is really not necessary. It can also be very costly indeed.

There is a great advantage in not changing measurement procedures too often. It is recommended that measurement protocols only be changed whenever significant gains in sampling, measurement or prediction efficiency can be gained. The reason is that it may cause difficulties handling the different measurement protocols in both the data base storage and prediction systems. However the possibility of changing protocols to make inventory more efficient and more cost effective has to be considered very seriously.

Recording measurement procedures should not be an afterthought but part of any forest mensuration activity. The plot data may outlive the usefulness and life of the measurer!

Further References

6.12.1 Continental Forest Monitoring Framework

The Department of Agriculture, Fisheries and Forestry Bureau of Rural Sciences was, in 2006, investigating the development of a Continental Forest Monitoring Framework.

Now this continental level inventory is unlikely to be directly relevant to forest valuation which is at a much reduced scale but the basic underlying inventory procedures are the same and the procedures developed may be of considerable use.

The terms of reference include;
- be designed to meet national reporting and monitoring requirements,
- measure a specified list of metrics (including - forest extent and structure (height, crown canopy cover), forest type (genus, species), growth stage, tenure (including private individual, industrial, institutional), reserve status (including reserves on private land), intended land use (areas zoned or intended to be managed for various objectives), disturbance, and forest health),
- be simple flexible and repeatable,
- be based on permanent/relocatable site-based measurement,
- report to accuracies commensurate with current international practice, and,
- provide estimates of change at 5 yearly intervals.

The NFI has also specified that the monitoring framework apply measurement methods that are;
- objective and measured (rather than subjective/estimated),
- yield continuous numerical values (for example tree diameter) rather than categorical values (for example soil type, crown class),
- repeatable,
- a direct measure rather than a surrogate of the attribute of interest,
- not technology dependant (i.e. enduring),
- link directly to the relevant Montreal indicator, and,

As at 2007, reformatted 2012 but no textural changes
• meet national and/or international standards (where they exist).

For more information see the web site.

and search for Continental Forest Monitoring Framework.

6.13 Accuracy

The question often asked is “how accurate is a forest inventory?”

Unfortunately all too often the person asking the question does not understand the question let alone is able to interpret the answer.

6.13.1 Concept of accuracy; precision and bias

Accuracy is a concept that really is in two parts, precision and bias.

Precision refers to the repeatability of the estimate, the degree to which estimates are clustered about their own average.

Bias is a measure of the difference between the expectation of a sample estimator and the true population value, systematically distorting results.

The diagram, reproduced with permission from Vanclay (1994), provides a useful way of depicting the differences between the two components of accuracy.

Commonly the accuracy of an estimate is judged from precision assuming that the estimate is unbiased, but that may or may not always be the case.

The true measure of accuracy is the mean square error (MSE) defined by:

\[ \text{MSE} = (\text{precision})^2 + (\text{bias})^2 \]

Many users confuse precision and accuracy. They have very specific definitions.

6.13.2 Components of error

There is an infinite range of sampling designs and so it is only sensible to suggest how inventory precision may be calculated for a few simple designs. The most commonly used sampling design for forest inventory is stratified random sampling but for convenience simple random sampling is also discussed.

The precision of an inventory prediction is rarely considered for, as Cunia (1990) notes, there are four quite different sources of error in an inventory and generally only one, sampling error is considered and quoted.

- Sampling precision. The sampling precision can calculated from the sample estimates.
- Model error. This is more difficult to incorporate into the overall estimate of precision. This could be the error in tree volume equations, in taper equations, and will apply where any statistical model is used to determine the variable of interest.
- Application error. When data are not available for an area of interest, but are available from another similar area, then application error may occur. If models were developed for an adjacent...
area then, similarly, application error may occur. Commonly, models are developed across a wide area and then applied to particular smaller units. In this case there may be application error in the use of the models for the subject areas individually but overall the predictions may be unbiased. Application error may or may not be material. Assessment of this error source must be subjective.

- Measurement error. This is also generally ignored but may in fact be quite high, adding significantly to the imprecision of an inventory.

Many inventories provide some estimate of precision but because the estimate considers only some of the error sources it is generally a considerable underestimate of the overall precision of the inventory, which is the figure generally wanted by clients or managers.

Which errors are included in the statement of precision needs to be clearly recorded in any report. Otherwise the estimate of precision is likely to be misinterpreted.

### 6.13.3 Sampling error for a simple random sampling

In simple random sampling the mean can be calculated simply by summing across all the observations \((i=1...i...n)\)

\[
\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}
\]

and the variance \(\sigma^2\) can be calculated

\[
\sigma^2 = \frac{1}{(n-1)} \sum_{i=1}^{n} (y_i - \bar{y})^2
\]

The confidence limits for the estimated mean value for the population \(\hat{y}\) is based on Student’s \(t\) for the desired probability.

\[
\hat{y} = \bar{y} \pm t_{p=0.05} \cdot \sigma
\]

This calculation can be implemented fairly simply. In most cases \(p=0.05\) is an appropriate probability level.

### 6.13.4 Sampling error for a stratified random sampling

The use of stratification of the forest and of stratified random sampling is a means of reducing the variance within strata and so aims to improve the precision of the overall estimate.

It is common to stratify the forest into areas considered sufficiently uniform for the next commercial harvesting operation, but the level of variation accepted in practice is a function of both the forest variability and the size of the unit. The level of variation that is generally tolerated is greater for a smaller potential harvesting unit than for a large one.

Within the harvesting unit it is common to stratify based on productivity or on past harvesting.

What is generally required are the estimate of the mean and the sampling error of that mean estimate at a harvesting unit level, for the variable of interest, generally volume. The results for the complete forest estate can then be calculated by combining the figures.

In most forest inventories it is necessary to balance the available inventory plot or point samples with the variability of the forest. A practical guide is that there should generally be a minimum of at least 3-5, preferably up to 10, plots in each stratum.

### Calculation of totals

Cochran (1963) provides the method of computing the mean estimate for a stratified random sample.
In forest inventory the sampling level is generally low enough that the finite population correction factor can be ignored. The Cochran reference provides the necessary detail if this assumption is not considered satisfactory. The following discussion assumes that the finite population correction factor can be ignored at both a stratum and a total level.

If \( w_h \) is the strata weight for the h’th strata (h=1...h...H), and this can either be based on the number of samples in a strata \( n_h \) as a proportion of all samples \( N \), or on the strata area \( a_h \) as a proportion of the total area \( A \)

\[
\begin{align*}
\quad & w_h = n_h / N \\
\text{or} & w_h = a_h / A
\end{align*}
\]

In this notation \( \sum_{i=1}^{N} \) represents the sum across all N observations.

If there are H strata, (h=1...h...H), and \( n_h \) is the number of samples in the h’th strata, then

\[
N = \sum_{h=1}^{H} (n_h)
\]

Then the unbiased estimate of the population mean \( \bar{y} \) can be based on the mean value \( y_h \) for the strata, which is calculated from the sum of \( y_{hi} \) which in turn is the i’th observation in the h’th strata which has \( n_h \) observations

\[
y_h = \sum_{i=1}^{n_h} \{ y_{hi} / n_h \}
\]

and when summed across all the strata (h=1...h...H)

\[
\bar{y} = \sum_{h=1}^{H} \{ w_h, y_h \}
\]

The variance \( \sigma^2 \) can be calculated from the individual strata variances \( \sigma_h^2 \) which are calculated in the normal manner from \( \sigma_i^2 \).

\[
\sigma_h^2 = \frac{1}{(n_h-1)} \sum_{i=1}^{n_h} \{ y_{hi} - y_h \}^2 \sigma_i^2
\]

and then

\[
\sigma^2 = \sum_{h=1}^{H} \{ w_h^2 \sigma_h^2 / n_h \}
\]

In general terms the strata weights will be better based on the strata areas and not the number of samples.

**Calculation of confidence limits**

For a stratified random sample the calculation of the confidence limits to the mean is similar to that for a simple random sample but the effective number of degrees of freedom is not a simple calculation based on the numbers of samples adjusted for the number of strata groups.

One method of calculating the effective degrees of freedom was developed by Satterthwaite (1946, Cochran 1963).

If \( g_h \) is defined as

\[
g_h = \{ w_h^2 / n_h \}
\]
then
\[ n_e = \left( \sum_{h=1}^{H} \left\{ g_h \sigma_h^2 \right\} \right)^2 / \left( \sum_{h=1}^{H} \left\{ (g_h \sigma_h^2) / (n_h - 1) \right\} \right) \]

where:
- \( n_e \) Effective number of degrees of freedom,
- \( g_h, \sigma_h \) are as defined earlier, and,
- \( n_h \) is the number of samples in the \( h \)’th strata (\( h=1 \ldots H \))

It should be noted that this effective degrees of freedom is only used to enter into a table of Student’s \( t \) for the desired probability value, generally \( p=0.05 \), to get the \( t \)-value for use in the calculation. It has no intrinsic utility in itself. One unpublished example from a forest inventory in practice shows a population of approximately 100 samples in five strata having an effective degrees of freedom of 4 and another similar example a value close to 90. The effect on the confidence limits of such changes is dampened because it is used only as an entry to the table of Student’s \( t \).

The confidence limits for the estimated mean value for the population \( \hat{y} \) is
\[ \hat{y} = \bar{y} \pm t_{p=0.05} \sigma \]

This calculation can be implemented fairly simply using the appropriate probability for the study.

A radiata pine study

Leech and Correll (1993) carried out an analysis of the sampling error in a radiata pine inventory based in stratified random sampling in South Australia. The study showed that the sampling error between logging coupes was considerable. This indicates that if the expected variation can be predicted then the number of samples to be measured can be higher in the more variable coupes and lower in the less variable coupes leading to considerable gains in economic efficiency. In essence the same precision can be achieved with fewer samples. Given the cost of inventory field work this gain in efficiency may well be worth pursuing.

The study also shows the effect of the Central Limit Theorem in that while the sampling errors are great at the coupe level (≈10-30%) they are considerably less (≈3-5%) for the total volume harvested in any one year. Thus although the precision of the prediction of volumes to be logged may be high at a coupe level the overall prediction precision may be quite acceptable.

Inventory design needs to consider the desired sampling precision at a logging coupe level, and at a higher level such as a forest estate level, or a cutting plan year level.

6.13.5 Systematic sampling

A systematic sample can be described as a regular sampling framework. It has some practical advantages and some statistical disadvantages. The statistical implications of systematic sampling compared with simple random sampling can be found in any sampling theory text book such as Cochran (1963) or Som (1973), or for a forestry perspective, Freese (1962).

In forest inventory one practical advantage of systematic sampling is that sampling can proceed without knowing the total population if a sampling fraction (or rate of plots per area) is fixed beforehand, and sampling may be easier and cheaper. Another is that systematic sampling at inventory would seem to better cover the total area as simple random sampling may produce a cluster of samples in one part of the total area, although many statisticians would argue strongly against this philosophy. Fixing the sampling fraction without knowing the population size can lead to more samples being measured than are necessary to achieve a desired precision. Systematic sampling has often been derided because the periodicity of the sample may be the same as some natural periodicity, such as the frequency of ridge tops or extraction rows, but in forest inventory practice systematic sampling has often been used for purely pragmatic reasons. In essence,
systematic sampling is imprecise when units within the same sample are homogeneous, and precise if the samples have the same variation as the population as a whole. Given that most forest inventories have no obvious underlying periodicity many inventory specialists have been prepared to accept the theoretical disadvantages.

Statistically it is common to compute means and variances, and also confidence limits, assuming that simple random sampling or stratified random sampling theory is appropriate when in fact it may not be. This assumption is appropriate if the systematic sample has the same underlying variation as the population.

One approach at developing a special procedure for systematic samples in forest inventory was that of Matern (1960). Matern’s methodology was used in Burma (Myanmar) by Jerry Leech (pers. comm.) but he later demonstrated using Indonesian data that it was not appropriate unless it was for a large contiguous area. Most inventory practitioners would argue that applying random sampling theory to a systematic sample is quite satisfactory and quite appropriate. Many statisticians would agree.

If systematic sampling is considered appropriate for practical and pragmatic reasons then it would seem quite sensible to assume that random sampling theory is appropriate and to disclose this assumption in any report.

Further References
Cochran, W.G. (1963) [General sampling theory]
Freese, F. (1962) [Forest sampling]
Loetsch, F. and Haller, K.E. (1973)
Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)
Matern, B. (1960)
Som, R.K. (1973) [General sampling theory]

6.13.6 More complicated sampling designs

Forest inventory is expensive and the cost of obtaining field samples needs to be very carefully monitored and controlled. Complicated multi-phase or multi-stage or cluster sampling designs may be used as they generally offer similar precision at an overall lesser cost.

Cluster sampling has the advantage that within cluster and between cluster sampling variances can be calculated, as well as any strata variances. This may assist in determining whether the stratification is appropriate, and may better indicate spatial variability than a simple strata sampling variance.

Cluster sampling also has the advantage that a number of the plots are close together thus generally reducing the travelling time between plots.

A number of general points should be made.

First, more complicated sampling designs may make extension to other areas more difficult and the cost advantages may come at a price of increased inflexibility. However it may not, so care must be taken to ensure that the design meets the clients current and expected future needs.

The second point is that the more complicated the design the more complicated the calculation procedures and the more difficult it is to explain the procedures to people without detailed statistical knowledge. In general terms it is undesirable to suggest a more complicated design if a simpler one will suffice, or, if the more complicated design is not readily understood by the various users. Lack of understanding may also lead to a reduction in confidence in the results which may be highly undesirable. Lack of understanding may also be an issue if there is some possibility of litigation.
Third, if it is expected that in the future an inventory may be repeated over the same forest and that some plots may be measured again on the same site so as to get a sampling with at least partial replacement, but not complete replacement, then the calculation procedures become exceedingly difficult if the stratification also changes. If cluster sampling is adopted for the first inventory then the calculation procedures may become too complicated for conventional statistical sampling methods. In essence the inventory design can become just too complicated.

For details about calculation of means, sampling error and confidence limits for designs other than simple random sampling and stratified random sampling, consult an appropriate and qualified statistician, read an appropriate text book or refer to refereed papers in reputable publications. The classic forest inventory texts of Loetsch and Haller (1973) and Loetsch, Zeohrer and Haller (1973) are especially useful.

It is not just the calculation of the mean and standard error that needs to be considered. For many complex sampling frameworks the methodology for calculating the number of degrees of freedom to be used when entering the table of Student’s $t$ is quite problematic.

**Further References**

Cochran, W.G. (1963)

Som, R.K. (1973)
Data for growth modelling

Data for managing forests can be divided into two broad categories.

- Data to determine just what is there in the forest, generally in terms of wood volume, biomass, number of trees, etc. The forest inventory should be an unbiased and precise estimate of what is in the forest at that point in time.

- Data to develop biometric models (including growth models). These models will be applied to the data from the current forest, the forest inventory, to predict what future outturn will be. These data do not have to be an unbiased estimate of the forest, and there are cogent reasons why they should not be, but rather they should cover the complete range of silviculture that any planner may consider plausible. The models should be able to predict across the whole range of the possible response surfaces and the models should provide unbiased predictions over the whole surface.

Data for growth modelling in particular should ideally cover long time periods with many measurements taken during that time. Ideally plantation growth modelling data should cover a range of plantations so that any seasonal fluctuations in growth caused by above or below average rainfall can be considered natural variation across the complete age range. This is not often feasible but it is the objective.

Not all prediction models require long term trend data.

Measurement protocol

For any data used for modelling, especially the long term trend data used to develop growth models, it is necessary to record the measurement protocols used as unfortunately they can change and may drift over time. Inconsistent measurements at various stages in a plot’s life can confound the trends that are being modelled and examples are known where biased models have resulted due to a lack of understanding of exactly how past measurements were taken. This is especially relevant for upper stand height measurements, where the definitions may have changed over a 10-30 year period, and for volume, where the measurement protocols for sample trees may also have changed.

Measurement precision

Inventory plot measurement is generally a one-off task and re-measurement may or may not be on exactly the same site. Determination of increment is generally not the objective. Measurement of these plots may be contracted out although the objective is still to obtain consistent and reliable measurements.

For research plots the need for consistency is far greater and the standards required are far higher because it is generally the trends and differences between successive measurements that are required. Poor measurements can prejudice an analysis and render a costly experiment of little use.

For research plots it is generally preferable to use well trained, experienced crews and to use the same crews over time to ensure consistency. This is generally best done by in-house staff.

Research trials

Research trials are generally established in order to test a particular hypothesis and the experimental design is generally chosen with a particular objective in mind.

The data can often be used in other analyses and it is rare that a trial is only used for the purpose for which it was originally intended. For this reason most forest managers and forest researchers aim to establish flexible experiments that can be used for multiple purposes depending on, as yet unknown,
future needs. Plot measurement, especially in research plots, can be very expensive so it is desirable to extract as much information from those data as possible.

**Range of treatments**

The range of treatments to be evaluated in a research trial should generally cover the complete array of possible future silvicultural practices and should not be limited to what a manager perceives as being economically feasible today. In this way it is possible to develop response surface models and these can then be evaluated to determine just what is managerially acceptable for a particular organisation at a particular point in time.

Modelling is easier if there is a great breadth of treatments.

**Plot size**

Research trials, including thinning trials, are generally established with the objective of measuring them for a number of years so that growth trends can be better determined.

Point samples are generally not considered satisfactory because as the trees grow the sample will take in more and more trees if the same BAF wedge is used, or a discontinuity can occur if a different BAF is used.

Plots are obviously better for longer term growth data. The question is what size should a plot be? Optimum plot size is a balance between having enough trees for the plots to represent the treatment satisfactorily and the increased costs of measuring more trees.

An example of this is for plantations which may be established at 1600 stems/ha but after various commercial thinnings may finish with as few as 50 stems/ha. Probably the most commonly used plot size is 0.1 ha and this may start with 150-170 trees which is obviously more than is really needed at that stage, and finish with as few as 4-6 trees, which is equally obviously less than desirable. However if plot size is changed during the life of the plot to overcome this particular difficulty then the trend may have a discontinuity. This can be accounted for by measuring two plot sizes at the time of change but this does cause future analytical challenges.

Part of the problem is that when a plot is established there is a specific objective in mind but by the time the data are used that objective has generally changed.

**Measurement interval**

One challenge is that measurement error can mask any increment, and it is increment that is generally the variable of interest.

An example of this is if, say, based on 10 plots the basal area of a stand is growing at 2 m²/ha/annum starting from 25 m²/ha and if the measurement error of the mean is only 3%, then over the three years (including two years growth) the mean values of $y$ are

$$\bar{y}_1 = 25, \quad \bar{y}_2 = 27, \quad \bar{y}_3 = 29$$

and

$$\sigma_1 = 0.75, \quad \sigma_2 = 0.81, \quad \sigma_3 = 0.87$$

and the differences are

$$\left( \bar{y}_2 - \bar{y}_1 \right) = 2.0, \quad \left( \bar{y}_3 - \bar{y}_1 \right) = 4.0$$

The combined standard error can be approximately obtained by summing the variances as

$$\sigma_{\bar{y}_2 - \bar{y}_1} = \sqrt{\sigma_1^2 + \sigma_2^2} = 1.10$$

$$\sigma_{\bar{y}_3 - \bar{y}_1} = \sqrt{\sigma_1^2 + \sigma_3^2} = 1.15$$

As at 2007, reformatted 2012 but no textural changes
In this example the increment over one year is not significantly different from zero using a Student’s t-test although the two year increment is. It would not be sensible to conclude that as the increment is not significantly different from zero it should be taken to be zero.

Measurement interval needs to take into account the quality of the measurements, the expected growth over the period, and the way the data are to be used. For example, it may make sense to measure every two or three years rather than annually, but if there are no other data available then it may be better to measure annually and develop interim growth models based on that data and use them with great care. Equally, it is important to have at least some plots measured annually if it is believed that annual rainfall patterns in growth may emerge.

It is a matter of balancing the modelling needs, the likely measurement errors, the cost of obtaining the measurements, and the expected use of the data. It is also a matter of second guessing future data needs.

**Importance of statistics**

The advantage of using a sound statistical analysis is obvious; the models can be shown to be precise unbiased estimators. Having models that have been developed in a statistically sound way should assist managers without statistical expertise gain confidence in the use of the models.

However, examples are known of complex large experiments that were established to test a particular hypothesis, but when the trial was analysed the different treatments were found not to be significantly different.

Some people have argued that because there are no statistical differences between treatments that there are no differences between treatments. However it is more correct to say that no significant differences could be discerned. The analysis does not say that there were no differences, just that no significant differences could be detected.

On the other hand it can also be argued in some cases that the failure to discriminate statistically significant differences could perhaps be due to the failure to use the appropriate analytical method.

Or, it may be that there were too few replicates in the experimental design. A trend may be obvious through the mean of the treatments, but the trend may not be statistically significant.

Ideally more work should be undertaken in these cases, either more data collected or a better analysis carried out, in an attempt to resolve the issues. In practice this may not be feasible, at least in the short term.

Forest managers generally want predictive models, not estimators, and the statistical testing of the differences between treatments is a test of estimators not predictors. Prediction models may be able to be developed and sensitivity analyses used to see if the effects of the models within the planning system are sensible, consistent and appropriate.

This must not be misinterpreted as carte blanche to ignore statistics, but as an indicator that for some uses, in some situations, prediction models that are less than fully satisfactory statistically may have a place. However using such models may be difficult to justify, and may be fraught with problems as the model may, in fact, not be appropriate at all!

**The challenge of repeated measurements**

For the development of growth models the use of long term trend series is intuitively appealing as each plot may be represented by a number of measurements and the long term growth trend may be quite obvious. However the use of long term trend data does provides some challenges in that it is necessary to consider the error term of the trend within the model based on the plot and the error term between the plots. The statistical issues are therefore complex.

The logical format for model development is to first develop a growth model for each plot in turn and then, in a second stage analysis, predict the parameters for the combined growth model using the
first stage plot based parameters as the input data. The error terms must be carefully considered (see Fuller and Battese, 1973, Ferguson and Leech 1978, Davis and West 1981, West et al. 1984, West et al. 1986, Gregoire 1987).

There are many ways in which the issues of repeated measurement can be managed but the subject is considered beyond the scope of this Handbook.

The information available from long term trend series is so powerful that the use of quite complex statistical techniques to overcome the statistical issues that arise with regard to handling the error structures is generally warranted.

### 7.2 Why not remeasure inventory plots?

Remeasured inventory plots can obviously provide growth data, and this can be collected at a low marginal cost in most cases simply because it is common to remeasure inventory plots on the same site, perhaps with a commercial thinning operation in between measurements, simply to provide a consistent coverage.

It is intuitively appealing to use these data for growth determination and the development of growth models.

However it must be recognised that these plots cover the range of silviculture practiced in the past and that range may or may not be the appropriate silviculture for the future.

At least one forestry entity went down this path some years ago and when they decided to dramatically change their silvicultural strategies to meet redefined forest management objectives, found that they had almost no plots that were relevant to the new silviculture and so could not develop soundly based growth models. Their planning suffered until new plots could be measured over a number of years.

### 7.3 Essentials for developing models

In general terms there are three major components essential to the development of models (Dixon et al. 1990, Adlard 1995);

1. an understanding of the process or relationship being modelled,
2. mathematical, statistical and computational techniques and equipment capable of handling the problem, and,
3. experimental or survey data.

Adlard (1995) points out that often foresters have generally had this list upside down and that they have generally collected the data and then tried to determine how it can best be used.

This is obviously not the ideal way of developing models but it is easy to see why it has occurred. The modelling strategy is often thrust on the modeller because the problem that the data were originally designed to address has changed and there are now no new data available that are appropriate to assist in resolving the new problem.

The result is that it is necessary for modellers to carefully consider how the data they collect might be used in the future, knowing that they will likely be used for purposes quite different to the current problem. This means that it is vital to record the protocols used for data collection, and also for the current analyses.

Unfortunately it is all too common to see analyses carried out on limited data, or less than ideal data, simply because no better data are available.
8  Biometric models in forest planning

Soundly based forest planning requires both data and statistical analyses to formulate appropriate prediction models. This section refers to the biometric models generally used in forest planning models and systems.

Statistical analyses have been evolving for a long time, for example some growth model structures were defined in the early 19th century. However the advent of modern computers and good statistical packages has only relatively recently allowed a wide range of alternative models to be evaluated, including variations in model structures that might better meet statistical and biometrical assumptions. The use of nonlinear modelling is common and modern packages can handle large data sets with relative ease.

Biometric modelling has in some ways has become a lot simpler as there are commonly several different model structures that experience suggests are better than others in particular circumstances. There are many statistical packages available that appear to be simple to use.

Care should always be taken to ensure that the underlying structure is soundly based, that the error structure is appropriate, that the statistical assumptions are not violated, and that the models are appropriate for the data. This is more difficult for nonlinear than linear models. The use of statistical packages makes it easier to develop models but if the modeller lacks the required expertise then the models may be quite inappropriate and may give flawed predictions.

In this section, generally the model structures are discussed followed by published examples that might be useful in forest valuation.

Disclaimer

A number of models are presented that are publicly available from reports and references and the sources of the models are cited. In some cases limited comments are made about the models and their possible use in particular circumstances.

This has been done to assist readers in determining what models might or might not be appropriate for their particular circumstances and to provide examples of the approaches used by model developers.

As stated earlier, this Handbook does not, and cannot represent itself as giving professional advice by or on behalf of the Association of Consulting Foresters of Australia, or any member of the Association, or the Forest and Wood Products Research and Development Corporation, or any member or levy payer of that corporation, for any particular purpose whatsoever or in general. It must not be relied upon as the basis for the implementation of any decision to take action in respect of any matter which it covers. Readers must make their own enquiries and obtain professional advice before making any decisions.

While every effort has been made to ensure that the contents of this Handbook are correct, neither ACFA nor its members shall be held responsible or liable for anything arising from the application of the details or methods referred to herein. Users must rely on their own professional judgement, or seek expert advice, about the relevance of any procedure suggested in this Handbook or to any particular set of circumstances.

Great care must be taken by the reader/user to assess the appropriateness or otherwise of any model in the circumstances in which it is planned to apply it. Models presented might have appropriate application in specific circumstances but might be inappropriate in others.

The uninformed application of any model presented in this Handbook is and shall remain the sole responsibility of the reader/user.

The presentation of the models is provided to better enable the readers/users to understand what is behind the various model structures.
Readers/users might not have sufficient data to develop models for their own particular circumstances and in these situations the correction of an existing model based on the limited data available might be attempted. It is for this reason that this presentation refers only to a selection of publicly available models and no representations are made herein as to the applicability or otherwise.

So, *Caveat emptor!*

### 8.1 Statistical basis

There are two types of data used in forest planning,

- data used to develop biometrical models, and,
- data which will be predicted using the biometrical models.

Examples of the first kind of data include permanent sample plots and research trials. Some argue that these data should reflect the variation in the forest while others more cogently argue that the range should be far wider and encompass the complete range of silviculture that might possibly be practiced as only then can a wide range of possible future silvicultural management strategies be modelled. Inventory data provide the most common example of the second data type. Here the objective should be to ensure that the data provide an unbiased coverage of the forest.

If the biometrical models are all defined, agreed and accepted, and if the data are all agreed and accepted, then any forest management planning system becomes a matter of simple mathematics. There may however be a lot of processing and a lot of complex interactions that need to be considered.

Models can be developed graphically, and even by educated and experienced guesswork. However models are usually developed by using statistical analyses as this generally develops better, potentially less biased models, although this can never be assured. The analyses may in themselves be unbiased but the models can be biased simply because the data bases used to develop the models are biased. It is rare for any forestry organisation to have all the data that are really required and some experienced judgements generally have to be made and argued.

The simplest models to develop are linear models and these are generally developed using Ordinary Least Squares (OLS) procedures. The linearity refers to the parameters to be estimated. The results are reproducible and are, by definition if the various assumptions are not violated, minimum variance estimates and therefore are statistically efficient.

In forestry it is common for modellers to find that linear model structures are too restrictive and in these cases nonlinear model structures may be considered more appropriate. Such models are generally only asymptotically efficient and greater care is required in their development.

Commonly used spreadsheets such as Excel®, have OLS statistical procedures built into them. If Excel is not satisfactory for some reason then other statistical packages such as Genstat®, Minitab®, ARC®, SPSS®, SAS®, and Statistica® provide better modelling facilities, including better facilities for evaluating errors and confirming that the assumptions have not been violated. ARC is freely available from the University of Minnesota at:

[http://www.stat.umn.edu/arc/software.html](http://www.stat.umn.edu/arc/software.html)

but the other packages may incur an extra cost. Most model developers at least have access to a spreadsheet package but great care should be taken when using a simple spreadsheet package for statistical analysis to ensure that the calculations are accurate.

There are now many packages that can develop nonlinear models. For those who do not have access to a suitable package one relatively cheap nonlinear regression modelling package is NLREG®, available in 2007 from

[http://www.nlreg.com](http://www.nlreg.com)
for US$140 for the standard version, US$ 195-245 for other versions. A free evaluation version with limited scope is available for a 30 day trial.

Please note that ACFA does not recommend or endorse any package in particular as there are many nonlinear packages that can carry out the desired analyses, but this is one relatively cheap alternative that modellers may care to consider.

Assumptions of OLS

This section should not be considered definitive in any way but is provided to assist any forest valuer who is developing models to test the assumptions. It should be noted that the assumptions all have specific definitions, generally in matrix notation, that make it more difficult for a neophyte modeller to understand just what they should be looking for. This section is therefore not a rigorous treatment but indicative of what may need to be considered.

The assumptions underlying the use of OLS estimation for classical linear regression models can be summarised as follows (Goldberger 1964).

1. The variance should be homogeneous over the range of the dependent variable.
2. The error terms should be independent of one another.
3. The error term should be normally distributed.
4. The rank of the matrix of observations should be equal to the number of parameters to be estimated and less than the number of observations.
5. The variables should be measured without error.
6. The model should have the correct structure and include all relevant variables but no others.

If OLS estimation methods are used for a model that is mis-specified in terms of any of these assumptions then the estimates may be biased, inefficient and/or inconsistent depending on the form of misspecification.

The general form of a linear regression model is

\[ Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots + e \]

and where

- \( Y \) is the dependent variable that the modeller desires to estimate,
- \( X_n \) are the ‘n’ independent variables available from the data,
- \( b_n \) are the parameters to be estimated, and,
- \( e \) is the error term.

Sometimes the dependent and independent variables and the error term are denoted with a subscript “\( i \)” to denote the \( i \)’th observation, for example \( X_{1i} \), where \( i=1,\ldots,m \) and where “\( m \)” is the number of observations.

Assumption 1 above can be gauged by plotting the data with the Y-variable on the y-axis and the various independent variables \( (X_n) \) on the x-axis. The data should show some general trend but for the assumptions to be met the variation in the Y-axis direction should be approximately constant for all values of \( (X_n) \) on the appropriate X-axis.

This can be tested in a number of ways but a common test is Bartlett’s test (1937, 1954). For this test the data are partitioned and the variance in each partition calculated and then tested for homogeneity. See Freese (1967) for a simple worked example. The test is against Chi-square. Different X variables can be tested. If the test indicates significant heterogeneity the data can be weighted by the inverse of the expected variation (see the section on tree volume equations as these generally require some form of weighting).
Assumption 2 requires that the data be independent. Serial correlation is commonly tested by the Durbin-Watson d-statistic (1951, 1971) and some statistical packages provide this d-statistic as part of their analyses. The test statistic is:

\[ d = \frac{\sum_{i=2}^{in} (e_i - e_{i-1})^2}{\sum_{i=1}^{in} e_i^2} \]

The nature of the test requires that the data must be in some logical order that the modeller expects may show serial correlation. Therefore different d-statistics are possible depending on the order of the data. The test is generally a two bounded test, with an inconclusive zone between the two bounds, although Theil and Nagar (1961) provided a single value for testing a particular model.

If the d-statistic is significant with this test then the cause may not be serial correlation in the data sense but model misspecification in that the model structure may not adequately reflect the data, see assumption 6 above. There might be a variable that is missing or perhaps a quadratic term may be needed as well as the linear term for a particular variable. Either way the model is mis-specified and measures should be taken to correct the problem.

Assumption 3 is that the error terms are normally distributed. Many packages provide normal probability plots of the residuals and departure from a straight line indicates non-normality. Two tests that are commonly found in statistical packages are the Anderson Darling test (Stephens 1974, 1976, 1977, 1977) and the Kolmogorov-Smirnov test (Chakravarti, Laha and Roy, 1967). Both are defined in many statistical texts. One of the more powerful tests for normality is the Shapiro-Wilk’s statistic (Shapiro and Wilk 1965, Shapiro, Wilk and Chen 1968) which is difficult to apply, but it is also available from some statistical packages. D’Agostino (1971) cautions that this powerful test may be inappropriate under some circumstances but it remains a commonly used omnibus test. In this sense the more powerful the test the better the test can discriminate significant departure of a distribution from normality.

The most common form of assumption 4, the rank criteria, can be described using the above general model form. If variables X2 and X3 are completely, or even very highly, correlated then the assumption can be violated. One example could be two variables such as diameter over bark and diameter under bark for a species with bark that sheds annually and for which bark thickness is therefore close to constant over time. In this case the modelling solution might be to have X2 as dbhob and X3 as double bark thickness as this should reduce the correlations, and X3 may be found to be not significant. In simple terms if two variables (say X2 and X3) are the same then there can be an infinite number of combinations of b2 and b3 that could provide the same predictions and therefore could be equally efficient. The model is said to be structurally over-identified.

This structural over-identification is not necessarily easy to ascertain for nonlinear models such as for the model

\[ Y = b_0 + b_1 \exp(b_2 + b_3 X) \]

which is nonlinear in its parameters but is over-identified as for any arbitrary value of b1 there is a fixed value of b2. The model can be simplified to:

\[ Y = b_0 + \exp(b_2 + b_3 X) \]

or \[ Y = b_0 + b_1 \exp(1 + b_3 X) \]

Model mis-specification like this needs careful attention. Examples are known of mis-specified models being used in practice in forest planning.

If the data are measured with error, assumption 5, then the error terms are generally inflated and the models are not as efficient as they should be. This generally means that some useful variables may be found to be not significant. However if the measurement errors for the data used for the modelling are similar to those for the data that are to be modelled then the difficulty is irrelevant. As growth plot data are generally measured with greater precision than inventory plot data, measurement error is generally not such a serious issue.
Assumption 6 has two aspects, first that all relevant and appropriate variables should be included in the model in the correct form, and second that no irrelevant variables should be included. Structural issues are often more relevant to nonlinear models than linear models but defining what is believed to be the correct structure is necessary.

One published example used the basal area of small trees (<17.5cm) as an explanatory variable in predicting the volume of sawlog (>25cm). The model implies that cutting down all the small trees would immediately increase the saw log volume standing which is nonsensical. Even though growth would be increased, simply cutting down the small trees cannot change the current volume of the larger standing trees. One suggested reason for the variable being statistically significant is that it represented stand density, and that there was an inverse relationship between the basal area of small trees and the basal area of large trees and that the form used provided statistically the best fit because better and more appropriate variables (such as perhaps the reciprocal of the basal area of larger trees) were not tested.

For linear regression models the parameters produced by statistical packages are considered efficient, and are generally best linear unbiased estimates (BLUE) with the sum of the squared errors when the model is used to predict the data observations being a true minimum. Nonlinear models can only be assumed to be asymptotically efficient and although often models can be assumed to be efficient that is not necessarily always true. See Bard (1974), Ratkowsky (1989) and Sadler (1975) for more details.

If any of the assumptions are violated than there can be no certainty that any hypothesis testing used to determine whether parameters should be included or not is statistically sound.

The parameters themselves are generally unbiased but the standard errors of the parameters, used in the hypothesis testing, may be biased to a considerable extent.

A number of quite different techniques have been developed in order to ensure that the assumptions of the analysis are met and these require a sound understanding of the underlying statistics. One such paper developing models for blue gum plantations is that of Wang (Wang et al 2007), but there are many others. This Handbook is best considered an introductory statistical treatment only.

It must be re-emphasised that this section is provided for indicative purposes and to suggest where more work may be needed in a particular analysis. This has become more necessary over recent years as there are now many easy to use statistical packages but they generally cannot ensure that the analysis is statistically sound and appropriate. That takes skill and expertise.

There are a number of useful web references to statistics.

- The NIST/SMATECH e-Handbook of Statistical Methods was found at the following URL in 2007 and it is a useful web reference;
  http://www.itl.nist.gov/div898/handbook/

- The Rice Virtual Laboratory in Statistics, from Rice University in Texas, USA, provides both a text and examples, and was found in 2007 at;
  http://onlinestatbook.com/rvls.html

- Vassar Stats from Vassar College, was found in 2007 at:
  http://faculty.vassar.edu/lowry/webtext.html
  http://faculty.vassar.edu/lowry/VassarStats.html

Many other sites can provide detailed information on specific issues.

Further References; forestry statistics

Freese, F. (1967)
Further References; linear models
Fisher, R.A. (1921) (1925)

Further References; nonlinear models
Sadler, D.R. (1975)

Further References; general statistics
There are many general references to statistics and there are often only very few differences between them that just reflect slight differences in emphasis. For an elementary statistical text one statistics lecturer recently advised “go to the nearest scientific or University bookshop and buy the out of date students text for $5”, advice that has proven quite satisfactory as, at the simpler level, the statistical procedures are now well defined.

Further References; Bayesian statistics
Bayes, T. (1763 (1958))
Raiffa, H. and Schlaifer, R. (1961)

Reporting models
There are a few general guidelines for reporting biometric models.

The equation should generally be specified with the standard error of the parameter estimates reported in brackets directly below the parameter estimates themselves. For example

\[
Y = 0.301 + 0.0003256 D^2H
\]

\[
(0.022) \quad (0.0000094)
\]

enables any reader to ascertain whether or not a parameter is significant or not using Student’s t-statistic.

The number of digits reported should be in balance with the data and should be in balance with the other parameters. For example reporting the constant as 0.30088765 would be too high a precision for a normal tree volume equation, and 0.3 would be too few digits. The number of digits reported should be consistent between the parameter and its standard error.

It is generally not desirable for all parameters to be quoted with the same number of decimal places or significant digits. In the example the parameter of \(D^2H\) has a great effect on the resulting volume prediction given the range of \(D\) in cm and \(H\) in m.

One common statistic quoted is the coefficient of multiple determination, sometimes called the correlation coefficient \(R^2\) or \(r^2\). This lies in the range 0.0 - 1.0 and the higher the value the better the correlation and so the better the fit. Care should be taken not to compare the \(R^2\) values for models with different dependent variables as any such comparison is generally meaningless.

Model structural considerations
In the preface and introduction to their book, Raiffa and Schlaifer (1961) provide some insights into biometrical modelling. They assert that it is rarely possible to find the best of all possible courses of action and that reasonable people “satisfice” much more than they “optimise”. They emphasized that the objective of any optimising analysis is not to find the best of all courses of action, as that is clearly impossible, and they state that the first step in any analysis is the purely intuitive selection of
those courses of action that seem worthy of further analysis. Then, and only then, does it become possible to apply formal procedures to select the final model from among the alternatives.

Formal statistical analysis can only be applied to a selected range of candidate model structures; it can never be applied to all possible model structures. This point is unfortunately often forgotten.

It is necessary to be careful in any consideration of model structure, be it the variables to be included in an OLS analysis, or the structure of a nonlinear model, or the appropriateness of a particular error structure. This is the essence of assumption 6 above. However it is not uncommon to see linear regression analyses where a whole raft of variables have been input and automated procedures used to determine the ‘best’ set of significant variables. Whether the model makes any sense biologically, or in forest management terms, is often ignored. Such a model is seen to be nominally objective and so is often considered quite acceptable as there is no hint of subjectivity, yet the model may or may not be satisfactory as a predictor in practice. An example of such a model failure is described earlier.

One desirable criterion for a model is that it behaves sensibly when used to predict data outside the range of that used to develop the model. If the model does not extrapolate sensibly then it may provide biased and imprecise predictions in practice and this may have serious implications for forest planning and forest valuation.

Occam’s Razor (named after William of Occam, or Ockam, 1280-1349) states “beings ought not to be multiplied except out of necessity” which can be interpreted in the statistical sense to imply that biological models should be simple, include no extra variables than are necessary, but include all those that are necessary. This has also been called the “Principle of Parsimony”.

The model should also satisfy the various biometrical assumptions described earlier.

However much more importantly, the model should behave “sensibly” although that particular term is impossible to define.

8.2 Evaluating models

There are a number of different aspects that should be considered when evaluating a model. One early text on computer simulation techniques (Naylor et al. 1966) provides a flow chart of the model development protocol shows model validation as a separate and distinct activity, but one integrated into the whole protocol. Too often model evaluation is left until after the model development phase when it should be part of the development process.

Goulding (1979) considered three stages;

- evaluating the model and the parameters,
- verifying the model, and,
- validation.

All three components are part of the overall evaluation of any model. The first stage occurs during the model development. The second is ideally carried out with independent data but that is not always possible. The last stage tests the ability of the complete model to predict the behaviour of the real system. In this sense it includes testing extrapolations of the model for reasonableness. The objective is to build a sense of confidence in the model.

Soares et al. (1995) considers the subject under five interrelated headings.

- **Theoretical and biological aspects.** Each model component and the whole model should be biologically reasonable. Does the model structure make biological sense? If the model appears to behave in a counter intuitive manner then the model should not necessarily just be rejected because it may be that the modeller’s preconceptions were incorrect.

- **Statistical properties.** Does the model meet the assumptions inherent in the statistical analysis procedures used? This may be especially important if there are repeated measurements from the one sampling unit.
• **Characterising model error.** A plot of the residuals or standardized residuals against the main independent variables may provide a very useful way of ensuring that the model structure is not unsound. Formal statistical tests are possible. Evaluating the error structure and the contribution of each model component may reveal a lot more than a simple analysis of total model performance.

• **Statistical tests.** There is no one single simple statistical test. It may be desirable to partition the data and to test the model to see how it performs in each partition. This may assist evaluate the utility of the model developed on data from across a large forest when it is applied to particular parts of a forest.

• **Sensitivity analyses.** This determines how sensitive the predictions are to changes in various driver variables. Sensitivity analyses can also be used to determine the expected error when the model is extrapolated, or is applied to areas other than the area for which it was developed.

The important point is that model evaluation should not be an afterthought to the analysis but should be integral to the whole model development protocol.


### 8.3 Diameter models

Diameters may need to be converted from over bark to under bark, and it may also be necessary to develop models to convert diameters from one breast height level of 1.4 m, as used in New Zealand, to 1.3 m as used in Australia.

#### 8.3.1 Over bark to under bark diameters at breast height

Models may be required to predict under bark diameter at breast height (dbhub or DUB) from over bark (dbhob or D).

**Radiata pine, NSW; Bi and Long**

For radiata pine Bi (2000, Bi and Long 2001) developed a model that also uses tree height (H)

\[
\text{dbhub} = \text{dbhob} \times \exp\left[\frac{1}{k}\right]
\]

where

\[
k = -35.9538 - 0.1376 \times \text{dbhob} + 6.0526 \ln(\text{dbhob}) - 0.2205 \times H + 5.6868 \ln(H)
\]

**Radiata pine, SA; Leech**

Also for radiata pine, Leech (1986) developed a model to predict bark thickness at 1.5m although subsequent unpublished analyses suggested that the model was an unbiased and efficient predictor of under bark diameter at breast height (1.3 m) if Dbhob (D₁.₃) is used instead of D₁.₅. If d₁.₅ represents diameter over bark at 1.5m and 2bt represents double bark thickness at that height then the model was

\[
2bt = d₁.₅ - \exp(2.589 - 42.808 / d₁.₅)
\]

which can be used approximately as

\[
\text{dbhub} = \text{dbhob} - \exp(2.589 - 42.808 / \text{dbhob})
\]
Eucalypts, NSW; Muhairwe

Muhairwe (2000) presents models to predict \( \text{dbhib} \) (diameter at breast height inside bark) from \( \text{dbhob} \) and tree height \( H \),

\[
\text{dbhib} = \exp[b_0 + b_1 \ln(\text{dbhob}) + b_2 H]
\]

and the parameters were as follows.

- **Eucalyptus pilularis** – Native forest
  - \( b_0 = -0.54524 \)
  - \( b_1 = 1.05063 \)
  - \( b_2 = 0.05976 \)

- **Eucalyptus pilularis** – Plantation
  - \( b_0 = -0.39015 \)
  - \( b_1 = 1.06154 \)

- **Eucalyptus obliqua**
  - \( b_0 = -0.34906 \)
  - \( b_1 = 1.29613 \)
  - \( b_2 = -0.28313 \)

- **Eucalyptus andrewsi**
  - \( b_0 = -0.61156 \)
  - \( b_1 = 1.12259 \)

- **Eucalyptus saligna**
  - \( b_0 = -0.25118 \)
  - \( b_1 = 1.04241 \)

- **Corymbia maculata**
  - \( b_0 = -0.54596 \)
  - \( b_1 = 1.05267 \)
  - \( b_2 = 0.07814 \)

---

### 8.3.2 Conversion of diameters from 1.4 m to 1.3 m

For shining gum, Candy (1997) provides a model to convert from diameter (dbhob) at 1.4 m, the New Zealand standard, to diameter at 1.3 m, the Australian standard

\[
\text{dbhob}_{1.3} = 0.13 + 1.0036 \times \text{dbhob}_{1.4}
\]

although the standard error of the parameter estimates are not reported and Candy does not discuss whether the parameter 1.0036 is significantly different from 1.0.

---

### 8.3.3 Bark thickness up the stem

If taper equations are used to determine over bark tree diameter up the stem then it may be necessary to develop bark thickness equations so that diameter under bark up the stem can be estimated.

Eucalypts, northern NSW; Muhairwe

Muhairwe (2000) presents bark thickness equations for five commercial tree species in regrowth forests of northern New South Wales. Six equations are presented for each species together with a discussion about the relevance of each. Users should consult the reference. The equation below might seem a complicated structure but it has few parameters and Muhairwe believes it provides good predictions. Other equations presented by Muhairwe do not require bark thickness to be measured at breast height.

If

- \( 2bt \) = double bark thickness at a point up the stem where
- \( dob \) = diameter over bark at that point, and,
- \( dib \) = diameter under bark (or inside bark) at that point,
- \( \text{dbhob} \) = the diameter at breast height over bark, and,
- \( 2bt_{bh} \) = the double bark thickness at breast height

then

\[
dib = dob - 2bt
\]

and if

\[
N = \text{the average number of observations per tree, is set to 12}
\]
then if \( \text{dob} > \text{dbhob} \)

\[
2bt = a (\text{dob} - \text{dbhob}) + 2bt_{bh}
\]

\[
a = 2(\text{bt}_{bh} / \text{dbhob}) + \left[ (\text{bt}_{bh} / (\text{bh}_0^{(N-1)}) \right] \text{b}_0^{(N-1)} \log(b_0) (N-1) \text{b}_1 / \text{dbhob}
\]

and if \( \text{dob} \leq \text{dbhob} \)

\[
2bt = 2(\text{bt}_{bh} / \text{dbhob}) \text{dob} - \left[ (\text{bt}_{bh} \text{b}_0^{(N-1)}) [1 - \text{b}_0^{(N-1)\text{(dbhob/dob)}}] / [1 - \text{b}_0^{(N-1)}] \right]
\]

This function has the advantage that predictions are identical at breast height and also it is conditioned to predict the actual measured \( 2bt_{bh} \). The parameters were:

- **Eucalyptus pilularis** – Native forest
  - \( b_0 = 0.6110 \)
  - \( b_1 = 1.9370 \)

- **Eucalyptus pilularis** – Plantation
  - \( b_0 = 0.6087 \)
  - \( b_1 = 1.8462 \)

- **Eucalyptus obliqua**
  - \( b_0 = 0.8356 \)
  - \( b_1 = 1.4752 \)

- **Eucalyptus andrewsii**
  - \( b_0 = 0.6833 \)
  - \( b_1 = 1.8868 \)

- **Eucalyptus saligna**
  - \( b_0 = 0.5839 \)
  - \( b_1 = 2.5107 \)

- **Corymbia maculata**
  - \( b_0 = 0.7638 \)
  - \( b_1 = 2.1768 \)

Muhairwe states that changing the value of \( N \) had no effect on the results.

Users should check the reference to ensure that they use the appropriate model for their particular purpose.

### 8.4 Tree height estimation

Tree height models are generally calculated from a sample of tree heights on an inventory plot and are only rarely calculated from stand based variables.

**Shining gum; Candy**

Candy (1997) provides one of the few available models. Candy developed a model to predict the height of trees of shining gum (**Eucalyptus nitens**) based on a log-reciprocal model. If

\[
H_k = \text{the height of the k'th tree at time } T \text{ (m)}
\]

\[
D_k = \text{the tree diameter (dbhob) in (cm)}
\]

then

\[
H_k = \exp(\beta_0 - \beta_1 / D_k)
\]

and if the stand based variables are

- **H** = mean dominant height
- **T** = age
- **Q** = the quadratic mean dbh given by \( Q=100\sqrt{(4*B)/(\pi*N)} \)

where

- **B** = basal area (\( m^2/ha \))
- **N** = stocking (stems per hectare)

then the second stage models are

\[
\exp(\beta_0) = \beta_{00} + \beta_{01}H + \beta_{02}N
\]

\[
\beta_1 = \exp(\beta_{10} + \beta_{11}Q + \beta_{12}H + \beta_{13}T + \beta_{14}N)
\]

and the parameters were

\[
\begin{align*}
\beta_{00} & = 5.039 \\
\beta_{01} & = 1.4030 \\
\beta_{02} & = -0.00211 \\
\beta_{10} & = 1.3650 \\
\beta_{11} & = 0.0100 \\
\beta_{12} & = 0.07787 \\
\beta_{13} & = -0.0612 \\
\beta_{14} & = -0.00029
\end{align*}
\]
8.5  Tree and stand volume estimation

There are two general concepts used to calculate estimates of tree volume and subsequently stand volume. In one approach an equation is developed to predict tree volume from tree and sometimes stand parameters. In the other a taper equation (that predicts how diameter changes with increasing height up a tree) is used, as by integrating a taper equation the solid volume can be obtained.

This latter method using a taper equation or taper function has the advantage of enabling products within a tree to be determined.

8.5.1  Tree volume equation model structures

Out of the infinite number of possible model structures that could be used for developing models to predict tree volume from other tree parameters there are a few commonly used, tried and tested, structures.

The most common form used is the so-called combined variable form

\[ Y = b_0 + b_1 D^2 H \] [8.5.1-1]

where

- \( Y \) is tree volume
- \( D \) is tree dbhob, diameter at breast height over bark
- \( H \) is tree height

although sometimes tree height may be replaced by a measure of upper stand height. Other forms based on this are possible including

\[ Y = b_0 + b_1 D^2 H + b_2 D^2 + b_3 H \] [8.5.1-2]

\[ Y = b_0 + b_1 (D-b_2)^2 (H-b_3) \]

\[ Y = b_0 + b_1 (D^2-b_2) (H-b_3) \]

depending on various plausible assumptions about the extension of the simple model structure. If equation [8.5.1-2] is generalised into a nonlinear model form

\[ Y = b_1 D^{b_2} H^{b_3} \] [8.5.1-3]

then the equation can be transformed by taking logarithms to make a transformed intrinsically linear model form

\[ \ln(Y) = b_1' + b_2 \ln(D) + b_3 \ln(H) \] [8.5.1-4]

where \( b_1' = \ln(b_1) \).

Using the concept of dimensional analysis (Khilmi 1957) the sum \((b_2+b_3)\) in [8.5.1-3] should equal 3.0 with \(b_2=2.0, b_3=1.0\). However, as trees are not cylinders but can generally be approximated by a neiloid or second degree paraboloid, the parameter values generally fall in the ranges \((b_2\approx2.2-2.5, b_3\approx0.5-0.8)\) with \((\text{sum}(b_2+b_3)=3)\).

Weighting

When developing tree volume equations a graph of the tree volumes against \(D^2 H\) generally shows considerable variation with the variation increasing markedly as \(D^2 H\) increases. This violates one of the basic assumptions of Ordinary Least Squares (OLS) regression analysis which, if not allowed for, would provide biased estimates of the parameter coefficients leading to the risk of developing models that are statistically unsound. The most common way to correct this data heterogeneity of
variance is to use weighting, either weighting the data by reformattting the model or by weighting the regression analysis itself.

The most appropriate technique is to partition the data into cells (generally on both height and diameter but it could be by $D^2H$) and then developing a prediction equation to enable the estimated variance for each tree to be calculated and so the appropriate weight ($w$) of the reciprocal of the estimated standard error to be used as a weight. This would change the formulation of [8.5.1.2] to the following.

$$Y_w = b_0 w + b_1 D^2H_w$$

In practice, experience suggests that if the data are heterogeneous and need to be weighted a weight of ($w=1/D^2H$) is generally quite appropriate and is readily applied. It should be noted that if the regression model itself is to be weighted then, depending on the statistical package, a weight that is commonly found to be appropriate is $(1/(D^2H)^2)$. 

Equations [8.5.1.1] and [8.5.1.5] below are in essence the same equation transformed to give different dependent variables. The lack of usefulness of $R^2$ values when comparing models with different dependent variables can be gauged from an unpublished study where for the same data the $R^2$ values for these equations were;

$$Y = b_0 + b_1 D^2H \quad R^2 = 0.96 \quad [8.5.1.1]$$

$$Y/ D^2H = b_0/ D^2H + b_1 \quad R^2 = 0.13 \quad [8.5.1.5]$$

However the parameter estimates for the two equations were such that equation [8.5.1.5] had lower standard errors for both parameter estimates and was therefore considered to be statistically the more efficient model.

Similarly using equation [8.5.1.3] as the base model the variance heterogeneity can be markedly improved by transforming the dependent variable.

$$Y = b_1 D^{b_2}H^{b_3} \quad [8.5.1.3]$$

$$\ln(Y) = b_1' + b_2 \ln(D) + b_3 \ln(H) \quad [8.5.1.4]$$

where $b_1' = \ln(b_1)$ as before. This model can be estimated by OLS techniques but the logarithmic transformation means that the model does not necessarily go through the mean of the data, it goes through the mean of the transformed data, and so the untransformed model that is used in forest planning will be biased. Again, the $R^2$ for equation [8.5.1.3] is generally far higher than for equation [8.5.1.4] but the latter equation is better if the logarithmic bias is removed.

There is no single standard method for removing the bias but the following seems as good as any in practice for tree volume equations. Calculate mean($Y$) and mean($D^2H$). Predict $\ln(\hat{Y})$ for each observation, transform into $\hat{Y}'$ where $\hat{Y}'=\exp(\ln(\hat{Y}))$ and determine mean($\hat{Y}'$). The correction multiplier to each estimate of $Y$, $\hat{Y}$, is the ratio $\{\text{mean}(Y) / \text{mean}(\hat{Y}')\}$.

Experience suggests that in practice the logarithmic bias is often not removed. The extent of the bias depends on the data used for model development but the bias for tree volume equations can be quite large and certainly of practical importance. It would be better to use equation [8.5.1.5]. If the logarithmic transform model is used then the magnitude of the logarithmic bias should be investigated and reported.

Although unbiased, the errors from the logarithmic transformed model are generally still heterogeneous, although not as bad as for the untransformed model, and so it is generally better to use weighted least squares with the data weighted by $(1/D^2H)$ as in equation [8.5.1.6] as this provides an unbiased model that generally meets the statistical assumptions of OLS. Many statistical packages can provide such an estimation procedure.

$$Y/ D^2H = b_1 D^{b_2}H^{b_3} \quad [8.5.1.6]$$
It is impossible to suggest the number of data points necessary for the determination of tree volume equations. A useful rule of thumb might be 30 trees for a species that is expected to contribute considerably to the overall volume, less for less frequently occurring species. Some suggest that the minimum number of trees should be 10, but in reality it depends on the model structure being evaluated. The more parameters there are to be estimated then the more data that are required to develop satisfactory models.

**Aggregating species**

In mixed species forest, especially tropical moist forest, there are commonly many species present and it is rare to have sufficient samples for all species to enable tree volume equations to be developed for each and every species. Even when such data are available the Principle of Parsimony would suggest that species should be aggregated whenever possible.

Leech, Correll and Aung Kyaw Myint (1991) developed a methodology for aggregating tree volume equations for different species in the Teak forest in Myanmar. The technique used by Vanclay (1991, 1994 p127-31) to aggregate diameter increment equations is also directly applicable to aggregating tree volume equations. Vanclay (1994) summarises the possibilities. It can be argued that a mix of statistical inference and pragmatism is required and that there can never be one ‘best’ set of equations. If it is necessary to aggregate equations it is suggested that these particular references and relevant statistical texts be consulted.

**Example models**

Some of the published models that may be useful follow.

**Eucalypts, Victorian SFRI; Wang and Hamilton**

Working on the Statewide Forest Resource Inventory (SFRI) in Victoria Wang and Hamilton (2003) developed models for regrowth mountain ash and alpine ash. They developed a complete set of models to facilitate volume prediction. They were particularly interested in merchantable volume, and the models are only appropriate to the Victorian merchantability criteria.

For mountain ash

\[ Y = 8.13570 \{1 - \exp(-0.03143 D)\}^{6.09734} \]

For alpine ash

\[ Y = 5.07601 \{1 - \exp(-0.03252 D)\}^{5.4202} \]

and where

- \( Y \) is merchantable volume (m\(^3\))
- \( D \) is tree dbh in cm

**Native eucalypts in New South Wales and Victoria; Bi and Hamilton**

Equations for some 25 native species of *Eucalyptus* and *Corymbia* were developed by Bi and Hamilton (1998). The equations were based on the combined variable equation and were developed using weighted OLS regression analysis. Species with less than 20 observations were combined into an entity named *E. spp*. The parameters are tabled below.

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Intercept</th>
<th>( D^3H \times 10^6 )</th>
<th>( D^2H \times 10^4 )</th>
<th>( D^2H^2 \times 10^{-2} )</th>
<th>D</th>
<th>H</th>
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The paper also provides upper and lower 95% confidence limits.

**Brown barrel, NSW; Bi**

Bi investigated tree volume equations for regrowth forests of *Eucalyptus fastigata* (brown barrel) on the south-east tablelands of New South Wales. He demonstrated that the addition of a lower stem form quotient based on the diameter at 4.5 m provided significant gain in accuracy. He provides a number of models the two most relevant being

\[
Y = 0.001329 + 0.21665 \times 10^{-4} D^3 H
\]

\[
Y = Q (0.013265 + 0.25928 \times 10^{-4} D^3 H)
\]

where

- $Y$ is under bark tree volume (m$^3$)
- $D$ is tree diameter (cm)
- $H$ is tree height (m)
- $Q$ is the form quotient, defined as the ratio of diameter over bark at 4.5 m to dbhob.

Equivalent over bark equations were also provided.

**Radiata pine, SA; Keeves**

Keeves developed a model for radiata pine in South Australia, (Lewis *et al.* 1976).

\[
Y = (-0.1012 + 0.007244 H - 0.0002466 H^3) + (1.884 + 0.3309 H) \pi D^2 / 40000
\]

where

- $Y$ is volume (m$^3$)
- $H$ is PDH not tree height, defined as the tallest 75 trees/ha, in m

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D is tree dbhob in cm

For a separate model for the thinnings elect sub-population for radiata pine in South Australia developed by Leech (Lewis et al. 1976).

Radiata pine, South Australian Regional Volume Table

A multiple variable tree volume table was developed in South Australia for radiata pine (Lewis and McIntyre, 1963, Lewis, McIntyre and Leech 1973). The tables are based on equations developed in imperial (1963) and converted to metric (1973). The variables used are:

- Diameter at 1.5 m height under bark,
- Tree height (m), and,
- Tree taper measured as the differences in diameter under bark at two heights (1.5 - 4.5 m or 1.5 - 7.5 m).

The table has variously been called a three variable and a four variable table because bark thickness is taken into account and the diameters used are under bark.

This equation (or table) is generally more appropriate for permanent plot measurements than inventory plot measurements. It has been shown by Dr Geoff Wood (pers. comm.) to provide good predictions for other species, presumably because it takes the four major variables affecting the shape of a tree into account.

The equations were developed prior to the advent of good statistical packages and the eminent statistician Dr George McIntyre developed them as segmented regressions to overcome heteroscedasticity problems.

The imperial parameters are detailed in the 1963 publication and these were converted into a metric computer routine to facilitate prediction. The parameters are not presented here because they are imperial based.

8.5.2 Taper equations

A taper equation defines the shape of a stem. Mathematically it generally defines the relationship between diameter (d) at height (h) for a tree of dbhob=D (d=D at h=1.3) and tree height H (d=0 at h=H). This over bark model may be reformulated as an under bark model if suitable data are available.

Taper equations have been the subject of a lot of research and this section aims to summarise the main developments only, as a basic entry point into the considerable literature, noting especially the main Australian literature.

The advantage of a taper equation is that it provides a model of stem shape that can readily be integrated to provide stem volume, either in total, or by sections defined by height or diameter restrictions, or if a MARVL style inventory is used, volumes by products.

Overview

One of the very early papers on stem form is that of Greenhill (1881) who was trying to determine the maximum height a tree can attain and still remain stable. He considered that the best assumptions were a uniform tapering tree stem and that the sectional area of branches in any horizontal plane is constant.

The classic early taper model was that developed by Gray (1956, but see also Carron 1968). The basis of Gray’s taper line was that sectional area (diameter squared) is linearly related to height up the tree, except for the lower butt swell region and at the tip which is generally above the merchantable limit.
This provided a very convenient and useful model for use with radiata pine and many other species but is limited in that it assumes tree form is a second degree paraboloid. It is also generally discontinuous at the height of any butt swell.

With the advent of computers, taper studies received a further impetus especially with the work of Demaerschalk (1972), Max and Burkhart (1976), Kozak (1988) and Nagashima (Nagashima and Kawata 1994, Nagashima et al. 1980), although there have been many papers produced on the subject. In general terms the objective is to ensure compatibility of tree volume equations and taper equations, to ensure that the models were constrained through the two known points (d=dbhub or dbhob at h=1.3 and d=0 at h=H), to provide a sensible model form, and to ensure statistical correctness.

This basic work has been extended. One example is that of Muhairwe, LeMay and Kozak (1994) who added in tree, stand and site effects into the model in an effort to develop a more generally applicable model. The paper of Williams and Reich (1997) provides some insights into the error structure and how the equations might best be statistically determined.

In New Zealand the work of Goulding and Murray (1976) and Gordon (1983) probably represent the most useful references. The general form of the many of the New Zealand models is based on a complex polynomial form. Scion (formerly Forest Research New Zealand) provide a service to calculate taper equations given a users data set. Most taper equations in use are proprietary information and have not been published.

In Australia the work of Candy (1989) and many others in formulating taper equations has been carried into the 21st century primarily by three people Dr Huiquan Bi, Mr Adrian Goodwin and Dr Christopher Dean.

The work of Bi (Bi 2000, Bi and Long 2001) for radiata pine is based on a trigonometric formulation. If

\[ b_r = \frac{1.3}{H} \]

\[ h_r = \frac{h}{H} \]

and if \( d \) is the diameter at height \( h \) up the tree and \( D \) is dbhob, then the model is

\[ d = D \left[ \frac{\ln (\sin((\pi/2)*h_r))}{\ln (\sin((\pi/2)*b_r))} \right]^{\theta} \]

where the power term \( \theta \) is of the form

\[ \theta = a_1 + a_2 \sin((\pi/2)*h_r) + a_3 \cos((3\pi/2)*h_r) + a_4\ln((\pi/2)*h_r)/ h_r + a_5D + a_6V(D) + a_7h_vV(H) \]

In this model \( \ln \) represents the natural logarithm. The model can be transformed by taking logarithms and least squares regression can be used to obtain the parameter estimates. Bi and Long suggest that this taper function has greater prediction accuracy than the compatible polynomial taper functions and is more flexible.

Goodwin (Goodwin and Thompson 2003) developed a modified hyperbolic tree taper model for radiata pine using the unconstrained equation

\[ d = \beta_0 + \frac{\beta_1}{(1 + \beta_2 h) - \beta_3 h - \beta_4 h^2} \]

which was then appropriately constrained through two known points using \( d=\text{dbhub} \) at \( h=1.3 \) (represented below as \( d=d_1 \) at \( h=h_1 \)) and also \( d=0 \) at \( h=H \) to provide

\[ d = (H-h) \left[ \frac{\beta_1 \beta_2 (h_1-h)}{(1+\beta_3(h_1)+\beta_4h_1)(1+\beta_2H)} + \beta_3(h-h_1) + \frac{d_1}{H-h_1} \right] \]

This was fitted to the individual trees and second stage models were developed. Details of the equations and the equivalent inverse and volume models are in the paper.

Dean and colleagues (2003, Dean and Roxburgh 2004, 2005, 2006, Dean, Roxburgh and Mackey 2004b) working for the CRC for Greenhouse Accounting centred at the ANU in Canberra, have also
developed taper equations as a part of their carbon sequestration forecasting research. Their preferred taper model is an extension of that of Nagashima and Kawata (1994) and Nagashima et al. (1980).

\[ d = Y \times \left( 1 - \left( \frac{H_{\text{max}} - h}{H_{\text{max}} - H} \right)^{m} \right) + \alpha \times \exp \left( -\beta \times h^{c} \right) \]

In this formulation, \( H_{\text{max}} \) is the maximum height for a tree of \( E. \text{regnans} \) (swamp gum in Tasmania, mountain ash in Victoria) and diameter (D), d and h are the diameter and height of the point up the stem as before, and the second stage models were variants of

\[
\begin{align*}
H_{\text{max}} &= b_{0} \ast [1 - b_{1} \ast \{\exp(- (3/2) D)\} \ast D] \\
Y &= d_{0} + d_{1} \ast D \\
\alpha &= a_{0} + D^{b_{1}} \\
c &= \text{constant} \\
\beta &= e_{0} - c \\
m &= \text{constant}
\end{align*}
\]

with \((a_{0}, a_{1}, b_{0}, b_{1}, c, d_{0}, d_{1}, e_{0}, m)\) the parameters to be estimated. This equation was found to be superior for \( E. \text{regnans} \) (and especially so for individual trees) to the trigonometric model structure developed by Bi for radiata pine and a range of Eucalypt species based on the formulation of Kozak (1988).

**Regionalizing or localising the taper model**

The first requirement is to measure a number of sample trees, generally by felling the trees and carrying out detailed stem measurements on the ground.

There are then two basic ways a taper model can be made appropriate for a particular region or locality. The data can either be used to develop completely new equations (generally of a predetermined form but this is not always necessarily the case) or the data can be used to adjust a parameter in a model that has been accepted as generally appropriate to a broad region of interest.

The data requirements for the development of completely new models are greater than if the data are to be used only to develop a correction factor, or to adjust a particular parameter in a model.


Goodwin (2003) extended the Goodwin Thompson model suggesting that it can be regionalized by allowing the parameter \( \beta_{4} \) to be replaced by \( \lambda \) where \( \lambda = \beta_{4} \ast H \). This provides a family of curves that would seem to be quite appropriate if it is desirable to ensure that a taper equation is unbiased for a particular region. This would also enable data collected for importance sampling for a coupe at inventory to be used to develop an unbiased correction to a basic taper model that could then be used to provide unbiased predictions by products.

**Example models**

**Radiata pine; Goodwin and Thompson**

The unconstrained model of Goodwin and Thompson (2003) of

\[ d = \beta_{0} + \beta_{1} / (1 + \beta_{2} h) - \beta_{3} h - \beta_{4} h^{2} \]

has five parameters but was constrained to a three parameter model using \( d = \text{dbhub} \) at \( h = 1.3 \) (represented below as \( d = d_{1} \) at \( h = h_{1} \)) and also \( d = 0 \) at \( h = H \). This was fitted to each tree.
Two alternative second stage models were developed; one based on tree height $H$ only (Model 1) the other on $H$ and $\text{Dub}$ (diameter at breast height under bark) Model 2.

\[
\begin{align*}
\beta_4 &= \lambda_1 / H \\ 
\beta_1 &= Y_0 + Y_1 * H^2 \\ 
\beta_1 &= Y_0 + Y_1 * H^2 + Y_2 \times \text{Dub} / H \\
\end{align*}
\]

and the parameters were

<table>
<thead>
<tr>
<th>$\beta_3$</th>
<th>$Y_0$</th>
<th>$Y_1$</th>
<th>$Y_2$</th>
<th>$\lambda_1$</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.28242</td>
<td>9.456</td>
<td>0.00643</td>
<td>na</td>
<td>1.1039</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.27995</td>
<td>2.951</td>
<td>0.00642</td>
<td>5.853</td>
<td>1.1063</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model 2 was significantly better than Model 1 but did have the extra variable.

**Radiata pine; Bi and Long**

The Bi (2000, Bi and Long 2001) model for radiata pine is based on a trigonometric formulation. If

- $b_r = 1.3 / H$ relative breast height
- $h_r = h / H$ relative tree height

then the model is

\[
d = \text{D} \ln \left[ \frac{\sin((\pi / 2) \times h_r))}{\sin((\pi / 2) \times b_r))} \right]^{\theta} \
\]

where the power term $\theta$ is of the form

\[
\theta = a_1 + a_2 \sin((\pi / 2) \times h_r) + a_3 \cos((3\pi / 2) \times h_r) + a_4 \sin((\pi / 2) \times h_r))/ h_r + a_5 D + a_6 \sqrt{D} + a_7 h_r \sqrt{H} 
\]

and

<table>
<thead>
<tr>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82183</td>
<td>-0.10193</td>
<td>-0.00872</td>
<td>-0.37145</td>
<td>-0.00112</td>
<td>0.0374</td>
<td>-0.03672</td>
</tr>
</tbody>
</table>

Bi and Long claim that this trigonometric function generally has greater prediction accuracy than compatible polynomial taper function. It is also believed to be more flexible and Bi believes that this should reduce the need for localised equations.

**Dean et al. model for E. regnans, (swamp gum or mountain ash)**

The Dean and Roxburgh (2006, but also 2004, 2005) model is as follows.

\[
d = \left[ Y \times \left( 1 - \left( \frac{H_{\text{max}} - h}{H_{\text{max}} - H} \right)^m \right) + \left( \alpha \times \exp \left( - (\beta - c) \times h^c \right) \right) \right]
\]

In this formulation

- $H_{\text{max}}$ is the maximum height for a tree of $E. \text{regnans}$ (swamp gum in Tasmania, mountain ash in Victoria)
- $D$ is DBHOB
- $d$ and $h$ are the diameter and height of the point up the stem as before.

The second stage models were

\[
\begin{align*}
H_{\text{max}} &= 120 \times [1 - 0.8851 \times \{\exp(- (3/2) D)\} \times D] \\
Y &= 0.4184 + 0.8851 \times D \\
\alpha &= 0.4066 \times D^{1.5197} \\
c &= 0.95 \\
\beta &= 1.25 \\
\end{align*}
\]

As at 2007, reformatted 2012 but no textural changes
8.5.3 Stand volume equations

The formulation of stand volume prediction models is generally very similar to that used for tree volume models. Stand based models are commonly used where the data are relatively poor and good models cannot readily be estimated.

For example if:
- $V$ is tree volume (m$^3$)
- $Y$ is stand volume (m$^3$)
- $H$ is PDH not tree height, defined as the tallest 75 trees/ha, in m
- $D$ is tree dbhob in cm
- $G$ is basal area (m$^2$/ha)
- $N$ is the number of trees per hectare

then if for example

$$V = b_0 + b_1 D^2 H$$

then as

$$\bar{D} = \sqrt{\frac{\sum_{i=1}^{N} (D^2)}{N}}$$

and

$$G = \pi \bar{D}^2 / 40000$$

it is easy to convert the tree model to a stand model, either as

$$Y = N \bar{V}$$

or

$$Y = b_0 N + b_1 N \bar{D}^2 H$$

or

$$V = b_0 N + b_1 G (40000 / \pi) H$$

Example models

Eucalypts; Wong et al.

Wong (Wong et al. 2000) found that there were no differences between the various agroforestry Eucalypt species in south eastern Australia, especially blue gum and shining gum, and so developed one stand based equation.

$$V = 0.3983 \text{BA} - 0.0661 \text{H} + 0.35366 \text{BA H}$$

where
- $V$ is volume (m$^3$/ha)
- $\text{BA}$ is Basal area (m$^2$/ha)
- $\text{H}$ is Dominant height (m)

8.6 Stand growth models

Stand growth can be modelled at a variety of levels. In some cases a very simple model, for example “n” m$^3$/ha/year, might suffice for slow growing mixed species native forest but the faster the growth rate and the more intensive the silvicultural management the more complicated the modelling structures that are generally required.
Growth models are generally stand based. Even tree models, which would seem more complicated, more sophisticated and more useful, are often constrained so that the sum of tree growth equals estimated stand growth. Many models perceived as tree models are actually based on tree data originally, but growth is stand based and apportioned back to the individual tree.

The most common approach is to model basal area and upper stand height growth and to use a stand volume equation to get to volume, although some prefer to predict stand volume growth directly. The latter is more demanding of data than the former.

Growth model structures have been evolving since the early 19th century but the advent of modern computers and good statistical packages has allowed a wide range of alternative models to be evaluated, including variations in model structures that might better meet statistical and biometrical assumptions. The use of nonlinear modelling is common and modern packages can handle large data sets with relative ease.

Stand growth modelling has in some ways has become a lot simpler as there are now a number of different model structures that widespread experience suggests are better than others. However care should always be taken to ensure that the underlying structure is soundly based, that the error structure is appropriate, that the statistical assumptions are not violated, that the models are appropriate for the data, and all this is more difficult for nonlinear than linear models. The use of packages makes it easier to develop models but if the modeller lacks the appropriate expertise then the models may be quite inappropriate and may provide flawed predictions.

### 8.6.1 Simple growth models

Often a very simple model is available based on very limited information. These simple “rules of thumb” can be useful.

One such example is the belief that in WA blue gum plantations there is a reasonable degree of volume growth predictability based on available soil moisture. The starting point is to assume that it takes about 35 mm of rainfall a year to produce a cubic metre of blue gum wood using good silviculture and genetics. Thus if there is about 700 mm of rainfall and no access to ground water then the growth rate, or maximum mean annual increment would be about 20 $m^3/ha$, ranging from about 17 $m^3/ha$ if only 600 mm of rainfall to 23 $m^3/ha$ if 800 mm of rainfall.

Similar rainfall effects are noted elsewhere where rainfall is limiting. In the southeast of South Australia these figures would also seem to be near the mark for radiata pine.

Such “rules of thumb” or very simple models must be used with extreme care but they are often a useful indicatory and confirmatory tool.

It should be remembered that the shape of the growth curve may change if ground water is accessed at some stage during the rotation, and that soil, genetics, establishment practices and other silvicultural practices, and seasonal climatic variation can all affect growth rates.

A recent publication by Garcia (2005) provides a way of unifying the disparate sigmoidal growth modelling forms that are commonly used. It is suggested that this reference be consulted if sigmoidal models are being developed.

### 8.6.2 von Bertalanffy family of models

von Bertalanffy (1942, 1957, 1969) developed a general equation based on the theory that growth is represented by anabolic growth rate (constructive metabolism) and catabolic rate (destructive metabolism), both of which are allometric in form. This results in

$$\frac{dY}{dA} = nY^m - pY^r$$

which cannot be integrated, but which can be integrated if ($r=1$) to give
\[ Y = \left( \frac{n}{p} \right)^{1-m} \left[ 1 - \exp(-p(1-m)(A-a_0)) \right]^{\frac{1}{1-m}} \]

where \( a_0 \) is the constant of integration, and can be interpreted or represented as the age at which growth commences.

Various forms of this have been developed including the so-called Chapman-Richards form (Richards 1959, Chapman 1961, Pienaar and Turnbull 1973).

\[ Y = c_1 \left[ 1 - \exp(-c_1(A-c_1)) \right]^{c_4} \]

Both forms reach an asymptotic maximum \( Y_{\text{max}} \)

\[ Y_{\text{max}} = \left( \frac{n}{p} \right)^{\frac{1}{1-m}} = c_1 \]

and both have four parameters to be estimated. The Chapman-Richards form appears simpler but the correlation between the parameters may make it difficult to efficiently determine the parameters. Leech (1976, 1978) showed that for radiata pine the parameters are less correlated if the von Bertalanffy form is used in preference to the so-called Chapman-Richards form.

Ratkowsky (1989) suggests how to re-parameterise nonlinear equations such as the von Bertalanffy or Chapman-Richards form to enable more efficient parameter estimation. This text should be consulted by anyone seriously looking at developing nonlinear growth models as he provides a lot of sound advice about nonlinear modelling.

### A model for Radiata pine

Leech (1978) used the von Bertalanffy form to develop a growth model for radiata pine that predicts volume to a 10 cm top diameter under bark. The model was constrained through a known value, total production volume yield at age 10, or site quality, \( Y_{10} \), and growth started at age \( A = a_0 \).

Analysis showed that if the parameter \( a_0 \) was included the power term approached zero, and approached the Mitscherlich (1910) model form. This yield model was then estimated as a periodic annual increment model.

\[ Y_A = Y_{10} \left[ \frac{1 - \exp(-p(A-a_0))}{1 - \exp(-p(10-a_0))} \right] \]

\[ PAI = \frac{Y_{A(i+n)} - Y_{A(i)}}{n} \]

The model was fitted to 20 unthinned plots with long trend histories and at least 9 measurements for volume over at least 20, average 33, years. This second stage model was used as a fully informative Bayesian prior together with 58 thinned plots with at least 9 volume measurements over at least 20, average 27, years, and Generalized Least Squares (GLS) techniques, to develop a growth model. This posterior GLS model appeared to meet all statistical requirements and has only three parameters. The models were successfully tested on independent plots with marginally fewer measurements and a wider range of site potential values.

### 8.6.3 Johnson-Schumacher family of models

The advantage of the Johnson-Schumacher model (Johnson 1935, MacKinney et al. 1937, Schumacher 1939) is that the model can readily be fitted by OLS regression analysis. The basic form (Clutter et al. 1983) is

\[ \ln(Y) = b_0 + b_1 / A + b_2 f(S) + b_3 f(D) \]

where \( Y \) = yield

As at 2007, reformatted 2012 but no textural changes
A = age 
\( f(S) = \text{some function of site potential} \) 
\( f(D) = \text{some function of stand density} \)

The simplest form

\[
\ln(Y) = b_0 + b_1 / A 
\]

can readily be fitted to individual plot information and then in a second stage analysis the model can be extended to account for variations in site potential and stand density.

Clutter (1963) was probably one of the first to use this model to develop soundly based growth models. He (Clutter et al. 1983) also provides a good description of the use of the model, primarily in the southern pine areas of USA.

Leech and Ferguson (1981) showed that the model is a good predictor of volume growth for radiata pine but a variant of the von Bertalanffy model was in the end preferred (Leech 1978). The model was also used by Ferguson and Leech (1976) to develop a model for the maximum basal area a site can sustain; a useful predictor in mortality modelling.

### 8.6.4 Other model structures

There are many variants of stand growth models apart from those described briefly above. The exact choice of model often depends more on the available data and the modellers own philosophy than on purely statistical based decision making. One pertinent comment is by Raiffa and Schlaifer (1961) who asserted that most contradictory theoretical models can be supported by the same observational material.

#### Gompertz model

The Gompertz (1825) model is based on

\[
\frac{dY}{dA} = aY \cdot \ln(Y / b)
\]

which can be integrated to

\[
Y = b \left[ \exp\left(-\exp\left(-c \cdot (A - a_i)\right)\right) \right]
\]

where \((a, b, c)\) are parameters and \((a_i)\) is the age at the culmination of increment.

The Gompertz model can be shown to be the limiting form of the von Bertalanffy model when \(m \to 1\), or the Chapman-Richards model when \(c_4 \to 0\), that is, when the exponent becomes undefined.

#### Polynomial models

Polynomial models have been used to only a limited degree in stand growth models as it is difficult to ensure that the model can be extrapolated reasonably, the underlying structure is not immediately obvious, and the correlation between the parameters may be so high as to make the parameter estimation inefficient.

### 8.6.5 Physiological models

Starting in the early 1980’s Dr J.J. Landsberg led the CSIRO Division of Forestry and Forest Products teams into research and development of physiological based growth models in Australia. CSIRO established a small but very intensively measured and monitored experiment called the BFG (Biology of Forest Growth) experiment. The research led to the development of models. See Landsberg and McMurtrie (1984) for early models, and see Landsberg and Waring (1997), Sands and Landsberg...
(2002) and the web site for details of the various models. The approaches are physiologically based or process based.

The work continued and has led to the development of a program called 3-PG (Physiological Processes Predicting Growth). There are two versions, a spatial version is linked to a GIS and a simple non spatial version based on an Excel spread sheet.

The model was developed to bridge the gap between conventional, mensuration-based growth and yield, and process-based carbon balance models. The output variables it produces are those of interest and relevance to forest managers. In 2007 the web site


provided the following summary of 3-PG.

“3-PG calculates the radiant energy absorbed by forest canopies and converts it into biomass production. The efficiency of radiation conversion is modified by the effects of nutrition, soil drought (the model includes continuous calculation of water balance), atmospheric vapour pressure deficits and stand age. The carbon produced by the canopy is allocated to leaves, stems and roots, using dynamic equations that update the state of the system on a monthly time step. Calculations can be started at any time for which the state of the forest is specified; the model is then self-constrained. It is a generic model but needs to be parameterised for individual species. The software now available makes this relatively simple. The 3-PG model requires, as inputs, standard weather data, and information about soil depth and water-holding characteristics. Initial tree populations are specified and changes in stem populations calculated using a well-established mortality function. The model has relatively few parameters and is simple to use. Output includes stem biomass and volume, average stem diameters, stand basal area at any time and the time course of Leaf Area Index. 3-PG can be used to evaluate site potential and analyse the probable effects of varying growing conditions or management actions such as thinning or fertilisation. It has considerable potential as a tool for estimating carbon sequestration by forests and plantations and has been shown to be a very valuable teaching tool.”

There have been a number of extensions, enhancements and variations. The web site provides a comprehensive summary and details part of the considerable published literature. A number of papers including Esprey, Sands and Smith (2004), Landsberg, Waring and Coops (2003) and Dye, Jacobs and Drew (2004) provide insights into the considerable potential for forest management planning and hence forest valuation.

Although offering considerable advantages physiological models are not commonly used in modelling large commercial forest enterprises as yet and so are not widely used in forest valuation exercises.

### 8.6.6 Other considerations

There are a number of other considerations in developing models.

#### Aggregating species

Refer also to the section on tree volume equations. In mixed species forest there are rarely sufficient data for every species to enable species dependent growth models to be developed, and aggregating species may be the only practical approach.

The techniques of Vanclay (1991, 1994 p127-31) and Leech, Correll and Aung Kyaw Myint (1991) are relevant. In essence a mix of statistical inference and pragmatism can be used to determine which species can satisfactorily be aggregated. It is also possible, if desired, to keep the major species separate so as to stop predictions for those particular species from being biased.
Basically the same problem can occur when evaluating plantation species trials where, for example, a large number of eucalypt species may have been trialled, but the data are limited and so pragmatic aggregation is forced on the model developer.

This suggests that care needs to be taken when reviewing any paper with species aggregation to determine whether the aggregation is because data were limiting or because the species have similar growth models and so can be satisfactorily aggregated. The appropriateness of the models for the planned use is the critical issue.

**Dynamical models**


The approach can be finetuned as better data become available and Chikumbo has shown that the approach can account for the variability normally observed in any type of forest.

The approach is quite different to commonly used statistical methods but appears to offer some promise. Prospective users should consult the literature.

**Further References**

Assman, E. (1970)

Vanclay, J.K. (1994)

**8.6.7 Example growth models**

Many forestry organisations have growth models that are based on sound data and sound statistical analyses. However few of these are published. Some of the published models that may possibly be useful follow. If they are to be used then it is necessary for any user to ensure that they are correct by referring to the original paper, to determine whether or not the models are appropriate for their use, and to consider whether the model may behave satisfactorily over the desired response range. Vanclay (1994) is a useful reference for this approach, and it is not just relevant for modelling tropical forest.

Generally there is a need for upper stand height models, basal area models and then a model to predict volume, or need a model to predict volume growth directly.

Care should be taken to ensure that the use of any of the models presented is appropriate for the task at hand. For example, the variation in the first 9 years of growth in a progeny trial of river red gum, *Eucalyptus camaldulensis*, ranged from an maï of 0.5 to 5.3 m³/ha/a (Mazanec 1999).

**South Australian graphical models for radiata pine**

See (Lewis *et al.* 1976) for graphically developed tables of total production volume (m³/ha), basal area (m²/ha) and predominant height (m) defined as the tallest 75 trees/ha. Seven site qualities are recognised.

**Posterior GLS volume radiata pine growth; Leech**

Leech (1978) developed a volume growth model for radiata pine in South Australia using Bayesian approach and Generalised Least Squares. The model was

\[
Y_A = Y_{10} \left[ \frac{1 - \exp(-p(A-10 \exp(-a)))}{1 - \exp(-p(10-10 \exp(-a)))} \right]
\]

\[
p = 0.05271 - 0.006484 \ln(Y_{10})
\]

As at 2007, reformatted 2012 but no textural changes
\[ a = 0.003467 \ Y_{10} \]

where
- \( Y_A = \) Total production volume yield to 10 cm top diameter under bark (m\(^3\)/ha) at age \( A \),
- \( Y_{10} = \) Site potential, total production volume to 10 cm top diameter at age 10,
- \( A = \) Age.

### Soil based volume models for radiata pine in Gippsland, Victoria; Turvey

Turvey (1983) presents volume growth models for radiata pine on 7 soil types in Gippsland, Victoria, based on the equation:

\[ Y = Y_{\text{max}} - b \exp(-p \ A) \]

where
- \( Y \) is Volume yield at age \( A \)

The parameters for each soil type are detailed in the table below.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil type</th>
<th>( Y_{\text{max}} )</th>
<th>( b )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA</td>
<td>Balook clay loam</td>
<td>1328.45</td>
<td>1738.18</td>
<td>0.0420</td>
</tr>
<tr>
<td>NA</td>
<td>Narracan clay loam</td>
<td>1152.60</td>
<td>1508.20</td>
<td>0.0456</td>
</tr>
<tr>
<td>SD</td>
<td>Stockdale loamy sand</td>
<td>413.58</td>
<td>877.00</td>
<td>0.1090</td>
</tr>
<tr>
<td>MA</td>
<td>Maryvale sandy loam</td>
<td>739.72</td>
<td>974.87</td>
<td>0.0427</td>
</tr>
<tr>
<td>MR</td>
<td>Morwell sand</td>
<td>424.91</td>
<td>697.69</td>
<td>0.0722</td>
</tr>
<tr>
<td>FL</td>
<td>Flynn sand</td>
<td>489.89</td>
<td>770.44</td>
<td>0.0686</td>
</tr>
<tr>
<td>WL</td>
<td>Wellington fine sand</td>
<td>1083.89</td>
<td>1329.48</td>
<td>0.0312</td>
</tr>
</tbody>
</table>

The paper shows that different soil types have different productivity levels (defined by \( Y_{\text{max}} \)) and that they also have different shaped growth trends (defined by the parameters \( b \) and \( p \)).

### Models for radiata pine; Candy

Candy (1989) developed an integrated set of models for radiata pine. In the models

- \( B = \) Basal area
- \( H = \) Mean dominant height
- \( A = \) age and \( A_2 \) and \( A_1 \) represent the ages at the start and end of the projection period (\( A_2 > A_1 \)) and the same subscripting applies to basal area (\( B_t \) and \( H_t \)) at age \( t \)

#### Mean Dominant Height

The model for MDH is based on the Chapman-Richards model formulation. There were three parameters to be estimated, \( H_{\text{max}} \), the asymptotic maximum MDH and two parameters \( \alpha \) and \( \beta \).

\[ H = H_{\text{max}} \left[ (1 - \exp(-\alpha \ A))^\beta \right] \]

If the height at the first age \( H_1 \) is known then this model can be conditioned

\[ H_2 = H_1 \left[ (1 - \exp(-\alpha \ A_2))^\beta / (1 - \exp(-\alpha \ A_1))^\beta \right] \]

The parameters were:
- \( \alpha = 0.06248 \)
- \( \beta = 1.633 \)

This model can be converted into a series of site index curves based on the base age of 20 or the model can be used to predict future height from any current height.
**Basal area**

The models are based on a modified Gompertz model

\[
B = B_{\text{max}} \{\exp[-\exp(\alpha + \beta \ln(A))]\}
\]

or in the equivalent conditioned form to the height model

\[
B_2 = B_1 \{\exp[-\exp(\alpha + \beta \ln(A_2)) + \exp(\alpha + \beta \ln(A_1))]\}
\]

The two parameters \(\alpha\) and \(\beta\) were estimated as linear models of stand variables. Now if \(S_{\text{di}}\) is Stand Density Index defined from the ratio of the standing basal area to the predicted maximum basal area that the site can sustain and where

\[
B_{\text{max}} = 229.568 \ln(1.7399 - 0.8633 / \exp(H / 30.48))
\]

is a model developed by Lawrence (1976) using imperial measurements, and if

\[
S_{\text{di}} = 100 (B / B_{\text{max}})
\]

and also if

- \(S\) = Site index, MDH at age 20
- \(Pr\) = Pruned ratio (the ratio of pruned height to mean dominant height)
- \(St\) = The reduction in \(S_{\text{di}}\) due to thinning expressed as a percentage
- \(At\) = Years since the last thinning

and the parameters \(\alpha\) and \(\beta\) are estimated from

\[
\begin{align*}
\alpha &= \alpha_0 + \alpha_1 S + \alpha_2 S_{\text{di}} + \alpha_3 S_{\text{di}}^2 + \alpha_4 St + \alpha_5 St At + \alpha_6 Pr \\
\beta &= \beta_0 + \beta_1 S + \beta_2 S_{\text{di}} + \beta_3 S_{\text{di}}^2 + \beta_4 Pr
\end{align*}
\]

then

\[
\begin{array}{cccccccc}
\alpha_0 & \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 \\
3.396 & -0.02317 & -0.01040 & 1.381 \times 10^{-4} & 0.3452 \times 10^{-2} & -0.7331 \times 10^{-4} & -0.1338 \\
\beta_0 & \beta_1 & \beta_2 & \beta_3 & \beta_4 \\
0.2061 & -0.1457 & -0.7533 \times 10^{-2} & -0.2655 \times 10^{-4} & 0.1157
\end{array}
\]

These models have the advantage of being path invariant.

**Volume**

The models are based on the generalised combined variable tree model but in the stand form where

\[
Y = \text{Stand Volume (} Y_1 \text{ being the volume at Age } A_1) \\
H = \text{Mean dominant height} \\
B = \text{Basal area}
\]

and

\[
Y = b_0 H^{-1} B^2
\]

or

\[
Y = \exp( b_0 \cdot B_1 \ln(H) + b_2 \ln(B))
\]

where \((b_0) = \ln(b_0))\). Then the conditioned model can be derived

\[
Y_2 = \exp[\ln(Y_1) + b_1 \ln(H_2/H_1) + b_2 \ln(B_2/B_1)]
\]

and this is in essence a constrained variant of the Johnson-Schumacher model.

Candy suggests that the model

\[
Y = \exp(\beta_0 + \beta_1 \ln(H) + \beta_2 \ln(B))
\]

should be used for unthinned stands and for this equation

\[
\begin{array}{ccc}
\beta_0 & \beta_1 & \beta_2 \\
-0.7466 & 0.8579 & 1.007
\end{array}
\]

and the model below is suggested for use with thinned stands

\[
Y_2 = \exp[\ln(Y_1) + \beta_1 \ln(H_2/H_1) + \beta_2 \ln(B_2/B_1)]
\]
and
\[
\beta_1 = 0.8992, \quad \beta_2 = 1.001
\]
Dimension analysis suggests that the coefficients \( \beta_1 \) and \( \beta_2 \) should each be approximately equal to 1.0 as, if the trees are considered cones the model for volume would be \( Y = \frac{1}{3}BH \). However, as trees are closer to second degree paraboloids it is expected that \( \beta_1 \) will be less than 1.0. In the Candy model neither the value of \( \beta_1 \) or the value of \( \beta_2 \) appear to be significantly different from 1.0 and the parameter should possibly have been constrained to that value, simplifying the equation further.

**Basal area and height models for Eucalypt species; Wong et al.**

Wong (Wong et al. 2000) carried out analyses of key agroforestry species in south-eastern Australia, including blue gum and shining gum. The upper stand height and basal area growth models are as follows;

\[
H_{T2} = H_{T1} \left\{ \frac{1 - \exp(a * T2)}{1 - \exp(a * T1)} \right\}^b
\]

and

\[
\ln(BA_{T2}) = (T1/T2)^c \ln(BA_{T1}) + \left\{ \frac{(a/c) + (b/c) SI}{1 - (T1/T2)^c} \right\}
\]

where

- \( H = \) Height \((m)\),
- \( BA = \) Basal area \((m^2/ha)\),
- \( SI = \) Site index, height at age 10 \((m)\),
- \( T1, T2 \) are the ages in years, \( T2 > T1 \), and,
- \( a, b, c \) are the parameters to be estimated.

If site index is known then it can be used directly, or if a height is known at an age then the height equation can be used to define height at age 10 and so define the variable in the basal area equation.

**Gippsland models**

Gippsland - parameters for the height model

<table>
<thead>
<tr>
<th>Species</th>
<th>( a )</th>
<th>( b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue gum</td>
<td>-0.1114</td>
<td>1.033</td>
</tr>
<tr>
<td>Shining gum</td>
<td>-0.1287</td>
<td>1.093</td>
</tr>
<tr>
<td>Manna gum</td>
<td>-0.1670</td>
<td>1.089</td>
</tr>
<tr>
<td>Salignae series</td>
<td>-0.1008</td>
<td>0.9568</td>
</tr>
</tbody>
</table>

Gippsland - parameters for the basal area

<table>
<thead>
<tr>
<th>Species</th>
<th>( a )</th>
<th>( b )</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue gum</td>
<td>2.443</td>
<td>-0.00193</td>
<td>0.4078</td>
</tr>
<tr>
<td>Shining gum</td>
<td>2.236</td>
<td>0.03516</td>
<td>0.6322</td>
</tr>
<tr>
<td>Manna gum</td>
<td>1.944</td>
<td>0.01947</td>
<td>0.3562</td>
</tr>
<tr>
<td>Salignae series</td>
<td>2.929</td>
<td>0.00591</td>
<td>0.6326</td>
</tr>
</tbody>
</table>

**South Australian models**

South Australia - parameters for the height model

<table>
<thead>
<tr>
<th>Species</th>
<th>( a )</th>
<th>( b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue gum</td>
<td>-0.1207</td>
<td>0.9935</td>
</tr>
<tr>
<td>Shining gum</td>
<td>-0.2277</td>
<td>1.605</td>
</tr>
<tr>
<td>Manna gum</td>
<td>-0.2017</td>
<td>1.446</td>
</tr>
<tr>
<td>Southern mahogany</td>
<td>-0.1605</td>
<td>1.255</td>
</tr>
<tr>
<td>Flooded gum</td>
<td>-0.2293</td>
<td>1.548</td>
</tr>
<tr>
<td>Sydney blue gum</td>
<td>-0.1755</td>
<td>1.596</td>
</tr>
</tbody>
</table>

South Australia - parameters for the basal area model

<table>
<thead>
<tr>
<th>Species</th>
<th>( a )</th>
<th>( b )</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue gum</td>
<td>2.181</td>
<td>0.0681</td>
<td>0.8183</td>
</tr>
</tbody>
</table>

As at 2007, reformatted 2012 but no textural changes
Dominant height and site index for blue gum in central Victoria; Wang et al.

Wang (Wang et al. 2007) used a mixed effects modelling approach that enables the variability of responses among the modelling units (random effects) to be determined after identifying a generic (fixed effects, or mean response) model structure and an appropriate error structure has also been identified. The approach facilitates predictions at the population level, a site or plantation level, and at an individual plot or point level. Modellers can more clearly see, understand and consider the error structure to be adopted, thereby providing a model that should be a more reliable predictor.

If Ordinary Least Squares (OLS) is used to develop models based on repeated measurements from plots then the standard errors of the parameter estimates are biased. By adopting a sound error structure this within plot correlation concern can be addressed, although that was not the primary focus of the study.

They developed models using blue gum plantation data from 19 sites in central Victoria. The models were based on the constrained nonlinear Chapman-Richards form. If

\[ H_i = \beta_0 \left( \frac{1 - \exp(-\beta_1 T_i)}{1 - \exp(-\beta_2 T_R)} \right)^{\beta_2 i} \]

and if

\[ A = \text{average annual rainfall} \]
\[ J = \text{average daily maximum temperature for July} \]

then, although other variables were considered, the model developed by Wang and his co-workers had the secondary structure

\[ \beta_0 = \lambda_{00} + \lambda_{01} A + \lambda_{02} J \]
\[ \beta_1 = \lambda_{10} \]
\[ \beta_2 = \lambda_{20} + \lambda_{21} A \]

with the parameters

\[ \lambda_{00} = -11.5846 \]
\[ \lambda_{01} = 0.02854 \]
\[ \lambda_{02} = 0.7171 \]
\[ \lambda_{10} = 0.1218 \]
\[ \lambda_{20} = -0.2122 \]
\[ \lambda_{21} = 0.001807 \]

The variable \( \beta_0 \) is in essence site index, defined as the stand dominant height (mean height of the largest 100 trees /ha at age 10. The parameters \( \lambda_{01} \) and \( \lambda_{02} \) suggest that for every 100 mm increase or decrease in average rainfall the site index increases or decreases by 2.8 m, and that for every degree change in mean July maximum temperature the site index changes by 0.7 m. This may possibly be a useful indicator of the growth potential if new areas are planted with blue gum in central Victoria. However care should be taken as the variables may, to at least some degree, be acting as proxies for other variables that were not found to be significant in the analysis or were not considered.

It is strongly recommended that the paper be consulted so that the methodology can assessed to determine whether it is appropriate or not for any particular modelling circumstance.

Eucalypts, Victorian SFRI; Wang and Hamilton

Wang and Hamilton (2003) developed a basal area prediction model for regrowth mountain ash and alpine ash forest of the Statewide Forest Resource Inventory (SFRI) in Victoria. If

\[ G1 = \text{Basal area at age T1} \]
\[ Q = \text{Site index} \]

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$R = \text{Treatment regime code (1 for thinned stands, else 0 for unthinned stands)}$

$S = \text{Species code, 1 for mountain ash, 0 for alpine ash}$

then their model was

$$G_2 = G_1^{(T_1/T_2)^r} \exp\left[c_1 \left(1 - \frac{T_1}{T_2}\right)^{c_1}\right]$$

where

$$c_2 = a_0 / c_1 + (a_1 / c_1)Q + (a_2 / c_1)R + (a_3 / c_1)S$$

and

$$\begin{array}{cccccc}
a_0 & a_1 & a_2 & a_3 & c_1 \\
2.5508 & 0.0150 & -0.1977 & -0.1433 & 0.6089
\end{array}$$

This was part of a series of models to predict merchantable volume and the paper should be read to determine how the predictions were proposed to be carried out.

**Shining gum; Candy**

Candy developed an integrated set of models for shining gum in Tasmania and New Zealand. If

- $B = \text{Basal area}$
- $H = \text{Mean dominant height}$
- $A = \text{age and } A_2 \text{ and } A_1 \text{ represent the ages at the start and end of the projection period } (A_2 > A_1)$
- $S = \text{Site index, MDH at age 15}$
- $P_t = \text{The proportion of basal area removed in thinning at age } A_t$

Models were developed to predict $H$ (MDH) from Predominant height (PDH) and from Mean Top Height (MTH)

$$H \equiv \text{MDH} = 0.0065 + 1.10367 * \text{PDH}$$

$$H \equiv \text{MDH} = -0.0906 + 1.0311 * \text{MTH}$$

**Mean Dominant Height**

The model for MDH is based on the Chapman-Richards model formulation. There were two parameters to be estimated, $H_{\max}$ the asymptotic maximum MDH and a shape parameter $\alpha$.

$$H_2 = \left[1 - \left(1 - \left(\frac{H_1}{H_{\max}}\right)^{\frac{T_2}{T_1}}\right)^{c_2}\right]$$

As noted earlier this formulation is notoriously difficult to converge and the best model was found to be when

- $H_{\max} \text{ was set to } 60$
- $\alpha = 0.9113$

**Basal area**

The models are based on the Johnson-Schumacher model form as used by Clutter (Clutter et al. 1983) as described earlier. The yield curve for basal area was

$$B = \exp[(\alpha_0/\alpha_2) + (\alpha_1/\alpha_2) S + \beta T^{(\alpha_2)}]$$

with a thinnings effect model with ‘linear age components’.

$$\eta_1 = A_2 + \alpha_3 P_t + \alpha_4 P_t T_1 + \alpha_5 P_t T_1 S$$

$$\eta_2 = A_2 + \alpha_3 P_t + \alpha_4 P_t T_1 + \alpha_5 P_t T_1 S$$

and then

$$\ln(B_2) = \{\eta_1 / \eta_2\}^{\alpha_2} \ln(B_1) + \{(\alpha_0 + \alpha_1 S) * [1 - (\eta_1 / \eta_2)^{\alpha_2}]\}$$

As at 2007, reformatted 2012 but no textural changes
and

\[
\begin{array}{cccccc}
\alpha_0 & \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 \\
3.53173 & 0.03442 & 0.85751 & 6.78663 & 1.69372 & -0.09569 \\
\end{array}
\]

One advantage of this model is that it is path invariant.

**Starting basal area**

If a family of yield curves is required then a base value must be predicted and Candy developed a model to predict \( B_{10} \), the basal area at age 10, from site index \( S \).

\[
\ln(B_{10}) = 4.8432 - 38.52 / S
\]

**Volume**

The volume model is similar to the tree model equation [8.5.1-4] but was fitted as the nonlinear model to preserve the error structure. \( V \) is volume, \( B \) and \( H \) are basal area and mean dominant height as before, and \( \beta_0, \beta_1 \) and \( \beta_2 \) are the parameters to be estimated.

\[
V = \exp\{\beta_0 + \beta_1 \ln(H) + \beta_2 \ln(B)\}
\]

As expected by dimension analysis the parameters \( \beta_1, \beta_2 \) were close to 1.0 with \( \beta_1 \), the coefficient of height, being marginally less. The parameter \( \beta_1 \) was significantly different from 1.0 but \( \beta_2 \) was not.

\[
\begin{array}{ccc}
\beta_0 & \beta_1 & \beta_2 \\
-0.4885 & 0.8252 & 0.9682 \\
\end{array}
\]

**Ash eucalypt mean dominant height models; Chikumbo et al.**

Chikumbo, Hamilton and Leerson (Chikumbo et al. 1998) used a von Bertalanffy form equation to develop models to predict mean dominant height.

\[
\text{MDH} = \text{SI} \left[ \frac{1 - \exp(a \times A)}{1 - \exp(a \times 20)} \right]^C
\]

where

- \( \text{MDH} \) = Mean dominant height (m)
- \( \text{SI} \) = Site Index, MDH at the base age of 20
- \( A \) = age (years)

The parameters for the two species were as follows:

- Mountain ash (also known as swamp gum)
  \( a = -0.0199 \)
  \( c = 0.8040 \)
- Alpine ash (also known as woollybutt)
  \( a = -0.0262 \)
  \( c = 0.9135 \)
- combined
  \( a = -0.0207 \)
  \( c = 0.8164 \)

The paper also compares these models with other models.

**Further General References**

Assman, E. (1970)


Vanclay, J.K. (1994)

**Further Specific References**

Candy, S. (1997) ["Eucalyptus nitens" plantations]
8.7 Tree growth models

The most used tree growth models predict growth in diameter or height and the growth is commonly a function of the current values of the variable. Thus \( \Delta d = f(d) \) could be a simple linear model or possibly even a complex non-linear model.

Probably the most commonly used form is the simple polynomial

\[
\Delta d = \beta_0 + \beta_1 d + \beta_2 d^2 + \beta_3 d^3 + \ldots
\]

but this form does not ensure robust results and it is common to add other variables into the equation.

The models really require tree density variables as well as stand density variables, and also site potential and other variables. A number of approaches have been used including some of the following characteristics.

1. If spatial information is known about each tree then the area of influence of each tree can be calculated based on a map of the stems. The influence of each tree can be considered proportional to the ratio of the tree diameters or the square or some other power of the ratio. This area of influence can be a useful predictor variable. These approaches are mathematically very plausible but the necessary spatial information is rarely obtained at inventory.

2. The relative tree diameter \((d/D)\), the ratio of tree diameter to the quadratic mean diameter for the stand, is often a useful variable as it reflects the relative growth rate in the past. It is non spatial.

3. Other explanatory variables may be useful. Vanclay (1994) suggests that the basal area of trees larger than the tree of interest, or overtopping basal area, may be a useful variable in developing prediction equations. Logically, for stands of constant site potential, the higher the overtopping basal area the lower will be the tree increment for a tree of a particular diameter. Further, the lower the overtopping basal area the higher the tree increment is likely to be.

4. Site potential is another often used variable.

8.7.1 Allocation models

To preserve additivity and limit the risk of erroneous predictions when extrapolated too far outside the range of the data used to develop the model, it is generally desirable to constrain the tree models so that the sum of the sectional areas increments based on the tree diameter model is equal to the predicted basal area increment. In essence the tree models are commonly used to apportion basal area increment to each tree rather than to predict tree diameter increment per se.

One commonly used method is simply to allocate stand basal area in proportion to the tree basal area

\[
\Delta g / \Delta G = (g/G)^w
\]

where \( g \) is the tree and \( G \) is the stand basal area and the value of \( w \) is commonly 1.0 or close to 1.0.

A more complex model is that of Leary (Leary et al. 1979) that allows for different species to be modelled in mixed species forests. The structural form is

\[
\ln(Y+\gamma_1) = \beta_0 + \beta_1 \ln(X+\gamma_2) + \beta_2 \ln(X+\gamma_2)^2 + \beta_3 \ln(X+\gamma_2)^3
\]

where \( Y=\Delta d/\Delta D \) and \( X=d/D \), and the \( \beta \)'s are constants varying by species and the \( \gamma \)'s vary with species and stand conditions. Vanclay (1994) suggests that the allocation rules become quite complex for stands with many species.
8.7.2 Direct prediction models

Direct prediction models are feasible including various explanatory variables

\[ \Delta d = \beta_0 + \beta_1 d + \beta_2 d^2 + \beta_3 d^3 + \ldots + \beta_4 X_1 + \beta_5 X_2 + \beta_6 X_3 + \ldots \]

where \( X_n \) represent variables other than diameter that may be stand or tree based. If the total increment of the trees is constrained to be equivalent to some modelled stand basal area increment then this generally reduces the difficulties with extrapolation outside the data range as the model is in essence applied as an allocation model.

Leech (Lewis et al. 1976) developed a linear regression model for predicting short term volume increment for the sub-population that is expected to be removed in the next commercial thinnings. The parameters are published, and the model apparently works well, but the structure of the model is not ideal.

8.7.3 Diameter distribution models

Another approach that is often used is to grow basal area and then model the diameter distribution. This is less satisfactory than allocating the increment to the existing distribution as the existing diameter distribution is thus ignored.

This is the least satisfactory basic approach but one that is commonly used when appropriate data are not available.

8.7.4 Transition matrices

A transition matrix defines the probability of a tree of one diameter class transitioning into another class during a specified time period. The matrix is a square matrix of size dependent on the number of diameter classes recognized. The matrix can be multiplied by the vector of number trees in each class to provide a new vector of tree numbers by diameter class.

Transition matrices are really a formal extension of the old, often manual, system of stand table projection.

One method is the Markov Chain which assumes that a forest at any time is in a state such that during the next time interval the probability of moving to any other state can be defined. The Markov Assumption is basically that the probability of a tree moving from one class to the next, an event, lies only in its current state and not in any previous state. Under this assumption the probability of a tree moving from one diameter class to the next cannot vary with the history of how the tree got to that state. This is considered by some to be unduly restrictive and unsatisfactory.

A difficulty in developing a Markov Chain model occurs if periodic non annual increment data are to be used but projections are required to be annual as there is no exact solution for apportioning the annual probabilities.

Approaches such as the Leslie (1945, 1948) matrix and Usher (1966, 1971, 1976) matrix (Vanclay 1994) are more appropriate. The Usher matrix approach reduces the number of parameters to be estimated by adopting a time interval and diameter class interval such that trees can only stay in the same class or move one class.

A true Markov Chain model contains only probabilities of transitioning from one class to another but by relaxing the assumption and allowing non-zero values in the first row of the matrix recruitment can be modelled. Mortality can be modelled either as a separate column in a true Markov Chain model or by allowing the sum of the probabilities in any row to be less than one, thus implying mortality.
Michie and Buongiorno (1984) provide a forestry example of a matrix model approach, describing various methods for computing the coefficients of the matrix. Their simple conclusion was that it seems best to tabulate the data and to determine the probability for each class directly.

This transition matrix approaches has the advantage that it is distribution independent.

Another approach pioneered and recommended by Vanclay (1994) is the cohort model. In this approach the trees in a stand are divided into cohorts of trees that are similar in some respect (generally by species and size). Instead of the diameter class remaining uniform and the number of trees in each class varying, in the cohort approach the number of trees in each cohort is equal and the mean diameter of various classes are not equidistant. The approach allows for mortality and ingrowth by changing the expansion factors. Stand growth is modelled by accumulating the ‘tree’ growth of each cohort. The approach allows diameter increment, mortality and recruitment to be modelled. The approach is especially relevant and appropriate if stocking varies markedly as it does in a plantation during a rotation because of commercial thinning.

### 8.7.5 Example tree growth models

There are only a few published models of tree growth as the larger organisations that use such models generally treat them as being ‘in confidence’ and a corporate asset.

**Shining gum; Candy**

Candy (1997) based his model on earlier work by McMullan (1979). If

\[
\Delta B = \text{the basal area increment between two intervals (m}^2/\text{ha)}
\]

\[
\Delta G_k = \text{the basal area of the k'th tree between two intervals}
\]

\[
D_{1k} = \text{the tree diameter at the first measurement (cm)}
\]

and if

\[
D_0 = \text{is the diameter below which increment is assumed to be zero}
\]

\[
Q = \text{the quadratic mean dbh given by } Q=100\sqrt{\frac{4B}{\pi N}} \text{ where } B \text{ is the basal area}
\]

\[
N = \text{stocking (stems per hectare)}
\]

then

\[
\Delta G_k = c (D_{1k} - D_0) \quad \text{if } D_{1k} > D_0 \text{ else } D_{1k} = 0
\]

constrained so that the sum of the tree sectional areas is the same as the stand basal area increment

\[
c = \frac{\Delta B}{(\sum_{k=1}^{n_0} D_{1k} - n_0 D_0)^{1}}
\]

where \( n_0 \) is the number of trees where \( D_{1k} > D_0 \) and where

\[
\Delta D_{2k} = \sqrt{D_{1k}^2 + \frac{4}{\pi} \Delta G_k} - D_{1k}
\]

which was reparameterised to the equation to predict \( D_0^2 \)

\[
D_0^2 = \exp(\beta_0 + \beta_1 Q + \beta_2 Q^2 + \beta_3 H + \beta_4 H^2 + \beta_5 N)
\]

where

\[
\begin{align*}
\beta_0 & = -1.1460 \\
\beta_1 & = 0.1530 \\
\beta_2 & = -0.00180 \\
\beta_3 & = 0.2956 \\
\beta_4 & = -0.00533 \\
\beta_5 & = 0.000377
\end{align*}
\]

**Diameter distribution model for radiata pine; Candy**

Candy (1989) presents a diameter distribution model based on a Weibull model and using the parameter recovery and parameter prediction methods as described by Hyink and Moser (1983).

The three parameter probability density function (pdf) is given by

\[
f(D,c,\theta,d_0) = c\theta^{-1} ((D-d_0)^{-1} \exp[(-(D-d_0)\theta)]
\]

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where D is dbh0b and c, θ and d0 are the shape, scale and location parameters respectively. The corresponding alternative re-parameterisation as a cumulative density function (cdf) is

\[ F(D,c,θ,d_0) = 1 - \exp\left[- \left( \frac{D - d_0}{θ} \right)^c \right] \]

or

\[ F(D,c,θ,d_0) = 1 - \exp[-c \ln(θ) + c \ln(D - d_0)] \]

The procedures for estimating the models are complex but well defined in standard texts, and they are also well described by Candy.

Now if μd and σ²d are the mean and variance of the Weibull distribution and Γ(.) is the gamma function then

\[ μ_d = d_0 + θ \Gamma(1+1/c) \]
\[ σ²d = θ^2 \{Γ(1+2/c) - Γ^2(1+2/c)\} \]

and

\[ Q_w^2 = \int_{d_0}^{∞} D^2 f(D,c,θ,d_0) dD \]
\[ = μ_d^2 + σ²d \]

and the scale parameter θ can be recovered given estimates of c and d0. Candy used an approximation of the gamma function Γ(.)

\[ Γ(1+x) \approx 1 + α_1 x + α_2 x^2 + α_3 x^3 + α_4 x^4 + α_5 x^5 \quad 0 ≤ x ≤ 1 \]
\[ = x Γ(x) \quad x ≥ 1 \]

\[ α_1 = -0.5749 \quad α_2 = 0.9512 \quad α_3 = -0.6999 \quad α_4 = 0.4246 \quad α_5 = -0.1011 \]

and if

\[ H = \text{mean dominant height} \]
\[ Q = \text{the quadratic mean dbh given by Q=100V((4/π) B) where B is the basal area} \]
\[ N = \text{stocking (stems per hectare)} \]
then

\[ c = \exp(β_0 + β_1 H + β_2 N + β_3 Q) \]

where

\[ β_0 = 1.2247 \quad β_1 = -0.01865 \quad β_2 = -0.0002168 \quad β_3 = 0.01909 \]

and where to use this model d0 is set at the first non-zero diameter class in the stand to be projected (being after thinning if a thinning is carried out at that initial point of time).

The scale parameter theta is obtained by solving the quadratic equation

\[ θ^2 Γ(1+2/c) + 2θ Γ(1+1/c) d_0 + d_0^2 - Q^2 = 0 \]

### 8.8 Other models

A planning system basically requires methods for inputting aspects of the silvicultural history, of future silviculture and also requires prediction models that consider the effects on forward yield predictions. These generally include the following.

- Models describing past silviculture (including fertiliser, genetics, thinning).
- Models of the current state (based on inventory, generally stocking, basal area and upper stand height, and form).
- Models of the planned future silviculture (including future thinning or silvicultural treatment regimes, clear felling age, later age fertiliser applications).
Models to grow the current inventory according to the future regimes, allowing for past silviculture as necessary, predicting either basal area and height growth, or tree growth or stand volume growth, including mortality models, harvesting residue models, and other relevant models, in order to predict future outturn by size and product assortments.

The examples included in this handbook are certainly not complete and different forest planning systems have quite different components. However all have the objective of predicting wood flows, generally by size and/or quality products, as that is the basis for forest management planning which in turn is the basis for forest valuation.

Further References

Assman, E. (1970)
Vanclay, J.K. (1994)

8.8.1 Size and product assortment models

Size and product assortment models generally are of two distinct forms. In the first, simpler form the sizes and products are predicted from stand based model structures. In the second, for example if a MARVL inventory has been carried out, size and product information is obtained directly at a tree level from the inventory data and is then summed to give stand level information.

The approaches used in practice are generally considered proprietary information and few are published.

Example models

Radiata pine, South Australia

For tree size assortments a simple table is presented by Lewis, Keeves and Leech (1976). This details for diameter (dbhob) in 2 cm classes, the percentage of tree volume to a 10 cm top diameter under bark that is predicted to be greater than various arbitrary top diameter limits (2 cm and 5 cm intervals from 14-50 cm).

For stand tree size assortments another simple table is presented by Lewis, Keeves and Leech (1976). This details for mean tree volume (m³/ha) the percentage of stand volume to a 10 cm top diameter under bark that is predicted to be greater than arbitrary top diameter limits (7 cm, 12 cm, and 5 cm intervals from 15-50 cm).

These models are simple to use but the presented models are look up tables rather than equations making computer implementation problematic.

8.8.2 Mortality models

For many forest estates, but especially for plantations, it is desirable to have models that can predict mortality.

Mortality can be divided into three broad types, each of which may need to be treated differently.

1 Early age mortality post establishment. If plantation establishment results in an acceptably high post-planting stocking rate this may be able to be ignored. It can be modelled as a variation to initial stocking.

2 Competition induced mortality. This may occur when a stand reaches an upper stand density limit (stocking, volume or basal area) that causes significant mortality to occur. For radiata pine this may occur in unthinned stands by about age 15-25 depending on site productivity and stocking. Generally any commercial thinning operation will avoid future
competition induced mortality during a typical rotation. Modelling this may not be necessary if commercial thinning is carried out on time but may be necessary for steep country that is unlikely to be thinned or for isolated pockets of plantations unlikely to be thinned commercially. Mortality in blue gums is less likely to be an issue because the rotation length is generally shorter and mortality is less likely to occur.

3 Catastrophic mortality. This most commonly occurs due to severe drought but other causes are possible. The extent will generally depend on the stand density prevailing at the time of the catastrophic event as the higher the level of competition the greater is the likely impact of a catastrophic drought event. This is almost impossible to model on a stand basis and is generally included in the analysis of risk, or by the use of a contingency allowance. This parallels other catastrophes such as fire, hail, and wind that are generally handled in this way. It can also be modelled effectively at a forest estate level as a stochastic process. Some users model it as a deterministic model.

For post-establishment mortality one approach is to use stocking at some age say 5-10 as by this stage any establishment mortality has already occurred. Another approach could be to assume a mortality percentage at establishment. Many forest managers have records of post-establishment stockings, by plantation areas, which can provide the necessary information for planning models.

Competition induced mortality is difficult to model. To develop effective models requires data from plots where competition induced mortality has occurred and the complex interaction with drought effects and the need for annual data, which increases the impact of measurement error on modelling, makes mortality modelling even more imprecise and difficult than growth modelling. Few forest managers have adequate data to model this aspect of mortality well.

The main modelling approach can be dated back to Reineke (1933) who developed an index of stand density based on fully stocked stands, i.e. stands where mortality was occurring due to intense competition. Reineke showed that for these stands the graph of the number of trees per hectare against the quadratic mean diameter, with both plotted as logarithms, is linear. This was also the basis of work in Japan and led to the development of stand density diagrams. If the maximum basal area or volume that a site can sustain can be determined then this may also provide a site invariant, age invariant indicator of a constant stand density level and so it is useful for stand density modelling.

If such a model can be developed it can also provide the basis for a mortality model.

One simple way would be to predict the age at which competition mortality is likely to occur, based on site potential and initial stocking, and then to predict the annual mortality from that stage forward as a proportion of live stocking.

Mortality could be assumed to occur equally in all age classes but a mortality type \((Mt)\), equivalent to thinning type described elsewhere, could be appropriate. This could be the ratio of the quadratic mean diameter of the trees modelled as dying to those before any mortality occurs.

\[
Mt = \frac{\bar{d}_m}{\bar{d}_{b4t}}
\]

where the subscripts “m” and “b4t” refer to the mortality, and the stand before any thinning by mortality, respectively.

A simple model could be based on determining the age at which competition induced mortality can be expected to occur, say age 20, for stands planted at about 1600 /ha, and then from that age assume 2% mortality, with a mortality type of 0.7. A cursory inspection of any plantations exhibiting competition induced mortality would allow these three figures to be significantly improved. The approach is feasible with quite limited data.

This style of model has a sudden shift from no mortality to full competition mortality. If the data to develop the models are plot based (as they generally are) then the variation in competition within the plot suggests that a transition effect may need to be modelled. One possible way is described in Hann, Marshall and Hanus (2003). However, as in all modelling, the models in a complete planning
and prediction system should be in balance and this refinement may not be as high priority for development as other component models.

A transition matrix approach can also be used to model competition induced mortality by relaxing the assumption that the probabilities must add up to one.

The simple alternative to modelling this competition induced mortality is to assume none exists, which may lead to serious biases in predictions.

Two simple options can be applied at a tree level when the level of mortality to be modelled has been determined. Trees can be selected from below, or trees can be selected equally from all diameter classes. Applying mortality at a tree level cannot sensibly be done as a zero-one binary variable as the level of mortality is often too small for any modelled mortality to occur.

The better approach is to adopt a transition matrix approach, determining the probability of mortality for each diameter class, which can therefore be modelled at a tree level.

Selecting simply from below, or equally across all diameter classes, are just special cases of a more general transition matrix.

Example models

**Radiata pine; Ferguson and Leech**

This model for radiata pine in South Australia was proposed by Ferguson and Leech (1976). The maximum basal area a site can sustain can be predicted from:

\[
\log(B) = -0.217 - 4.669 / A + 0.057 S - 0.090062 S^2 + 0.315 E
\]

where

- **B** = Maximum basal area,
- **A** = Age,
- **S** = Site index, PDH at age 30,
- **E** = Stocking at age 10, and
- **log** are logarithms to base 10.

Then the standing basal area can be predicted for any age from the graphical yield table of Lewis (Lewis et al. 1976) and mortality can be assumed to occur at the intersection of the two curves. Ferguson and Leech (1976) provide an estimate of mortality from this point at 2.2% per year.

**Shining gum; Candy**

A better structured model is that of Candy (1997) who used a proportional hazards model to model mortality. This was desirable so that a complete set of equations could be presented. The model was

\[
M_2 = N_1 \left[1 - \exp \left(- \int_{T_1}^{T_2} \eta(t) \, dt \right) \right]
\]

where

- **M_2** = the mortality between ages **T_1** and **T_2**
- **N_1** = the number of live trees at age **T_1**

and \( \eta(t) \) is the hazard function given by

\[
\eta(t) = \exp \{ \beta_0 + \beta_1 S + \beta_2 t + \beta_3 t^2 \}
\]

and where **S** is site index as before. The parameters were

- **β_0** = -8.600
- **β_1** = 0.1124
- **β_2** = 0.1487
- **β_3** = -0.0067
Candy states that the parameter estimates are of similar magnitude to those in his 1989 paper for radiata pine.

**Radiata pine, Candy**

Candy (1989) originally used his proportional hazards model structure described above for shining gum to predict the mortality of radiata pine.

The parameters were

\[
\begin{align*}
\beta_0 & = -12.68 \\
\beta_1 & = 0.1255 \\
\beta_2 & = 0.4458 \\
\beta_3 & = -0.00837
\end{align*}
\]

**Further References**


Hamilton, D.A. jnr (1980)

Vanclay, J.K. (1994)

8.8.3  **Thinning models**

There are two different types of models required for modelling thinning. The first defines the thinning regime that has been, or is to be, practiced. The second defines the effects of that thinning on forest growth.

**Definition of a thinning regime**

In plantation forest management thinning can best be defined in terms of the following parameters.

- Age of first thinning.
- Extraction row interval or frequency applied at the first commercial thinning operation.
- Thinning interval (the number of years between thinning operations).
- Stocking (or basal area) after each thinning operation, often called thinning intensity.
- Thinning operation type, commonly defined at a stand level in terms of either tree diameter, tree basal area or tree volume as the ratio of the mean for the stems to be removed to the mean diameter of the stems before thinning (for example \( TT = \bar{d}_t / \bar{d}_{b4t} \)) where the subscripts “t” and “b4t” refer to the thinned stem subpopulation and the stand before thinning respectively.

At a tree level thinning operation type can also be modelled as a modification of a transition matrix.

- Clear felling age.

Row spacing and tree spacing may also be important. If the ratio of the two is less than about 2:1 then growth will generally not be affected by spatial geometry, but for higher values like 4:1 Lewis and Ferguson (1993) believe that growth may be impacted.

In natural forest where age is not relevant the year of treatment may be defined by the year at which the stand reaches a particular upper stand height, or standing volume. For example, it may be to cut the forest at intervals taking out all trees greater than a fixed diameter limit.

The Burmese selection system is to take out all Teak (*Tectona grandis* L.f.) trees greater than 7’6” girth (ca 75 cm dbhob) every 30 years. After the first cut in the 1880’s the records show that for Pyu Township on the Bago Yoma of Myanmar, the next three cuts provided an almost constant, and economically harvestable, level of cut.

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Effect of thinning on increment

Langsæter (1941) defined the pattern of increment under various stand density conditions. In the graph there are three stages with two transition stages. The vertical axis is increment and the horizontal axis is stand density, in this case starting from zero stems/ha on the left hand side. The figure has been taken from his paper with permission but it is schematic only.

Stage I is the period of free growth, and suggests that for every extra tree the increment increases proportionately.

Stage III suggests that for a wide range of stand density there is constant increment /ha.

Stage V suggests that as a stand increases in stand density mortality occurs and net increment is reduced.

Stages II and IV are transition stages.

In this figure of Langsæter, stand density increases from left to right along the x-axis. It can be thought of as stocking (number of trees per ha), basal area (m²/ha) or volume (m³/ha).

The horizontal scale can be thought of as site use and the vertical scale as site capacity (Lewis and Ferguson 1993).

Möller (1954) basically stated part of the same principle, but he did it in English so his name is often (erroneously) given to the general shape of the curve.

His graph, reproduced here with permission, is similar to the graph above but the X-axis is inverted, with 0% being the proportion of the stand density relative to that which provides maximum stand increment.

The Moller model in essence represents stages I-III of Langsæter. This is the part of the Langsæter curve that is relevant to the modelling the effect of thinning on growth.

The data points plotted by Möller suggests that for his example, the increment is reduced to approximately 90% of the maximum attainable at about 35% of the maximum stocking.

These two curves suggests that for any age and stage in a forest if it is possible to determine what full site increment is it is then possible to develop a model to modify this to account for the possible effects of thinning.

The extent of the flat Stage III part of the Langsæter curve varies between species and probably also with age and site productivity within a species. In some species it would seem to be almost non-existent.

One simplistic approach therefore has been to model the surface as a quadratic. This may be satisfactory for some species but it is essential to ensure that the data on one side of the maximum do not unduly influence the model on the other side as a quadratic model is symmetric. This would be a form of structural misspecification. It is also necessary to ensure that extrapolation of the curve towards a very low stocking is also satisfactory and that the model does not make absurd predictions about the increment when there is 1 tree/ha.
Published models are rare within Australia although models are understood to exist in a number of forestry organisations.

One approach that has been suggested for radiata pine is to define for each age and site potential a stocking value $\hat{S}$ which is the midpoint of stage II of the Langsæter plateau, then the stage I – stage II boundary ($\hat{S}_I$) and stage II – stage III ($\hat{S}_U$) boundary could be defined as a proportion of that stocking value $\hat{S}$. The shape of stage I and stage III are both linear and the shape of stage II could be a quadratic with slope at $\hat{S}_I$ equal to the slope of stage I and the slope at $\hat{S}_U=0.0$, the slope of stage III. An unpublished study (Jerry Leech pers. comm.) indicated that such an approach estimating only $\hat{S}$ and the proportion could be useful and better than other alternatives which might require more parameters to be estimated.

These are stand based approaches, but they can be converted to a tree base relatively simply by apportioning the effects.

### 8.8.4 Silvicultural spacing models

Carrying out early aged non-commercial thinning to waste, or silvicultural spacing, is an expensive operation that may be difficult to justify. It may be easier to justify if it is carried out as part of a considered integrated pruning policy to create clear wood.

There are however a number of circumstances where such an operation might be economically justified, even without pruning. If an area has been established by natural regeneration then such an operation may be necessary to thin the stands out so as to gain diameter growth on potential final crop trees. On steep country where cable logging may be the only way to harvest the forest, and where access is difficult, then generally fewer commercial harvesting operations will be feasible over a rotation and production thinning operations may not be viable. If thinning is not economically viable then silvicultural spacing may become a viable economic operation. A third example could be when there has been a massive planting or replanting program (for example after a major bush fire) and the age class distribution departs from the ideal normal series of age classes with equal areas of overall productivity in each age class. In this case silvicultural spacing may provide greater flexibility as commercial first thinning is unlikely to be able to be carried out on all areas as they silviculturally fall due.

A silvicultural spacing can be defined by the age of the operation, the stocking after the operation and, for a stand based model, the thinning type ($T_t$) which could be defined by the ratio of the mean diameter of trees thinned to the mean diameter before thinning, a variable which parallels that commonly used for thinning.

$$T_t = \frac{\bar{D}_t}{\bar{D}_{obs}}$$

This thinning type could vary from 0.7 to 1.0, the latter being appropriate for a mechanical thinning, but could equally be appropriate if the selection of trees to be thinned is primarily from below but also to remove the larger malformed trees. A simple trial marking could easily determine an appropriate ratio. This model can reasonable easily be incorporated into a planning model.

### 8.8.5 Late age fertiliser models

The application of fertiliser at the later stages of plantation development, commonly after a commercial thinning, is a convenient way of increasing growth rates and increasing future wood availability. It can be a very useful forest management tool.

Miller (1981) suggested that there are three phases in the development of a stand that need to be considered in terms of the response to Nitrogen fertiliser.
Phase I  
The early stage where tree crowns utilise nutrients predominantly available from the soil. During this phase additions of nutrients in the form of fertiliser will directly increase growth.

Phase II  
During this stage the nutrients are recycled and so soil demands are reduced. Fertiliser application during this phase is unlikely to produce large increases in growth.

Phase III  
Later in the rotation nutrient immobilisation can lead to deficiencies. O’Hehir (2001) considers that this stage is unlikely to occur within a rotation of radiata pine but may become an issue with multiple rotations.

Waring (1981) proposed that fertiliser can be considered empirically as two types of responses. His work has been further developed by Snowdon and Woollons (Snowdon and Waring 1981, Snowdon, Crane and Woollons 1995).

Type I  
Advances plantation development but does not change the inherent productivity of the site. It can be modelled by modifying age.

Type II  
Changes the longer term productivity of the site. It can be modelled by changing site productivity.

Both Dr Peter Snowdon and Dr Richard Woollons (pers. comm.) recognises that most fertiliser responses are a combination of Type I and Type II effects but the description remains very useful as a start point for modelling.

Mr Robert Boardman (pers. comm.) suggests that for radiata pine not all trees respond to fertiliser application evenly. He suggests that approximately one third of the trees do not respond at all, and that this occurs across all diameter classes, one third respond somewhat but that the main part of the response is concentrated on the remaining one third of the trees. He is not believed to have reported his considerable investigations. If this does occur then it has implications for thinning type as there will be a tendency to take out in later commercial thinning operations those trees that are not obviously responding to the fertiliser application.

Models to define the effect of later age fertiliser application could predict the gain directly but more commonly predict a modifier (generally a multiplier) that can be applied to the base increment from other sources. This approach has been widely used in Sweden, United States and Australia. There are two components models that are required.

The first models the trajectory of the fertiliser response multiplier with time. Increment is commonly low immediately after fertiliser is applied as it takes up to three years for the foliage biomass to expand and the volume (or basal area) increment to be at its maximum before slowly reducing back to approximately the base level.

The response period varies but after reaching a maximum the modifier commonly returns to a value of 1.0 after approximately 7 years (Möller and Ryterstedt 1974, Miller 1981, Turner, Knott and Lambert 1996).

The second model is required to model the effects of varying the amount of fertiliser applied. It is not possible to generalise as different tree crops react differently to different elements on different soil types and different crops. The most commonly used base element would seem to be the amount of elemental Nitrogen applied but it is also common just to define the fertiliser applied and to use the weight/ha as the level. Other late age fertiliser models ignore this effect and base the modelling on some base level that has been found by research to be satisfactory.

Hann, Marshall and Hanus (2003) predicted the effect of fertiliser on diameter and stand height growth. Their models are interesting in that they used a Mitscherlich style model to predict the effect of different levels of fertiliser, modelled the effects of thinning (albeit rather simplistically) and modelled the effects of multiple fertiliser applications.

O’Hehir (2001) provides models for radiata pine that incorporate the interaction between late age fertiliser application and thinning.
Example models

Radiata pine, South Australia

Three models described by Sutton (1992) were earlier used by Leech (1988) to model the economic sensitivity to variations in fertiliser response models.

The solid middle line represents the best estimate of the response with a high and a low estimate presented to facilitate sensitivity analyses. The vertical axis shows the multiplier to be applied to the base level of volume increment if fertiliser is applied one year after a commercial thinning.

The models do not allow for variation in the amount of fertiliser applied.

The models were developed in the early 1980’s and may now be superseded.

It may be useful to note that the accepted “best” model can be approximated by assuming that the fertiliser gain represents two years increment which could be approximately modelled as a 30% gain in volume per year over 7 years.

Radiata pine, New South Wales

Turner, Knott and Lambert (1996) investigated different levels of Nitrogen and Phosphorous in a number of trials in New South Wales. A table presents 7 year percentage gain in basal area compared with the controls. A graph shows mean dbhob plotted against years since treatment and it shows a similar trend to the volume trend in South Australia noted above. By considering the appropriateness of each trial area it is possible to assess the optimum treatment and the expected gain in basal area.

8.8.6 Possible changes in site potential

Changes in site potential may be a convenient way of modelling some fertiliser responses but there are other reasons why changes in site potential may be modelled.

Changes between successive rotations

Keeves (1966) was possibly the first to publish evidence of changing productivity between successive rotations of radiata pine. If such a loss in productivity between successive rotations does in fact occur then it is important to consider it in any long term planning model covering a number of rotations.

Such evidence is always in danger of being confounded by differing establishment methods being employed for the two rotations and so it is often difficult, if not impossible, to be definitive in discriminating the effects. The evidence has often been challenged, with evidence cited of gains in productivity rather than a loss but almost all cases would seem to be due to improvements in genetic improvements, establishment techniques and early aged silvicultural techniques.

Boardman (1988) details his estimates of a number of different component effects.

Improvements due to genetic gains

The improvements in volume growth that are due to the use of improved seed stock as a result of tree breeding may need to be modelled.
One way of modelling the gain is to model a change in site potential. Alternatively the gain may be modelled by changing the age. In essence this parallels the Type I, Type II response for fertiliser of Waring and Snowdon described earlier (Waring 1981, Snowdon and Waring 1981).

**Effects of weedicide**

The effects of weedicide applications may also need to be modelled. Again, the effects may be modelled as a gain in site potential, a change in age, or possibly they may be ignored.

### 8.8.7 Ingrowth or recruitment models

In native forest it is necessary to predict ingrowth into the smallest diameter class recorded at inventory. This ingrowth or recruitment can be modelled as a simple prediction function.

One useful approach is to use a transition matrix approach for tree growth as then both mortality and ingrowth can be incorporated by relaxing the assumption that the probabilities must add up to one.

Modelling ingrowth or recruitment is generally not an issue in plantations.

### 8.8.8 Harvesting residue models

There is a need to predict the proportion of the wood theoretically available on a site that can be effectively and efficiently utilised.

The terms logging waste or harvesting waste are often used but these have connotations of errors, mistakes and problems with harvesting when that may not be the case at all. Residue can be divided into different categories; some may be left by mistake, some may be left because current market conditions make collection uneconomic, some left because it cannot meet the products specified for that operation, and some is just unavoidable residue including logging smash.

Further, in any planning system some allowance must be made for stumps. This may be built into the predictions and this can be achieved in some inventory processing systems, or may be another model that can be superimposed over the predictions.

Ideally it is necessary to measure residue (by category) on a range of sites and then to develop prediction models that can be incorporated into the planning system.

The base data can come from small plots measured in the field but these are difficult to measure and costly. An alternative is to use a line intersect methodology based on Buffon’s needle problem, an example of which is presented for radiata pine by O’Hehir and Leech (1997). Care must be taken to overcome the effect of directional felling and circular transects achieves this.

Care must also be taken to include all residue including residue on skid sites (or landings or dumps). A simple percentage of the available volume may suffice as a model. Extensions to vary the percentage by harvesting operation type, by age, and definitely by species, are sensible. Some managers have models that allow the percentage loss to vary by log diameter class. Models are generally proprietary and not in the public domain. Forest valuers should consult the owner to determine what information might be available and what models might be used. Whatever the decision it should be clearly documented.

### 8.8.9 Converting measurement methods

Most contracts for the provision of wood are predicated in terms of volume (m$^3$) although some are predicated in weight (tonnes) or in numbers of pieces of certain dimensions (more common for
roundwood such as is used for fencing). The use of weight is generally for simplicity and to facilitate the audit of measurements, but the objective is generally to provide a measure of volume. The predictions from any planning system are generally in volume (m$^3$) and it may be necessary to convert from one mensuration measurement method to another, or to a series of different measurements depending on the product or products being predicted.

For pulp wood it is common to measure by weight and convert to volume using a density figure. This may be based on sample scaling but it is not uncommon for radiata pine to assume 1 green tonne is 1 cubic metre (m$^3$) of wood. Given that the standard deviation of density may be 5% and given seasonal fluctuation may be another 5%, then considerable error and possibly bias may be built into any predictions by using this assumption.

The conversion may also be over bark weight to under bark volume. Over the last 10-20 years the proportion of bark that is removed in the forest has increased, partly as a result of the almost total change from manual to mechanical harvesting methods. The conversion does not stay constant over time.

For preservation treated products the roundwood input is commonly measured in terms of pieces and if this is the case then it is necessary to develop conversion figures, and more importantly to monitor these. Again, bark thickness issues may need to be considered.

Another common problem occurs when volume measurement is based on measurement by a log scanner on entry into a sawmill. Many sawmill scanners work in one dimension not two. Logs are commonly elliptical and the log transit mechanism may turn logs onto the flat side and this may bias the scanner measurements. Some scanners scan in the horizontal plane, others in the vertical plane and this may either over or under estimate average log diameter. Also, as the scanner is designed for measuring logs to determine the best processing option, the software in the scanner may estimate log volumes in a different manner to those inherent in the predictions, and may even assume that the small end diameter holds for all the log length. Harvest operation overcut allowances may or may not be built into the software used to calculate volume.

There is no simple way of resolving all these measurement method conversion issues. For some forest valuations they may be insignificant and unimportant, but the issue should at least be addressed as the effects may be quite considerable.

But, it must be remembered that volume in one part of the prediction system may not be equivalent to volume in another part.

In most forests sawlog volume is measured according to a pre-defined formula (see Annex) but commonly this is either Huber’s or Smalian’s formula. A conversion model may be required to convert from the volume measured in the standing trees (generally true volume under bark, or based on either 2 or 3 m long sections) to the log measurement method. The differences are often ignored but can be considerable. In the later section on Revenues the Japanese Agricultural Standard (JAS) will also be discussed as this generally pertains for export sawlogs.

### 8.8.10 Other models

In some specific circumstances other models may need to be developed and used.

#### Stochastic models

The models that have been described so far are almost all deterministic models which will provide one result for a prediction. There is another class of models, stochastic models, that use probability
based modelling approaches. These are more commonly used when analysing risk but the approaches can just as easily be used for forest modelling.

Vanclay (1991) provides one such discussion paper.

This class of models will not be discussed in any depth, simply because at present most models underpinning forest valuation are deterministic models. This is not to suggest that stochastic models are not important, nor useful, nor appropriate.
9 Processing systems

This chapter provides a general introduction into the processing systems required for processing forest inventory data and for developing the information necessary to support forest planning and forest valuation. The next chapter will discuss some of the proprietary systems that are available.

Processing can be simple or complex and must be balanced with the needs of the organisation. The larger the forest estate generally the more complex and the more flexible the forest planning systems that are used.

In general the more precise and less biased the information available from a planning system the less allowance has to be made in planning and in forest valuation for risk and uncertainty. Thus the apparent overhead cost of extra system complexity can be at least partly offset by better utilisation from the forest because of a lessened need to account for risk. This is difficult to quantify, but this argument has been used effectively in some organisations to justify increased emphasis on the development of their planning systems.

The financial gains that can be made by improving planning systems can be considerable.

9.1 Inventory and planning systems

The purpose of an inventory system is to get the data from the field into a computer file suitable for processing, and then to process that information to provide estimates of volume, generally by log size classes and product classes, that enables short term plans to be prepared. In essence it generally takes the plot or point based field estimates and provides the estimates and predictions for a stratum.

The purpose of a planning system is to take that inventory data, adopt a future silvicultural and management strategy, and then to predict volumes by size and product classes at the various points of time during the selected planning horizon. This is basic to, and essential for, determining the value of a forest estate.

The systems can range from the extremely simple to the very complex. At the simple end of the spectrum data entry can be on field sheets and the calculations can be by hand, although often a simple spread sheet is used to minimise calculation errors. At the more complex end of the spectrum inventory systems are available with modules that facilitate field data entry direct onto hand held computers, the ability to download the files to another computer for processing, and then provide, almost automatically, the required information about all the strata in the forest and so provide the base information for short term planning and for forest valuation.

The boundary between inventory processing systems and short term planning systems can be blurred in some packages.

The important consideration is that the package or system or methodology used should be appropriate for the task at hand, and appropriate for the valuation of the forest estate.

Further References

Abed, T. and Stephens, N.C. (2003) [for simple systems]
Loetsch, F. and Haller, K.E. (1973)
Loetsch, F., Zoehrer, F. and Haller, K.E. (1973)
Spurr, S.H. (1951)
9.2 Components

The models that may be required in any inventory and planning system are described in earlier chapters; this section aims to describe how some of the components may be put together in the systems. There are as many different approaches as there are forests and this section summarises only some of the alternative options that may be sensible.

There is a need for consistency between all areas in the whole planning system, and a need for sound integration of all components.

In the published literature there are a number of examples of various component models that can be integrated into a planning system. Generally the published examples infer that some components are available elsewhere and concentrate on specific aspects only.

One example of an integrated biometric model is that of Candy (1997). He provides equations for shining gum to predict basal area (B) and mean dominant height (H) growth, equations to calculate stand volume from B and H, models for stocking mortality, models to predict diameter increment (suitably constrained so that total increment across all trees is consistent with stand basal area increment). Candy details the models needed to predict growth under a variety of silvicultural regimes. This follows equivalent earlier work for radiata pine (Candy 1989).

9.2.1 Field data entry

In the past, data entry in the field was generally onto specially prepared field forms on paper and these were taken back to the office for processing. This may still be appropriate but for larger inventories it is increasingly common to enter the data directly onto hand held data capture devices in the field.

Then, the data can be downloaded to the office computers for processing. One of the earlier papers was by Leech, Sutton and Archer (1989) using hand held Husky Hunter micro computers that were extremely rugged. Since then a number of devices have come on the market that are less rugged but more powerful, including small lap tops and smaller hand held computers. These are now being used quite satisfactorily. Choosing the best device for a particular application depends on the forest situation as ruggedness comes at a cost.

9.2.2 Calculation of inventory

The objective is to take the tree and/or plot data, generally diameter, height and sometimes other variables, and predict volume at a stratum level. The predictions of volume are commonly by size and product classes, and may be for specific sub-populations, such as the trees to be removed in the next commercial thinning and those to be left, or for different species.

If inventory has been carried out using point samples, or angle count sampling, then the individual tree information may have been lost. If the individual tree diameters have been recorded then it is possible to calculate the area of influence of each tree, in essence equivalent to plot area, and so the individual size characteristics can be preserved and size and product information can be obtained.

In the case of plots, two alternatives are possible; convert diameters to basal area and then process at a stand level, and the much more common approach of calculating individual tree volumes and then accumulating the tree information to get the required stand level information.

Tree volumes can be calculated by a number of different methods but basically there are two main methods.

- The use of taper equations describing the shape of the tree, in which case product volumes may also be obtained, for example if a MARVL inventory is carried out.
• Tree volume equations. In this case tree volume assortment equations may be necessary if it is necessary to predict volumes to various size classes. Products are generally not available, or if they are available then only in relatively simple terms.

Some models require tree height information and this may have only been measured on a sample of trees whereas diameter is generally measured on all trees. Tree heights need to be predicted for all the trees and this may require the use of a tree height diameter model. The sample tree heights may also be used to predict upper stand height.

If a MARVL style inventory is carried out then utilisation factors can be taken into account, including stump heights, log cross cut allowances and overcut allowances, malformation, standard log lengths and so on. For other inventories it may be necessary to adjust the predicted volumes to account for the different mensuration methods used for plot measurement and prediction and those used to measure the harvested wood products. It is commonly also necessary to account for logging residue.

The tree volume information is then accumulated into plot based information. The plots are then accumulated within coupes or harvesting units and this may use stratified random sampling methods.

### 9.2.3 Calculation of future wood flows

A planning system combines the inventory information and whatever biometric models and planning models an organization believes desirable and prepares predictions of expected wood flows. It basically combines all the aspects described earlier in this Handbook. If the multitude of components are all understood and accepted by management then the planning system just simply carries out the arithmetic. The complexity of the system and its components depends on the required precision for the predictions of future products, the prediction of wood flows which are generally the basis for forest valuation. Obviously the desired precision is a balance between the cost of the whole planning process and the expected requirements and this will vary between organizations.

This is a check list of components that may or may not be appropriate in different circumstances. In the simplest cases many of these components can be ignored, but in the larger forest planning exercises other factors may also need to be considered that are not mentioned below.

The various components are integrated to provide a yield table which is basically a list of expected future outturn from a particular stand. Yield tables commonly predict per hectare yields as these can then be applied to the area of a planned logging coupe. These are then commonly stored as computer files and input into the planning system.

#### Modelling current status

The current status includes the basic inventory.

• Stocking, basal area, upper stand height and volume, by size classes and/or products.

#### Modelling forest history

Information about the silvicultural history of the plot may be very important to determine how the stand may behave in the future. Aspects that may be important include the following, but not all aspects may be required in every situation.

• **Soil type.** This may include the soil type, soil depth, depth to water retentive layer, and geology. It may include drainage aspects.

• **Site preparation.** This may include ploughing, mounding, ripping, burning and wind rowing.

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- **Plantation establishment.** The year of establishment, possibly the date of establishment, initial stocking, row spacing and within row spacing, description of the genetic stock, whether seedlings or cuttings, application of weedicide and application of fertiliser.

- **Post establishment.** Early age weedicide applications, early age fertiliser applications, occurrence of browsing, insect or pathological damage and the treatments applied. Information about any early age mortality may be important later.

- **Pruning.** The age and prescriptions for each pruning lift and also certification if considered appropriate.

- **Non-commercial thinning or silvicultural spacing.** At early ages some trees may be taken out before a commercial thinning is possible, to space the trees, release pruned trees or to remove severe malformation. If atypically large areas have been planted then early age spacing thinning may be economically carried out to improve later wood flows and to increase future silvicultural flexibility. The silviculture applied needs to be recorded.

- **Commercial thinning.** For each commercial thinning, the year (age) and stocking after thinning (basal area and/or number of trees).

**Modelling of future management**

The future silvicultural management strategy needs to be modelled. This should be from the current forest state but that may be, for a plantation, from the age of establishment. Aspects that may need to be considered include the following.

- **Plantation establishment.** The expected year of establishment, initial stocking, row spacing and within row spacing, genetic stock, whether seedlings or cuttings, application of weedicide and fertiliser.

- **Post establishment.** Early age weedicide applications, early age fertiliser applications, expected occurrence of browsing, insect or pathological damage.

- **Silvicultural spacing.** Early age non commercial thinning may be desirable to improve management flexibility. Specify year (or age), stocking to be retained, whether an extraction row is removed or not, thinning type (although commonly this may be 1.0, a mechanical thinning).

- **Pruning regime.** The age and prescriptions of each pruning lift.

- **Cutting cycle.** The interval between harvesting operations.

- **Thinning regime.**
  - The age of the first commercial thinning,
  - The extraction row interval,
  - The interval between thinning operations,
  - The stocking after thinning (basal area or number of trees), and,
  - The thinning type (generally the ratio of mean tree size of each thinning operation to the mean tree size of the stand before thinning).

- **Clear felling age.** Commonly this is fixed but may be scheduled to vary during the planning horizon in order to even out wood flows.

- **Fallow period.** This may differ between normal plantation reestablishment and replanting following fire. In some situations it may vary during the planning horizon.

- **Late age fertiliser application.** May be scheduled after some or all commercial thinning operations, or at various ages.
• **Site productivity changes.** The site potential changes that may occur between successive rotations. This may be a gain or a loss in productivity between rotations.

**Growing the stands to create a yield table**

Aspects that may need to be considered include the following.

• **Basic growth models:** predict growth, either tree or stand based models.

• **Mortality models:** predict the onset and amount of any mortality and then to predict the effect on growth. Three different forms of mortality may need to be recognised.
  - Mortality in the year after planting.
  - Competition induced mortality caused because the stands have not been thinned on time.
  - Catastrophic mortality that can occur due to unforeseen droughts, insect or pathogen attacks, other climatic events such as wind or snow, and generally the extent of the mortality varies with stand density and other stand characteristics.

• **Size and product assortment models:** tree models are generally used for inventory and short term yield projection but stand based models are often used for longer term projections.

• **Thinning and silvicultural spacing models:** predict the effect of silvicultural treatments on growth.

• **Pruning models:** predict the effect on growth and on product assortments of the pruning strategy modelled; including the prediction of diameter over stubs (DOS) which impacts on outturn recovery when the trees are processed.

• **Later age fertiliser models:** predict the effect of scheduled late age fertiliser application on growth.

• **Harvesting volume models:** used to convert volume as predicted to the measurement method used for measuring harvested volumes; for example log volumes by Huber or Smalian’s formulae, or other formulae, volume from scanners, or by weight.

• **Logging residue models:** predict the amount of harvesting residue, the difference between the modelled volume and that likely to be achieved. Different models may be required for unavoidable residue, for residue left because of temporary market constraints, or residue left because of poor harvesting practice.

• **Area change models:** predict changes in area over time during the planning horizon; land acquisition, land revocation and sale, smaller area losses such as small fires and lightning strikes and catastrophic large scale are losses such as from wildfire or wind. There are a number of deterministic and stochastic methods possible.

These models are generally built into a planning system.

**Preparing a plan**

When all the yield tables from each coupe have been prepared (although they may be internal to the computer and not even in a separate file) they can then be summarised into management plans.

Commonly two plans are developed with different planning horizons.

The first is the short term plan demarcating where harvesting is likely to be carried out in the next few years, generally 1-5 years. This may be used as the basis of a more detailed plan used to schedule contractors and exact operations over time.
The second is the longer term plan used to determine what the forest can actually supply in the longer term. It is the plan used to set commitments or to determine levels to be sold by tender. It is also the plan used to determine whether or not the level of cut is sustainable.

Some intensively managed plantation organisations are known to have many more temporal planning levels with the long term plan being say up to 50-70 years out to determine long term effects on the forest, a shorter term 5-25 year plan used to base long term contracts, a harvesting plan of 1-5 years used to determine how the contracts can be met, this being the basis for a more detailed annual plan, which in turn is used to prepare a 8-12 week plan, and also a weekly plan. The time frames for the various plans used by different entities differ considerably but the division of time into arbitrary planning periods is generally to meet corporate philosophical desires.

The plan may be either a single simulation of each harvesting coupe in the forest or a number of different silvicultural strategies for each coupe. Optimisation procedures are then used to determine which combination of coupe strategies provides the optimum according to some predetermined criterion.

It is these plans that generally form the basis for the forest valuation, especially if a discounted cash flow (DCF) or present value (PV) approach is used for forest valuation.

### 9.3 Some considerations

There are a number of issues that need to be considered in determining a philosophy to be adopted for a planning system.

#### 9.3.1 Tree or stand based projection?

Should growth be based on tree growth or are stand based models more appropriate?

There are a number of issues that need to be considered.

- Is the requirement to predict volume at a coupe level or at an aggregated level across all coupes? If the latter then stand based models may be quite satisfactory and are generally simpler. If the former, then tree based models may better reflect the diameter distribution differences between stands and so provide less biased predictions.

- Are the data good enough to support tree models or are stand based models more appropriate?

- Tree models have the advantage that it is possible in the short term planning to gain better information about products as well as size because they can reflect the tree diameter distribution better. Stand based models to predict products or sizes are generalisations.

- Are the tree growth models consistent with stand based models, for example does the sum of future diameters convert exactly to modelled future basal area? This may or may not be an important issue.

- Some users are concerned about the possibility of error propagation becoming a major issue if tree models are used to predict too far into the future. It is possible to limit the difficulty by careful use of stand based constraints but care is needed.

There is no one simple answer to the question as to whether to model trees or stands and often the question is irrelevant in practice as the available models can only sensibly be used one way or the other. One way is to consider the likely relative prediction errors of alternative systems depending on the numbers of years into the planning horizon, perhaps in four phases; immediately, within 1-5 years, between 5 and 20 years, and past 20 years into the future. Then it may be possible to determine the more appropriate technique depending on the organisations needs.

It is necessary to make a sensible, balanced judgement when developing a forest planning system.
9.3.2 Grow basal area and height, or grow volume?

The most common stand based procedure is to develop growth models for basal area and upper stand height and a model to convert these predicted values to stand volume. Models are well defined and the wealth of published modelling experience allows a modeller to ensure that a system of models can be developed relatively simply.

The alternative that is only used rarely is to convert basal area and upper stand height to volume and to grow volume directly. This is the basis of the South Australian mensuration philosophy (Lewis et al. 1976).

In the south-east of South Australia height growth is affected by wind and micro-topographic effects on the coastal plain. Leech (2006) used a completely orthogonal data base with volume measurements obtained from sample trees to develop volume, basal area and predominant height growth models, and a model to calculate standing volume from basal area and predominant height. The data base was of unthinned plots to avoid any thinning effects. Two alternatives were considered.

- Start with basal area and height, convert to volume at the first measure and grow volume to each future measurement and compare with the actual volume obtained.
- Start with basal area and height at first measurement, grow each and convert to volume at the time of each future measurement and compare with the actual volume obtained.

The results showed that it was better to grow volume rather than basal area and height, for although the basal area model was very good there was great variation in height growth that was not reflected in volume growth. For South Australia it was better to grow volume rather than basal area and upper stand height.

This is not necessarily true elsewhere.

It should be remembered that good permanent plot data are needed for growth modelling and that basal area measurements are generally more accurate than height measurements, which are in turn generally more accurate than volume measurements, and so it may not be feasible to develop volume growth models simply because suitable data are not available.

In these cases, which are believed to be the majority of cases, it is necessary to develop basal area and height growth models as it is just not possible to develop volume growth models. However in these cases it should be recognised and accepted that the decision is based on the availability of data and not on sound statistical reasoning as to which method is better.

In any growth modelling used in planning systems it is necessary to understand, recognise and accept the limitations that might be imposed by data availability.

Care should be taken not to use one modelling approach simply because it has been widely used but to ensure that it is appropriate for the organisation and based on a consideration of the models and data available, and a consideration of what is feasible.

9.3.3 Short and long term planning, one system or two?

The question as to whether short and long term planning should use one system or two needs to be answered.

If there are two separate systems there are a number of problems.

- The data sets may not be compatible.
- Predictions may not be consistent between the two systems leading to uncertainty as to which is correct.
• There may be a discontinuity between predictions from the two systems at the temporal interface. Importantly this may lead to questions by management.

If there is only one integrated system there may be problems too, although many consider the problems are far less significant.

• Harvesting coupes that are in progress at the start of the short term planning period either have to be maintained as separate coupes for the whole of the long term plan or a method is necessary to combine them later. This can be achieved relatively simply if a simple simulation systems approach is used, but is more difficult of linear programming is used.

• Some models really need to be applied at a forest level and although this can be achieved by treating each coupe separately and aggregating the results the individual coupe figures may then become almost meaningless. An example of this is allowing for area changes due to large fires or even small fires or lightning strikes. Areas lost to large fires can be replanted almost immediately whereas the areas lost to small fires and lightning strikes are more likely to be replanted when the adjacent areas are clear felled. In one case the area is replanted in 1-5 years; in the other case the area is replanted on average half the rotation hence. If a simple average area loss is applied over all coupes then this is appropriate for long term planning. However for short term planning it is generally superior not to consider any area changes at all. There is a difference between how area losses should be treated for both short and long term planning. What is really needed is a stochastic model but, even then, some of the issues will still remain.

• Some organisations allow for risk by subtracting a contingency allowance of say 5-10% to the long term planning estimates before making form contractual commitments. This is to allow for the cost of over-cutting being considerably more expensive and more difficult to manage than the cost of under-cutting. The attempt is basically to balance the cost risks, not the volume risks. This allowance should generally only be applied to the long term yields, not the short term yields. One difficulty with this approach is that it may not account for the way risks change over time.

The issue is not as trivial as it seems and care should be taken to ensure that the right decision is made for the organisation.

Further References


9.3.4 To optimise or not; linear programming or simulation?

Should an organisation use linear programming or not? Is a simple simulation model of the future predicted yields for the forest estate more satisfactory?

In a simulation approach predictions are prepared for each coupe in a forest based on one fixed set of information, forest inventory, volume prediction models, future expected silvicultural prescriptions, and future growth models to apply those silvicultural prescriptions, in order to provide a yield table for each coupe. These yield tables predict volumes by the desired size and product classes and are then aggregated to provide one expected outcome from the forest over time.

In a linear programming approach a number of different strategies are modelled for each coupe and optimisation procedures are then used to determine which set of strategies provides the optimum for the forest. Linear programming is the most commonly used procedure but other procedures including integer linear programming, goal programming and nonlinear optimisation methods have also been used.

There are other search algorithms which can find near-optimal solutions through iterative simulation. These tend to be more flexible than LP. Habplan, for example, which can be downloaded from the
Web for free, has been shown to be able to handle Australian forest planning problems but does not seem to have been used in practice in Australia (Turner et al. 2002). The web site at 2007 was: http://ncasi.uml.edu/projects/habplan/

In deciding whether a simulation or a linear programming approach is the most appropriate approach there are a number of issues to be resolved and questions that need to be asked. The questions that should be asked are many and the solutions are not necessarily simple.

The table below summarises the major issues without making any firm recommendation as to which should be used in any particular set of circumstances.

<table>
<thead>
<tr>
<th>Linear Programming</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needs a stand simulator to generate yield tables.</td>
<td>Needs a stand simulator to generate yield tables.</td>
</tr>
<tr>
<td>Needs a way of automatically generating yield tables from a simulator.</td>
<td>Can vary the management regimes for each stratum. But only one set of variations per computer run.</td>
</tr>
<tr>
<td>Generally only a limited number of alternative regimes can be handled.</td>
<td>Generally an almost unlimited number of stands can be modelled.</td>
</tr>
<tr>
<td>Commonly only a limited number of stands and alternatives can be managed, although this is far less of a problem than it used to be.</td>
<td>Can more readily change regime during the rotation.</td>
</tr>
<tr>
<td>Cannot change regime during the rotation although many alternative regimes can be tested.</td>
<td>Predicts units as entities.</td>
</tr>
<tr>
<td>Optimum will commonly split some stands between treatments which may or may not be feasible in practice. This can be overcome by the more complex forms of optimisation including mixed integer programming.</td>
<td>Almost impossible to assess non timber and environmental values.</td>
</tr>
<tr>
<td>Can include non timber values and any other environmental effect that can be quantified.</td>
<td>No certainty of optimum.</td>
</tr>
<tr>
<td>Optimum is assured, but generally (unless goal programming is used) for only a single objective.</td>
<td>Simpler to implement.</td>
</tr>
<tr>
<td>More complex algorithm to implement.</td>
<td>Constraints not used, but any form of constraint can be applied post processing to determine whether a model is feasible.</td>
</tr>
<tr>
<td>Constraints must be linear unless more complex forms of optimisation are used.</td>
<td></td>
</tr>
<tr>
<td>Constraints must be explicitly stated and may over-constrain the solution in which case some have to be “backed off” or slackened.</td>
<td></td>
</tr>
<tr>
<td>The effect of some constraints can be overlooked.</td>
<td></td>
</tr>
<tr>
<td>Needs considerable response surface analysis to ensure the optimum found is practically feasible.</td>
<td></td>
</tr>
<tr>
<td>Can be difficult to explain the relative effects of various components in the model to senior managers who do not have LP experience.</td>
<td></td>
</tr>
</tbody>
</table>

The point should be made that for simulation to be truly effective, a large number of alternative runs must be made to determine the sensitivity to the parameters, variables and models considered of most importance. Similarly if linear programming is used it is necessary to evaluate the sensitivity of the optimum to the various constraints. Either way, these extra runs are generally limited by the availability of time and by management directives, sometimes to the detriment of the planning process.
Many organisations prefer to use linear programming as it provides a mathematical certainty of optimising the objective function. They accept the weaknesses and the difficulties in translating the optimum into a practical planning model. Some organisations prefer to use a simple simulation model as they consider that the ability to match the regime with the stratum and the ease of implementing the selected run as a planning model outweighs the disadvantages, including not being certain that the optimum has been achieved.

Overall, it is a matter of management philosophy as much as anything.

**Further references**

These references are later versions of long serving text books on Operations Research.

Hillier, F.S. and Lieberman, G.J. (2001)


**Evaluating products other than volume**

It is often necessary to attempt to evaluate products other than just wood flows, products such as water flow, wildlife or environmental considerations. Because the economic effects are so disparate an optimisation methodology is often appropriate.

Wildlife planning in Victoria using the package FORPLAN (now SPECTRUM) using linear programming has been described by Burgmann (Burgmann et al. 1994). If wildlife or other disparate effects need to be taken into account in valuing a forest estate then this paper provides references on how it has been carried out.

### 9.3.5 Accuracy of predictions

Accuracy is a combination of precision and bias as described earlier. However it is rarely possible to be completely quantitative in determining the precision of predictions, let alone whether they are biased or not.

What is always desired is that all the component models in a planning system are as independent as possible, have known accuracy characteristics, and are appropriate for the application.

It is common that only some aspects of the predictions from a planning system can be known with mathematical confidence and, unfortunately, it is common to restrict consideration of precision to those aspects that can be assessed competently and to ignore the other aspects.

One common example of this is that the precision of a forest inventory is often quoted but the figure quoted is generally the sampling error alone. The errors in the mathematical models used to compute the volumes, often by products, are generally ignored. The measurement errors in the data are also generally ignored. So too is the application error, the error attached to using a model or data from one circumstance in a completely different circumstance. A manager reading a report that quotes the sampling error of an inventory, even if the error is clearly specified as just that, the sampling error, will generally, and quite incorrectly, interpret the figure as the precision of the overall predictions.

Some managers have been known to complain when they find that say 2 or 3 harvesting coupes out of 20 were outside the expected 5% error level because they expected only 1. Care must also be taken to consider the statistical Type I -Type II error situation as 2 out of 20 is not significantly different from the expected 1, although 3 would be.

It is not just the precision of the inventory. The precision of the predictions from a complete planning system may have many such issues embedded in the consideration of accuracy.
Predictor or estimator

In developing a component model in a planning system it is common to use a statistical package and the summary statistics are then well known. These statistics are of the model as an estimator. The common use of Analysis of Variance in research is to determine whether two different treatments are statistically significantly different or not. This is generally very important but a note of caution should be expressed.

First, did the data and the models meet the assumptions of the statistical analysis? For example if the error terms were not normally distributed or are heteroscedastic then the estimated parameters themselves may be unbiased, but the standard error of the parameter estimate may be biased leading to the risk of including parameters that should not be included or excluding parameters that should be included, or making an incorrect determination of significance or non significance. Great care needs to be taken with the statistical analyses to ensure that the underlying assumptions are appropriate and are acceptable.

Then there is the possibility that the design of the experiment may not be sufficient to enable significant differences to be discriminated. If two treatments are not statistically significantly different is this because of the design and the data, or are they truly not different? It may be that the statistical procedures used were not sufficiently robust.

What is generally needed is the accuracy of a planning system when used as a predictor, not as an estimator. This may require arbitrary assessment of such components of total accuracy as application error, measurement error, application error, and the error caused by the interaction between component models.

Simulation model or statistical model

It is not really a matter of one or the other as the better longer term prediction systems used for forest management generally include a mixture of both.

A simulation model is designed to simulate mathematically the process being modelled and it may or not be a statistically valid model. It is generally easier to justify a model if it is soundly based statistically but just because a model does not have a sound statistical basis does not mean that it may not be useful. Adopting models from other areas and organisations does not mean that they are necessarily biased just that the application error should at least be considered.

Some examples might be the ‘fences’ that are often placed on models to stop crazy behaviour when the model is extrapolated too far outside the range of the data used to develop it. A planning model may, for example, be predicated on a commercial thinning regime that leaves 20 m$^2$/ha basal area after thinning. Should the growth model be constrained to only operate if the standing basal area is greater than say 15 m$^2$/ha? It should never be needed, so why bother? The answer is simple. Somebody may desire to see what the effects of heavy thinning might have on wood flows, and in this case unless the fences are in place then the predictions may well be quite inappropriate. Even an arbitrary model that says something like “if the basal area is below 18 m$^2$/ha then pro rata reduce basal area increment” would be useful as it would be likely to underestimate rather than overestimate predictions if management was to decide to see what the model produces for heavy thinning operations. Of course it would be better to have a soundly based model but sometimes these rather arbitrary models may help avoid considerable misunderstanding and avoid wrong conclusions being drawn.

The important point is to remember the basis of each and every component model in a planning system and so be in a position to judge, albeit often quite qualitatively, the likely precision and therefore utility of the final outputs.

It is possible to develop a model on theoretical or logical grounds, on limited data from elsewhere, and even by guess work, and then test it as a predictor using sensitivity analysis to determine whether the model is having a trivial or non trivial effect on the predictions.
9.3.6 Other possible considerations

Carbon sequestration

Predicting carbon sequestration may be an important consideration in forest valuation depending on whether or not carbon credits have been given a value by the forest entity. Carbon trading is not well developed but is expected to become so as countries adopt the Kyoto Protocol developed under the UN Framework Convention on Climate Change.

The CRC for Greenhouse Accounting centred at the Research School of Biological Sciences in the Australian National University in Canberra is developing carbon sequestration forecasting models. The CRC has developed an appropriately long term forecasting model for carbon sequestration in *Eucalyptus regnans* (swamp gum or mountain ash) forests under a variety of silvicultural and management regimes and their work is ongoing.

The work of the CRC may provide a useful starting point if carbon sequestration is an issue in forest valuation (see Dean 2003, Dean and Roxburgh 2004, Dean, Roxburgh and Mackey 2004b).

In 2007 the contact site was


but the Australian Greenhouse Office


can also provide a number of useful references as can

http://www.pointcarbon.com

in terms of more general carbon trading issues.

Modelling carbon sequestration as part of the determination of carbon credits requires consideration of a number of aspects not normally considered part of the classic forest valuation process. However the rapid developments in carbon credits mean that this modelling of carbon sequestration may become an important consideration in the future.

It is expected that more commonly the value of the carbon credits will have been calculated externally to the forest valuation and that the annual change in value can then be considered and handled in the economic calculations as described elsewhere. This is reflected in the ACFA (2004) standard and also in the revision (ACFA 2007).

However this may not always be the case and it may be necessary to determine carbon sequestration and then to value it.

The following lists just some of the aspects that may need to be considered, many not normally being considered in forest valuation.

- Stem volumes and stand growth rates. These can be determined by classical means. The amount of carbon sequestered can be determined using relatively simple, generally allometric, models based on volume.
- Fire history. In native forests, where more frequent fires occurred in the past, soil carbon levels will generally be lower. Frequent low intensity fires in a stand generally leads to a more depauperate understorey and more damage to the canopy species.
- The understorey species. This is especially important if they are part of rainforest succession as the understorey can have more biomass than the original canopy species. In *Eucalyptus regnans* forest a healthy myrtle beech and sassafras understorey will generally provide much higher carbon sequestration than a scraggly understorey of silver wattle and cutting grass.
- The type of senescence that affects a stand. Some old growth *E. regnans* can remain solid with no heartwood decay even when the diameter (dbhob) is >6 m, whereas others are quite hollow
when the diameter is only 5 m. This effect is a function of genetic stock, fire disturbance, site quality, nearby disturbance (perhaps wind stress due to roading or neighbouring timber extraction), and it can be modelled and included in the forecast.

- Site potential. This will influence overstorey and understorey growth, fuel build up, and senescence. Building site potential into a spatial forecasting model (such as that of Dean et al. 2004b) is straightforward. However, the effect of site potential on senescence and forest succession are more complicated.

- The amount of fluting or non-circularity of the stem. This varies with age and diameter and relates to genetic stock, environmental effects and stand density, amongst other causes.

- Wood products that might be extracted. These can be modelled but are expected to vary in the future with technological advances and further population increases.

- Transport and on-site logging equipment emissions. These have generally been ignored to date but nevertheless may be very important in determining carbon sequestration.

- The above issues refer to above ground carbon sequestration, an equivalent level of detail for below ground would add immensely to the complexity, and as such has generally been considered ‘too hard’.

- The length of any contract to be entered into as this may place unacceptable demands on maintaining forestry as the land use.

This is a developing field. If carbon sequestration is to be modelled as part of a forest valuation then ACFA recommends that appropriate expertise may need to be consulted to assist.

For information, as at 2007, on the UN Framework Convention on Climate Change

http://www.unfccc.int/

and for emissions trading see the Australian Emissions Trading Forum

http://www.aetf.net.au/


http://www.ieta.org/

Other potentially useful references include Brown (2002), Coomes et al. (2002), McKenzie et al. (2000) and Phillips et al. (2000).

**Coppice**

It may be necessary to measure and to predict the growth of coppice. One method is to assume that each stem is equivalent to a tree in modelling terms and that the stump height is sufficiently high to account for the volume lost at the tree base during harvesting.

Generally coppice growth should not be predicted using growth models based on planted stock as the growth rate is expected to be higher at early stages as the coppice stock already has control of the whole site whereas planted stock takes some time to gain full site occupancy.
Proprietary planning systems

ACFA does not endorse the use of any particular planning system.

The objective of this chapter is to provide basic information to assist users in making a judgement about whether or not to further consult the system vendors.

The list of systems discussed does not purport to be comprehensive.

A general, but very important, issue is to determine whether or not the whole data collection, modelling and planning approach embedded in a proprietary planning system is relevant and appropriate to the organisation.

Vendor discussions

In order to obtain the best possible information, discussions were entered into by a member of ACFA with a number of vendors. The draft comment on each system was prepared and then in almost all cases sent to the vendor for comment, being careful to ensure that ACFA retained the right to say what it deems appropriate. This enabled potential misconceptions and differences in interpretation to be aired and corrected.

As stated earlier ACFA does not endorse any particular product or its application for any purpose and these descriptions are provided simply as information that might assist users make initial judgements about which systems may or may not possibly meet their needs.

Atlas Technology invited an ACFA member to Rotorua to discuss their product development plans, to discuss their existing products, and to answer a number of questions, a highly desirable event given the breadth of the Atlas products and its fluid and dynamic development.

Messrs Brian Rawley of Silmetra (YTGen), Doug Jones of Remsoft (Woodstock), Ian Wild and Martin Strandgard of the University of Melbourne (PLYRS, Prophecy), Andrew Warner of Private Forests, Tasmania (FFT) and Drs Kerrie Catchpoole and Marks Nester of the Forestry Plantations Queensland (STEPS) kindly responded to all requests for information, also providing answers to specific questions. They agreed that the draft that they were provided with represented a fair description of their respective products. Their help is gratefully acknowledged by ACFA.

The Spectrum team was not represented but it was considered that as the system has been in use for many years, the available documentation was more than sufficient to enable its description to be prepared.

By dividing many of the descriptions into sections called “scope” and “summary / possible issues” there is a clear separation into what information is available from the vendor and what might be ACFA’s own view of the product.

Potential users must always rely on their own judgement about each system, and are reminded that not all available systems are described in this Handbook.

Potential users should request from the vendor a list of clients for any package they are evaluating and then talk with a range of the users to ascertain exactly how the packages, are being applied so as to be better determine the applicability of a package to their own situation.

There are a number of other proprietary systems known to exist that might be useful ranging from simple Excel spread sheets to complex data base systems, but these are believed to be only used ‘in-house’ and may not to be available for use by external users. This is not to say however that arrangements might not be possible for their external use. ACFA is not in a position to comment on these systems in this Handbook.
System maintenance

System maintenance is a general issue that potential clients should address when considering any software package and as to whether or not the package is adequately maintained and supported by sufficient competent staff, whether the organisation is committed to their customers, and to the long term provision of a support service.

When ACFA requested information from the vendors almost all provided appropriate levels of feedback. However in the discussions it was obvious that the likely level of support is variable, and it is appropriate for potential users of any system to consider whether the level of support offered is sufficient for their particular needs.

10.1 Atlas Technology – Scion New Zealand

Information as at May 2006.

Vendor contact

Business Development Manager
Atlas Technology
Sala Street
Rotorua
New Zealand

Web: http://www.atlastech.co.nz
Email: software.support@atlastech.co.nz

Pricing of all available products is available from the vendor by emailing to the address above and requesting information.

General scope

Since the MARVL forest inventory concept was first described by Deadman and Goulding (1978), Scion New Zealand (formerly Forest Research New Zealand) has continually developed the method. Atlas has also developed all the associated processing systems necessary to compute the inventory, prepare yield tables and to optimise projected outturn using linear programming in order to prepare forest management plans. The complete suite of systems has become the basis for forest management in New Zealand.

Some users experienced operational difficulties with the older systems which led to enhancements and new systems, some of which are proprietary, but most are available for general use. This has also led to the current development of the Atlas suite.

This summary does not aim to be an in depth summary of all the modules but aims to provide information in balance with the likely relevance of each module to valuers of commercial forests.

10.1.1 The Atlas Suite

All Atlas products are based on the Microsoft Component Object Model (COM) and .NET architecture at the front end and use MS SQL Server at the base end. Windows CE is used for data entry modules. This means that the modules are compatible with many other software packages, including MS Office, and the modules can be run as an extension to other systems, including a GIS. The components can also be run independently.

For development products, prospective purchasers should contact the vendor to determine just what the current development status is at that particular time.

As at 2007, reformatted 2012 but no textural changes
In terms of the relevance to forest valuation the software available, or planned, can be broadly grouped.

- **Data attribute collection and management software.** These modules are generally operational.
  - FieldMan to enter the field inventory and other data.
  - Cruiser replaces the system called MARVL and computes the inventory information. Cruiser has growth and yield table generation capabilities as well.
  - SilviQC has the primary focus of managing the quality control of silvicultural operations but can manage a wide range of plot and tree based data.
  - PSP is an extant module to manage permanent sample plot measurements, data and information.
  - PSPDC is for Permanent Sample Plot data capture, is currently being rewritten and is a module of FieldMan.
- **Spatial integration software;** now Atlas Geomaster but the predecessors were TFM2 and Forest Master. This software manages the stand records especially the attribute information, and provides the spatial linkages to a GIS. It buffers and protects the rest of the Atlas suite from vagaries of the underlying GIS as versions change.
- **Stand simulation.**
  - Forecaster (formerly Standpak) to prepare the families of yield tables needed for forest management planning.
  - Yield Table Manager (YTM) to manage the yield tables obtained from various sources (for example ForeCaster and Cruiser) and to provide these to the forest estate management planning modules.
- **Forest estate management planning modelling.** As at mid 2006 HarvestManager had been released and the other modules were either being developed or at the planning phase.
  - HarvestManager to prepare the operational harvesting plans.
  - TactiPlan to prepare tactical plans up to 6-9 years out but more commonly used to prepare operational plans for 1-3 years.
  - StratiPlan, to prepare the longer term strategic plans, commonly to cover 2 rotations or about 50-90 year planning horizons. This was at the concept stage in mid 2006 and will replace the FOLPI system.
  - MarketSupply, manages the scheduling of crews into harvesting coupes and the meeting of explicit product requirements in the short term, up to 8 weeks. It is being used in prototype.
- **Other packages aimed primarily at operational management.** Most of these modules were at the conceptual stage in early 2005 and can be expected to change.
  - RoadManager for maintaining a roading network.
  - CrewQuip, for managing crew contractor and equipment information.
  - ContractMan, for managing contracts, resources and costs related to forestry operations.
  - OptiSaw, a sawing simulation package.
The ATLAS Suite

The diagram, kindly provided by the Atlas team and printed with their permission, broadly indicates how the various Atlas components can be viewed, that is when all are available. This diagram will continue to evolve as development proceeds.

The diagram is not wholly consistent with this summary, indicating the state of flux natural with ongoing systems development. It is expected that better diagrams and descriptions will be available as the modules are developed and the whole Atlas suite settles down.

Development philosophy

Atlas could be thought of as one complete integrated package, but the nature of many modules suggests that not all are relevant to all organisations. For many organisations, especially those involved with forest valuation, it would not seem to be terribly useful to look at the Atlas suite as a complete package.

It would seem better to view Atlas as a linked set of compatible modules that can be combined to meet the needs of an organisation. If the needs cannot be met by a particular module then there are a number of options that Atlas is prepared to consider. Atlas could just make the enhancements, Atlas could require some level of co-funding of enhancements, Atlas might be allowed to quote for major user defined changes with the changes remaining the property of the client, and Atlas can provide the interfaces to assist the client integrate an externally developed module or product.

The apparent complexity of Atlas has the advantage that clients can licence just the components that they need. However that flexibility may come at a potential loss of flexibility to integrate with products from other vendors. The software architecture should assist integration and the data structures to facilitate such integration can be made available providing suitable arrangements can be made to define the various responsibilities on both sides of the interface. These aspects would need further discussion between clients and Atlas Technology and would depend on exactly what was required.

The current complete re-development and extension of parts of the system seems eminently sensible but caution and concern must be expressed about system integration as at mid 2006 not all...
the Atlas components were available. Users should be certain that any components they acquire should be able to be linked together to meet their needs.

Given that all the components are not expected to be developed before 2007-08, there are also some concerns that future developments may not match the currently stated objectives of the developers. There may be some systems design drift. It is suggested that any potential user should take care to ensure that any capability that a user considers essential is actually available at time of purchase and not just part of some planned development path.

**Master Consultants**

Atlas Technology has established Master Consultants in Australia who are able to licence Atlas products to clients.

Importantly they are able to use Cruiser to carry out an inventory and charge at a rate per plot established and not necessarily at a rate per area of forest. This is basically a “pay as you use” approach which may suit some organisations wishing to trial Atlas Cruiser, or some smaller organisations who want to carry out only a limited inventory.

**Summary / possible issues**

Atlas Technology is a wholly owned subsidiary business unit of Scion New Zealand and is financed solely from sales of its products. This may be both a strength and a weakness depending on the way clients and potential clients look at it. The strength is that the Atlas team are closely linked with the scientists at Scion and have a large enough team to be able to ensure continuity. They suggest that they are closely in contact with users and that they are prepared to make changes to meet client’s needs. A possible weakness is that the Chief Executive Officer of Scion theoretically has the power to direct what the team does, which may or may not be in sympathy with the objectives of clients.

Clients should also consider the possible effects on their business and their ability to recover if they adopt the complete Atlas suite to handle vital core processing and for some unlikely and unforeseen reason the organisation fails. To cover this unlikely possibility Atlas are prepared to discuss escrow provisions in any contract.

The further the management of a potential client’s forest differs from the rather narrow range of forest mensuration and silvicultural options practiced at present in New Zealand, the less appropriate the underlying system structures may be. However the underlying Atlas structure is such that it will be possible to break in and out of the whole chain at various stages and so it is possible to acquire just the modules a client may need and not more. Atlas is not a large inflexible system but can be used (or rather will be able to be used) as a series of modules that can be picked up individually, or more likely in groups of modules.

If, for example, an organisation decides to use Cruiser and FieldMan for inventory field data, Geomaster to interface to their corporate GIS, prepare yield tables with Forecaster and manage the yield tables in Yield Table Manager before carrying out planning in TactiPlan and StratiPlan then they may find the underlying mensuration models somewhat limiting. One option might be to measure other plots and store them in SilviQC, but these are not currently available to Forecaster although that non availability is likely to be reviewed. Another option might be to develop an independent version of Forecaster that can access other corporate information and models and this may provide more flexibility at some system maintenance cost, but not at the cost of a completely different alternative system. This latter approach might assist in keeping the understanding of the way the organisations biometric models fit together within the organisation and could minimise the amount of internally developed software that would have to be maintained. There is no one single solution appropriate for every organisation.
10.1.2 Atlas Cruiser – formerly MARVL

The MARVL inventory concept was first described by Deadman and Goulding (1978) and has been enhanced since then (see also Lawrence 1986, Gordon and Lawrence 1995). Basically it extended the classic forest inventory methodology to record stem characteristics as well. This facilitates optimal cross-cutting of the stem into expected log products.

The nomenclature has sometimes become a little confused with an inventory being called a MARVL inventory which may or may not have been processed by the associated software package MARVL. The inventory is described elsewhere, this section refers to the processing software Cruiser and FieldMan, replacing the software originally called MARVL.

A number of organisations use the MARVL framework as the basis for their inventory but not all will use Cruiser to process that inventory. Some users of the earlier MARVL software have commented on its inflexibility and difficulty of operation, and this was undoubtedly part of the reasoning that led to the complete revamp of the forest management software.

Field data are entered into FieldMan which is Microsoft Windows CE based and can run on a range of hand held computers. The MARVL predefined data dictionary has been replaced by stem descriptions; structure (to detail stem and leader characteristics), shape (sweep classes primarily) and features (including fluting, zones of a maximum branch size and rot). User defined variables can be added. Cruiser requires detail of the log product definitions to be used which are primarily based on diameter, length, and the stem characteristics. This is superior to the way MARVL has generally been used in the past as it separates stem characteristics from log product definitions. It would seem that the way MARVL inventory is practiced has “drifted” and that Cruiser now has reverted to what is considered by some to have been the original intention of MARVL.

FieldMan has a inventory crew management component which is run on a desk top computer.

Processing in Cruiser generally starts with a stratified random sample of plots with measured diameters (dbhob) and a sample of tree heights. A modified Pettersen curve (see earlier) is used to predict the height of each un-heighted tree and also a measure of upper stand height. Atlas considers it unnecessary to correct for the transformation bias in using the Pettersen curve. Using a taper equation (which can be input for each stand or group of stands) product volumes by size and quality are calculated. A dynamic bucking algorithm is used to optimise product outturn within each stem. Detailed reports are available and summaries are also available for processing by other Atlas modules. Sampling errors are also calculated, presented as Probable Limits of Error or PLE.

Alternative taper equations can be readily used if it is just re-parameterisation of a structure already existing in the system. New structural taper model forms can be incorporated by the vendors.

Cruiser includes growth models and so can prepare yield tables, although not quite as flexibly as can be achieved with Standpak and its current replacement Forecaster. Atlas recommends that Cruiser be limited to growth projection periods of around 8 years.

Atlas has developed a taper model that can change over time although this model structure is not embedded in the current modules available to users.

Summary / possible issues

Cruiser and FieldMan provide a neat, consistent and coherent way of carrying out a forest inventory. It is especially appropriate if the inventory is pre clear felling and the growth projection period is less than 8 years. The modules provide a sound base for harvest planning. It would seem to fit much of the range of New Zealand practice.

In the Australian context the situation is generally a little different. The forest management emphasis is on local rather than export production, there are generally smaller areas of uniform forest, there are commonly slower growth rates that generally lead to better formed trees, coupe size is generally smaller, and the emphasis is more on multiple thinning operations compared with heavy thinning.
and butt log pruning. This reduces log variation, which may affect how an organisation considers what is and what is not appropriate biometric modelling practice.

For example, Cruiser at present develops a height – diameter curve based on all the samples from the plots in a stratum and uses that curve to predict the heights for all un-heighted trees on all plots in that stratum. If the stratum is itself variable, as may happen if the coupe is small, then it may be desirable to use all the samples from all plots to develop the height – diameter curve and then adjust this average curve on a plot by plot basis based on the limited number of samples measured on each plot. This is likely to be more desirable in Australia than in New Zealand. This capability is currently believed to be available in Cruiser through pre-specified height-diameter curves that are localized to each plot although this would need to be confirmed as satisfactory, and practical, by any prospective user of this approach.

Cruiser requires a taper function and for forests like Kaingaroa there are unlikely to be great differences over the whole forest. One option that would seem logical in Australian forest conditions would be to measure upper stem diameters on sample trees in inventory plots, in essence carry out an inventory based on Importance Sampling principles as well as the MARVL approach, and to then use these samples to correct a more general taper function. This would ensure that the volumes in each area of interest are unbiased estimates, regardless of how coupe sizes may change during the planning processes. It would reflect the effects of past silvicultural practices on stem form, including early age silvicultural practices and later age fertiliser application. In New Zealand the larger coupe sizes make it feasible in some circumstances to collect enough samples per coupe to develop local taper equations. This is generally not feasible in Australia although it may be feasible to collect enough samples to develop a correction to a general taper function. This correction would need to be carried out within Cruiser.

ACFA recognises that these particular issues are not important to most users but suggests that they, and other similar issues caused by the differences between Australian and New Zealand circumstances, may need to be considered.

10.1.3 Atlas Forecaster – formerly Standpak

Forecaster is now available as a replacement to the Standpak system.

The module generates medium to long term predictions for stands by simulating growth, harvesting, and processing on a stand basis. The starting point may be routine inventory from Cruiser, or may be from bare ground or other predetermined stand conditions. Yields may be expressed as log volumes and grades and/or yields of graded sawn timber although the former are commonly used for forest management planning.

The module embodies the early age growth models developed by Scion New Zealand, and can model multiple lift pruning and accompanying thinning to waste as well as multiple commercial thinnings. Diameters over stubs are predicted at various tree heights. Being tree list based the predictions are in considerable detail.

A useful feature of Standpak was that it could predict mill conversions and green rough sawn timber grades or machine stress grades that may be produced by processing a specified log resource in a specified mill using a specified processing method. Sawing costs, returns and residual log values are estimated. This capability has being redesigned to exploit the additional wood quality detail now possible.

The module Yield Table Manager is used to manage the family of yield tables that are created by Forecaster. These are input into the planning systems with their various planning horizons.
Summary / possible issues

Standpak has been a very useful package for New Zealand forest management but its suitability in Australian conditions is considered by some users to be limited. As at 2005 it seemed that Forecaster would initially at least not extend the capability of Standpak to meet all likely needs under Australian conditions.

For example, Standpak cannot model growth following late age fertiliser application although there are some proprietary extensions that are believed to achieve this capability. Mortality may also be an issue for some potential users. Some concerns have been expressed by users about the flexibility to predict the effects of multiple commercial thinning operations commonly practiced in Australia. These capabilities may or may not be important to users and it is necessary for any potential Atlas clients to review the capability of Forecaster to determine whether or not it is appropriate.

Of all the modules in the Atlas suite Forecaster is possibly the one most likely to be lacking necessary capability for use in Australia in its basic form. However Forecaster is a framework for growth, yield and wood quality models and can be extended by “plugging in” new components and this capability will enable it to be used in many circumstances.

10.1.4 Atlas GeoMaster

GeoMaster is the central core that interfaces the other Atlas modules with an organisation’s Geographic Information System (GIS). It provides the interface between the spatial and attribute information, and maintains the various interfaces with the GIS, interfaces that commonly change between the different versions of a GIS.

The core philosophy of GeoMaster is to provide cushioning, or safety, between the attribute information and the underlying base GIS. This philosophy is eminently sensible. GeoMaster interfaces with ArcGIS 9.1 from ESRI and with MapInfo. Atlas has only ever been asked about interfacing with one other GIS package and that was not in the end an issue. But, Atlas can develop the interface if a user wants it, although likely at a cost.

The basic structure is forest – compartment – stand, and the stands can be non contiguous, for example equal productivity areas – and then patch and ultimately polygon. Alternatively it can be structured at forest – block – harvest area – setting (which in New Zealand are the areas treated by a harvester, or skid sites). One useful construct is that GeoMaster has a floating layer so that it is possible to store boundaries and plot data for a partially clear felled harvesting coupe but it is still possible to schedule actions for the replanting of the whole area.

Geomaster has a temporal model capability that GIS constructs cannot handle.

Summary / possible issues

Geomaster effectively buffers the various Atlas modules from the vagaries of a proprietary GIS.

When the Atlas team was asked how to address various tricky issues in Geomaster they could almost always provide solutions to the challenges presented. The concern remains however that some of the solutions may not be practicable if the issues are widespread and not just of minimal extent. This is an issue that potential clients may need to consider.

Plot summary information from Cruiser and SilviQC can easily be stored in Geomaster. With Cruiser it is possible to view the distribution of plot attributes spatially, and a similar capability will be developed for SilviQC.
10.1.5 Atlas HarvestPlan, TactiPlan and Stratiplan – replacing FOLPI

Originally developed by Dr Oscar Garcia, FOLPI© (Forest Oriented Linear Programming Interpreter) can be used together with Forecaster or it can be used as a standalone component, accepting inputs from a user designed systems and can then perform the optimisation. Outputs can then be reformatted as the user wants.

The modules being redeveloped basically divide the planning into three time horizons suggesting that Atlas consider that is not always sensible to try to ensure consistency between the results from planning at different levels. The modules will basically use information stored in Geomaster and the yield tables created in Cruiser and Forecaster and stored in Yield Table Manager, together with harvest scheduling requirements, to produce the planning reports.

Summary / possible issues

The size of the matrix that can be handled limits the number of coupes and alternative yield tables that can be modelled. Recent advancements have increased the size of the problem that can effectively be handled by FOLPI but some users of the package have commented privately that it is still not flexible enough to handle the wide range of silvicultural options that they desire to evaluate. It is hoped that this issue will continue to be addressed in the forthcoming systems development.

Other users have also expressed the concern that they want the ability to change from one silvicultural regime to another dynamically during optimisation and this would seem beyond the scope of all linear programming packages at present, including FOLPI.

It is not known how the re-developers plan to handle the issues surrounding product allocation optimisation and the need to allow for cross product transfer during the optimisation process.

A number of users have written their own software to create the yield tables for input into FOLPI and to summarise the output FOLPI produces. In essence they use FOLPI to do the optimisation only and treat FOLPI as a ‘black box’.

10.2 YTGen

Information as at 2006.

YTGen had its origins in a desire to easily generate a set of yield tables for a large forest estate with enough detail to satisfy both short term tactical planning needs and longer term strategic planning needs, integrating both seamlessly.

Vendor contact

Mr Brian Rawley
Silmetra Ltd.
2528 Old Taupo Road
Tokoroa
New Zealand

Email: Brian.Rawley@xtra.co.nz

Information about the pricing of licences to this package and its availability are available from the vendor.

Scope

The underlying modelling framework supports tree growth either by;

- distance independent single tree models, either alone or constrained by stand growth,
simple allocation of stand level growth, or,
parameter recovery.

Most of the 70 models currently implemented are the property of forestry companies or the New Zealand Growth Modelling Co-operative and are available only to the proprietors.

In some cases different model structures are incorporated for the same component and the users can provide the parameters, thus providing for information privacy. Silmetra can be contracted to implement new model structures, and this facilitates flexibility.

The package is designed around stratified random sampling which is the most commonly used basic sampling design. However it is not restricted to that design.

Input formats into YTGen are flexible.

Auxiliary inputs for growth models are allowed by the use of dummy variables. Examples in existing models include locality, soil nutrient levels, crown closure, and rainfall.

Simulation of thinning, both commercial and pre-harvest is included. The models are flexible and enable user developed models to be input.

YTGen supports dynamic log bucking algorithm to turn trees into logs to utilise maximum value within the constraints of user-defined log grade specifications which can include:

- minimum and maximum small end diameter, maximum large end diameter,
- allowable lengths,
- qualitative conditions, and,
- value by product.

These are supported by multiple overlapping user defined stem attributes. There is built in support for branch whorls and inter-nodal grades where data are available. Grade recovery rules allow reclassification of logs between log making and summarisation.

Output is flexible with summarisation within a stratified random sampling scheme available at plot, stratum or population level. Detailed output is available down to individual logs. Output format can be as text files, direct to a database, and also as input files to FOLPi© or Woodstock©.

There is a fully interactive Microsoft Windows© interface, a command line interface with batch processing, or a COM interface for embedding processing functions within spreadsheets, GIS and other COM-aware applications. This provides users with great flexibility.

YTGen has been use since 2001.

YTGen is not tied to specific data collection software, but very flexible field data collection software that leverages on the stem description flexibility is available and has been in commercial use since 2005.

Summary / possible issues

One possible concern to some users may be the size of Silmetra as an organisation and the possible impacts this might have in the future on maintenance and ongoing support. The flexible input and output structures would appear to diminish the risk in this regard but some may still consider it an issue preferring to stay with larger organisations that, theoretically at least, should be better placed to provide long term support. However small organisations are often more flexible and can often provide better focus on particular users needs. Silmetra works with consultant biometricians and systems integrators as necessary.

Philosophically, YTGen is a tree based system that in the short term enables tree growth models to be used with or without constraints to stand growth predictions, and this seamlessly translates as the planning horizon increases into a tree model based on stand growth and allocation of that growth to trees, in essence a tree based proxy for stand growth. Models such as thinning and mortality predict the effects at a tree level rather than a stand level as in some other systems. Whether tree or stand
based modelling is appropriate is a function of the models that are available as much as anything but YTGen would seem to be flexible enough for most possible applications. Later in the planning horizon tree information will obviously be less reliable than earlier, but the aggregated information can probably meet planning needs as well as, or better than, any stand based system. This philosophy would seem to be much more flexible for the future than a pure stand based approach and it is capable of being improved incrementally as better component models become available. As a planning system it may therefore have a good life expectancy.

However any potential user should discuss their particular circumstances and available models with the vendor to ensure that YTGen can meet their particular needs.

10.3 PLYRS

Information as at 2006.

PLYRS (Plantation Yield Regulation System) was developed by the University of Melbourne for three clients in the Green Triangle region of South Australia and south-west Victoria. The system was specifically designed for radiata pine although other species could be predicted if suitable biometric equations are available.

Vendor contact

Messrs Martin Strandgard and Derek Chong
School of Forest and Ecosystem Science
Institute of Land and Food Resources
University of Melbourne
Parkville
Melbourne Victoria 3052
email:
  mnstra@unimelb.edu.au
derekmoc@unimelb.edu.au

Determination of availability and pricing are available from the vendor.

Scope

The underlying concept of PLYRS was the incorporation of the basic South Australian mensuration developed over a long period by ForestrySA, formerly the Woods and Forests Department. This underlying mensuration is detailed in Lewis, Keeves and Leech (1976) although some models have been redeveloped and modified since that publication. The growth model generally used is the Bayesian Posterior GLS growth model of Leech (1978). The models predict stand volume growth directly rather than the more commonly used methodology of predicting basal area and height growth at a tree or stand level and converting that to volume.

PLYRS was developed by the University of Melbourne for a collaborative involving ForestrySA, Green Triangle Forest Products and Auspine with development partly funded by FWPRDC.

Other models can be incorporated into the system by the vendors.

The system operates under recent Microsoft Windows© operating systems.

Summary / possible issues

Prospective users should contact the vendors to determine the availability of the various models in the system.
As the system was developed for a collaborative, availability will depend on their collective determination.

Prospective users should also determine whether or not the models are appropriate for their use both in terms of applicability of models developed for the south-east of South Australia and whether the package will meet the user’s objectives.

Prospective users should also consult the vendors to determine maintainability.

10.4 Prophecy

Information as at 2006.

Prophecy is a blue gum plantation planning and management tool developed by the School of Forest and Ecosystem Science at the University of Melbourne under an agreement with the FWPRDC and supported by a number of plantation owners, Hancock Victoria Plantations and Grand Ridge Plantations, Timbercorp Pty. Ltd., Treecorp, Midway Pty. Ltd., ForestrySA, Green Triangle Forest Products, Auspine, and the Southern Tree Breeding Association.

Vendor contact

Messrs Martin Strandgard and Derek Chong
School of Forest and Ecosystem Science
Institute of Land and Food Resources
University of Melbourne
Parkville Victoria 3052
email: mnstra@unimelb.edu.au
derekmoc@unimelb.edu.au

Determination of availability and pricing are available from the vendor.

Scope

Prophecy is a software tool intended to provide reliable and consistent predictions of wood flows and cutting schedules for blue gum plantation managers. Predictions of future growth and product flows are based on a generic set of blue gum biometry (developed as part of the project) and the Prophecy field inventory component, or “best guess” estimates if inventory is not available. Schedules can be analysed in Prophecy in terms of wood flows and financial outcomes or exported to Microsoft Excel®, Microsoft Access® or similar tools for reporting and further analysis. Wood flows can be expressed as total harvested volumes or by product totals using user-defined product specifications. Prophecy can also be readily linked to a GIS for spatial display and analysis of results.

Prophecy is written using Microsoft Visual Basic.Net® and is designed to run on a personal computer running Microsoft Windows 2000® or XP®.

Development of the basic structure of Prophecy was completed by December 2004.

Future directions

Prophecy has been intentionally designed as an “open” system to readily allow new developments to be incorporated at low cost. This was seen as essential for a system targeted at a relatively new plantation species which is undergoing rapid changes to its silviculture, growth and management.

The primary future development envisioned for Prophecy is to incorporate functions such as pruning, thinning and fertilising to allow schedules for sawlog production to be simulated. The other required element for sawlog schedule simulation, the prediction of sawlog product outturns, can already be
performed in Prophecy using user-defined product specifications. With suitable biometric functions, this development would allow Prophecy to be used to develop sawlog schedules for both hardwood and softwood plantations.

Further development, customisation and maintenance of Prophecy are dependent on additional funding being obtained.

**Summary / possible issues**

The system can be purchased and prospective buyers should contact the vendor to determine the current status and availability of the system.

In late 2006 a cut-down version of Prophecy was being prepared for inclusion in the Farm Forestry Toolbox (Private Forests Tasmania, see later description).

### 10.5 STEPS

Information as at 2006.

**Vendor contact**

Dr K. Catchpoole  
Forest Policy Unit  
Forestry Plantations Queensland  
PO Box 944  
Brisbane QLD 4001

Dr M. Nester  
Forest Policy Unit  
Forestry Plantations Queensland  
PO Box 1339  
Gympie QLD 4570

email:  
kerrie.catchpoole@fpq.qld.gov.au  
marks.nester@fpq.qld.gov.au

For pricing refer to the vendors.

**Scope**

STEPS is a decision support system (Software Tools for Evaluating Plantation Scenarios) and is described by Catchpoole and Nester (2004).

It is species independent and is an MS Excel© application. It requires inputs of costs, prices and growth data. Growth information is input either as a yield table in text format, or as parameters to be used with a simple growth model. The outputs are various economic variables (NPV and IRR, average sawlog prices, merchantable volumes and prices and revenues at clear felling) and stand variables (predominant height, merchantable volumes, average stem volumes and mean annual increment). STEPS compares three alternative scenarios with a user defined benchmark. Users can select a number of different alternative silvicultural and management strategies.

Intending users can test a trial copy of the software before purchasing if they wish. A user manual is also available.
Summary / possible issues

This relatively simple model of a single stand may be useful to assist forest valuers consider the economic impacts of alternative silvicultural and management strategies.

Being based on MS Excel it should be relatively simple to interface with other Excel applications and so meet the information needs for forest valuation, provided the needs are relatively simple.

The vendors caution that STEPS requires detailed understanding of the inputs, but this is really no different from any forest management planning system.

Users should consult the vendor to determine whether expected future development and maintenance meet their requirements.

10.6 Spectrum

Information as at 2006.

Vendor contact

Inventory and Monitoring Institute Attn: Spectrum
USDA Forest Service
2150 Centre Av., Bldg. A, Suite 300
Fort Collins CO 80526
United States of America

Log onto the web site:

http://www.fs.fed.us/institute

and then go to the Download Centre to get to the latest version of Spectrum (Spectrum26 or release 2.6 as at mid 2006). An overview is available for download too.

Although the Spectrum software is free, it does not include the LP solver. It is set up to use C-WHIZ (a commercial package for which a licence must be purchased) for this purpose but can be adapted to use other LP solvers which use data in the same input format.

Scope

Spectrum has evolved from an earlier product from the US Forest Service, FORPLAN, which originated in 1980. It is basically an optimisation system that can use linear programming or other techniques such as goal programming to optimise resource allocation and scheduling.

FORPLAN has been very widely used, including in Australia, and there are competent analysts in the broader forestry community who can assist any potential user.

The overview to Version 26 states that Spectrum is designed to facilitate a multitude of analysis applications, including:

- assisting in forest plan amendment and revision,
- analysing landscapes and watersheds,
- designing sustainable management strategies,
- allocating and scheduling resources,
- estimating levels of goods and services,
- finding pathways to desired future conditions,
- facilitating environmental effect analysis,
- addressing economic and trade-off analysis,
- providing for sensitivity analysis, and,
- modelling policy.
Spectrum is flexible and can operate at multiple spatial and temporal scales.

As a possible linear programming package it is recommended that any potential user could well start by downloading the Spectrum Overview document. More detail can be obtained by downloading the Spectrum Users Guide.

The Overview includes references to a number of supporting documents but a general search of the forest management literature will find many, many more. It is one of the most widely used optimisation packages.

Summary / possible issues

This package, and its predecessor FORPLAN, have been widely used but it is believed that development has almost ceased. It does however still remain one option for users to consider.

10.7 Woodstock - REMSOFT

Information as at 2006.

Vendor contact

REMSOFT Inc. - Intelligent Software for the Environment
Suite 160, Frederick Square, 77 Westmoreland Street,
Fredericton, NB CANADA E3B 6Z3

Mr Douglas Jones (doug@remsoft.com) responded to questions initially posed to their web site: http://www.remsoft.com/

and subsequently answered many questions about the package.

Pricing is available from the Remsoft, but a single user licence for Woodstock in 2006 was $US 6000.

Scope

The REMSOFT Spatial Planning System comprises a number of software packages that work as a single interface when used together.

Woodstock is a strategic forest management planning model and users can address common modelling problems, such as harvest scheduling, economics and timber supply analysis, as well as non-timber related issues such as wildlife habitat, carbon loads, and biodiversity. It can be used in simulation and linear programming modes or it can be used alone.

Spatial Woodstock is a spatial analysis and data management tool. Spatial Woodstock connects the Woodstock model to maps allowing for specialized model hyperlinks, data error checking, automatic Woodstock file building, enhanced reporting, and spatial analysis.

Stanley is a spatial harvest scheduling model. Using a subset of the Woodstock treatment schedule, Stanley will automatically build and schedule harvest blocks subject to gap size and adjacency constraints in the shapefiles while maintaining landscape level objectives in the Woodstock model.

Remsoft has also developed the Allocation Optimizer to model product allocation to destinations from sources allowing users to capture the demand and supply relationships of wood supply modelling.

Woodstock is in essence a useful forest planning package system with linear programming and spatial components. Some features claimed are;

- User-defined classification schemes,
- Unlimited number of user-defined harvest, silviculture and other actions,
- Unlimited number of user-defined outputs,
• Queue actions in any order,
• User defined selection rules,
• Simultaneous control of multiple outputs,
• Age-dependent, time-dependent and complex yield curves,
• Simultaneous recognition of stands and forest-wide classes,
• Even and all-aged actions,
• Model random events and random outcomes,
• Models can be formulated and solved as either simulation or optimisation (LP) models,
• Binary search for quickly converging on maximum/minimum solutions,
• Linear programming (LP) extensions for true optimisation modelling,
• Solve LP using CPLEX, LPSolve and C-WHIZ, Mosek, Lindo and others,
• Customisable reports in ASCII, CSV or WK1,
• Customisable run-time graphs, and,
• Interactive and batch mode processing.

Woodstock does not include an LP solver; however the package does support 10 different solvers, some of which are available for free over the internet. Users most commonly use Mosek although C-WHIZ and Lindo are also known to be used.

Yield tables can be ported in from a user system and so can be as complex as the user desires. The inventory is defined in terms of themes, in essence different GIS layers, so it may be necessary to convert the attribute components of an inventory to the equivalent of a GIS layer.

Woodstock is an open system that would seem to be very flexible.

Spatial Woodstock provides hyperlinks from data to maps and allows database editing, querying and analysis functionality.

Stanley is a short term spatial planning tool that when combined with Woodstock and spatial Woodstock can be used for harvest scheduling, allowing for minimum and maximum constraints on the opening size that may need to be applied, amongst other features.

When the Allocation Optimizer is added then a very useful package results.

The Remsoft Spatial Planning System has been implemented in Australia, Canada, New Zealand, the United States of America, China, Korea, Brazil, Uruguay and Turkey. It is commercial off the shelf software and a maintenance program (including technical support and software updates) is available. This is complimentary for the first year. Extensive training services are also available.

Forestry Tasmania (McLarin et al. 2006) has developed a methodology for calculating the yield tables dynamically within Woodstock rather than inputting the yield tables as text.

Summary / possible issues

This would seem to be a typical Canadian system with good spatial linkages. The inherent strength of the Remsoft Spatial Planning system is the open data format allowing it to be easily adaptable to forest information in any geographical area. The packages would seem to be able to be interfaced relatively simply with user systems.

However there are believed to possibly be some limitations in the way some attribute information can be handled under certain Australian conditions. Just like any other package, users must consider whether or not it meets their specific needs, and they may need to discuss the possible issues with the vendor.

The suite is a convenient way of integrating the information from a forest estate into a linear programming based planning system.
10.8 FORSIGHT

Information as at early 2007.

FORSIGHT has been produced to simplify and streamline the workload placed upon forest analysts when answering questions associated with wood flow optimisation and forest valuation. Specifically it combines a flexible method of compiling a standard forest description with forest estate modelling, and forest valuation reporting. In short, FORSIGHT has been created by an Australian and New Zealand forest analyst for other such forest analysts.

Vendor contact

Mr Simon Walker
Stewart Murray (Singapore) Pte Ltd.
Orchard PO Box 2
Singapore 912301
Email: simon.walker@stewartmurray.com

Information about the pricing and product availability is available from the vendor. Typically, FORSIGHT is licensed on an annual basis, incorporated with an agreed number of professional service days (over and above standard business software support). This business model has been designed so that clients receive maximum benefit from the software in terms of in-house skill transfer, and/or the opportunity to outsource specific organisational requirements such as annual estate planning and/or in-house forest valuation.

Scope

FORSIGHT can be thought of as having three distinct, but consecutive components.

The compilation of a Standard Forest Description of the forest assets as at a specific date, in a compact and standard format using Microsoft Excel.

The ability to use such a Standard Forest Description to undertake forest estate modelling and analysis using linear programming optimisation.

The combination of the Standard Forest Description and the results of forest estate modelling and optimisation to produce a comprehensive forest valuation output.

FORSIGHT has been developed using the Microsoft .NET 2.0 platform, and relies upon Microsoft SQL Server 2005 as its underpinning database. In the first instance FORSIGHT uses the freeware version of this database (SQLExpress). FORSIGHT uses MOSEK as its solver and, like other forest estate modelling packages, requires users to operate a fully licensed version of the linear programming solver.

FORSIGHT uses Microsoft Excel as a platform in which a Standard Forest Description can be compiled and resulting forest valuation cash flow models presented. Users can choose to avoid the compilation of a Standard Forest Description in Microsoft Excel if necessary and instead draw data from their wider information systems directly into the FORSIGHT data structures.

However, the benefit of the Excel based Standard Forest Description is its ease of audit and compilation, and the ability to then provide a complete forest asset description as at a particular date, that is to third parties such as auditors, investors and/or external forest valuers.

The Standard Forest Description template holds area, age class and other physical and spatially defined attributes of the tree-crop. It also holds yields, unit revenues, costs of production, operational expenditure classes, modelling constraints and the allocation of log product volumes to end use destinations. The concept is the provision of all the inputs that a third party would need to independently model and value a forest asset in a convenient, manageable and transparent template.

As at 2007, reformatted 2012 but no textural changes
FORSIGHT implements typical forest estate modelling constraints such as non-declining yields, non-increasing yields, smoothing and volume/area harvest constraints. In addition, it fully integrates the allocation of log products to end use destinations with the ability to overlay log mix constraints as necessary.

The results of a forest estate model can be quickly interpreted through a variety of inbuilt charts and analytics, including the ability to drill into the results and determine the various allocations of volumes at end use destination by planning unit. A further level of allocation is possible such that constraints can be placed on end use destinations so that supply volumes adhere to specific ratios from certain forest units/types. For example this enables an analyst to model the proportion of natural forest compared with plantation forest that is supplied on an annual basis to a particular pulp mill within the model.

Full forest valuations can then be generated for the entire estate, or any portion of the estate that may be required. The FORSIGHT forest valuation template has been designed for use in forest estate acquisition and divestment processes, and provides a comprehensive cash flow representation of the forest assets.

Summary / possible issues

As is the case with a lot of professional vendors to the forest products industry, the developer of FORSIGHT is a small, owner operated firm. This inevitably raises concerns amongst users that this is a business risk. Such an argument is hard to counter, however the vendor believes that if the benefits of the software product outweigh the risk then a balance is possible.

FORSIGHT has been built using new technology, from the ground up. The optimisation engine has been developed using C++ to maximize processing speed, while the interface and data structures rely upon the Microsoft .NET platform. This has been driven by a desire replace legacy technologies and future-proof the software product, as well as to achieve significant advances in processing time. Time will tell how successful this strategy is.

To achieve the necessary processing speeds, FORSIGHT has fully integrated MOSEK using the MOSEK API. As such, a possible issue is that MOSEK is the only linear programming solver that the software currently utilises.

FORSIGHT has to-date been used in numerous forest asset valuations, both by third party independent valuers, as well as by due diligence teams undertaking forest asset acquisition and divestment.

10.9 Farm Forestry Toolbox (FFT)

Information as at end 2005.

Vendor contact

Private Forests Tasmania have produced a Farm Forestry Toolbox (FFT). Version 4 was available in 2005 free on CD, simply by contacting any of their offices, including the head office:

Private Forests Tasmania
GPO Box 180
Kings Meadows TAS 7249

Further information and updates to each major version are available from their web site:

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

In 2005 the upgrade to Version 4.7 was freely available for download from the web site. In 2007 a new version was being developed.

As at 2007, reformatted 2012 but no textural changes
Scope

The package has an easy to use Windows interface. It has a series of useful tools basically designed for farm foresters but really of much wider interest.

- Forest health tool, a diagnosis tool for forest health problems in eucalypt and radiata pine plantations - primarily for South-East Australia.
- Surveying tool, to assist in calculating the area and perimeter lengths.
- Coordinate conversion tool, for converting AMG eastings and northings to latitudes and longitudes and for finding map coverages. Applicable for all regions of Australia by selecting the relevant region.
- Conversions, to convert standard units of measurement.
- Plot area calculations.
- Slope, resolves slope distances into horizontal and vertical components.
- Stocking, calculates stocking from average row distances and tree spacings in each row.
- Log stack volume, estimates the volume and weight of individual logs and stacks of logs.
- Tree and log volume, estimates for selected species the total volume of wood in a standing tree and volume and weight of logs in a standing tree.
- Site productivity, estimates the Site Index.
- Inventory tool, allows assessment of single trees or plots, log grades to be specified, and can calculate the values for a forest. A range of plantation and native species have been parameterised, using primarily Tasmanian data.
- Wedge calibration tool, calibrates angle gauges by calculating the BAF (Basal Area Factor).
- Management tool, tracks income and expenditure over the rotation and can also calculate discounted cash flows including PV and IRR.

This is a very useful package for valuing small forests.

Version 5 is expected to be released in late 2007 with an expanded set of models for most regions in Australia. See also the system Prophecy described earlier.

Summary / possible issues

The usefulness of the FFT will generally be restricted to small woodlots but it does provide a minimal set of essential tools for valuing a small forest.

As with any package it is essential to ensure that the models being used are appropriate.

10.10 Other possibly useful systems

The systems in this section are generally only of peripheral use in forest valuation in Australia but they are used. Because of their likely lack of significant relevance to forest valuation in Australia the vendors were not contacted.

Woodlands, the system

Information as at 2005.

Proprietor: Linnett

Web site: http://woodlandsthesystem.com
Email: forestry@linnet.ca

In 2001 this package was available in Australia from Fugro
http://www.fugro.com

but in 2004 the package could not be found on their web site.

This Canadian system has three suites; the Forestry Suite with Planner, Manager and Cruiser components, the Business Suite with Contractor, Scaler and Settlements components, and the Fulfilment Suite with Inventory Manager and Woodflow Manager components.

The system would seem to be heavily oriented to Canadian conditions and short term harvest planning.

At first glance it would appear to be of limited utility in Australia for forest valuation.

3-PG

The package 3-PG (Physiological Processes Predicting Growth) is a process based model developed by the CSIRO Division of Forestry and Forest Products. There are two versions a spatial version programmed in C++ and a non-spatial version that can be run within an Excel spreadsheet. See the earlier description of the approach. The Excel version is available for download free; but for the spatial C++ based version see the web site or contact:

Dr Nicholas Coops
CSIRO Forestry and Forest Products
PO Box E4008
Kingston ACT 2604
email: nicholas.coops@csiro.au

Carbon sequestration predictor (CSP)

An Excel spreadsheet, the Carbon Sequestration Predictor (CSP), was developed by State Forests News South Wales to allow estimates of the potential for land use changes involving revegetation to create increased carbon sinks.

It is freely available to anyone interested in estimating the carbon benefits of changing land use practices. See the web site: http://www.forest.nsw.gov.au/env_services/ess/carbonlink

The spreadsheet comes with a .pdf help file.

This is one of six tool kits developed by the Environmental Services Scheme. The contact in 2004 was:

Dr. Alastair Grieve
General Manager, Environmental Science
State Forests of NSW
Locked Bag 23
PENNANT HILLS NSW 2120

Tree carbon predictor

A very simple tree carbon predictor was available in 2004 from the CRC for Greenhouse Accounting within the Research School of Biological Sciences in the Australian National University in Canberra from:

The site provides the models used.

As at 2007, reformatted 2012 but no textural changes
CAR4D

The CAR4D model has been developed by the CRC for Greenhouse Accounting within the Research School of Biological Sciences in the Australian National University in Canberra. The model as described predicts long term carbon sequestration for *Eucalyptus regnans* (swamp gum or mountain ash) forest under a range of silvicultural and management strategies. Development is ongoing.

As at 2004 CAR4D was not a commercially available product but potential users should contact [http://www.greenhouse.crc.org.au/](http://www.greenhouse.crc.org.au/) for further information.

Cooperative work may be a possibility.

ANUCLIM

ANUCLIM is a software package and associated data bases that produce estimates of monthly mean climate variables, bio-climatic parameters, and indices relating to crop growth. The main components of the package are ESOCLIM, BIOCLIM and GROCLIM. It has been developed at the Australian National University (ANU) Centre for Resource and Environmental Studies (CRES) and consists of:

- **ESOCLIM** for calculating values of monthly mean climate,
- **BIOCLIM** and **BIOMAP**, the bio-climatic prediction system, and,
- **GROCLIM**, a simple generalised crop model.

The package is driven by a graphical user interface.


ANUCLIM uses mathematical descriptions of the way a set of climate variables change across a region (known as surfaces) in order to estimate those climate variables, or parameters derived from them, at user specified points within the region.

The basis for combining all the programs into the one package is their complete reliance on climate surface coefficient files as created by a separate package. If these files do not exist for the country of interest, then the first step, before ANUCLIM can be used, is to create them. The files for Australia can be obtained with the package.

ANUCLIM 5.1 was available in 2004 and would seem to still be the current version at 2007.

National Carbon Accounting Toolbox

The National Carbon Accounting Toolbox has been prepared by the Australian Greenhouse Office of the Department of Environment and Heritage.

In early 2005 V1.0 was available, see the web site: [http://www.greenhouse.gov.au/ncas](http://www.greenhouse.gov.au/ncas)

This CD and DVD provides a set of tools for tracking greenhouse gas emissions and carbon stock changes from land use and management and includes the Full Carbon Accounting Model (FullCAM), that is derived from Australia's National Carbon Accounting System and also provides all necessary supporting and technical documentation in a fully searchable format. The toolbox uses a number of other modules including 3PG.
Part IV FOREST VALUATION

Part IV provides information and explanation to assist users of the ACFA (2004, 2007) standard to value commercial forests. The standard should be read in conjunction with this part of the Handbook.

11 Basis of forest valuation

To carry out a forest valuation generally requires knowledge of what there is in the forest (the forest inventory), knowledge of what the future expectations might be for that forest, knowledge of the costs and returns that might be achieved, and a knowledge of the business of forestry. Then it requires an understanding of the various forest valuation methodologies, and also an understanding of when each methodology may or may not be appropriate.

In preparing any forest valuation it is necessary to document in detail the manner in which the various calculations and computations were made, the assumptions that have been made, the standards, data bases and models used, including their appropriateness, and where professional judgement has been used, this must be argued and supported.

As recently as 1998 (Herbohn and Herbohn 1998), a survey of forestry accounting practices revealed that there were a wide variety of methods used to value forests and that any changes in value were either ignored, treated as a capital maintenance adjustment in the balance sheet, treated as an adjustment to income in the profit and loss statement, or categorised into a volume change which was treated as capital and a price change which was treated as income. Changes to the AASB accounting standards starting in 2001, and the ACFA forest valuation standard (2004, 2007), should ensure that a more uniform treatment evolves in the future, but it is well worth remembering that only a few years ago the range of approaches adopted was great and the methodologies inconsistent.

Herbohn and Herbohn (1998) also comment that financial statements are an important communication tool which can be used to influence decisions made by resource providers such as creditors, investors, government agencies and the general public.

Good forest valuation practice is critical if forestry is to be considered a sound class of investment.

11.1 Standard

Earlier in this Handbook it was stated that the Association of Consulting Foresters of Australia (ACFA) has developed, and proposes to maintain, the document “An Australian Standard for Valuing Commercial Forests” (ACFA 2004). This is concurrently being revised (ACFA 2007). ACFA plan to keep a date stamped, current version on the web site:

www.forestry.org.au

It is mandatory for all members of ACFA to adhere to this standard. It is recommended for other valuers of forests.

Depending on the purpose of the forest valuation there may be other standards and legal requirements that must also be met.

In providing the information in this Handbook ACFA does not imply that any method or approach is relevant for any particular forest estate at any particular point in time. The information herein is provided as a guide only.

11.2 The evolution of forest valuation

Forest valuation is not a new subject. Faustmann (1995 [1849]) is generally credited with being the first to use discounted cash flows to value forests. The Society of American Foresters (1955) in their
Forestry Handbook describe how to value forest to determine damages pointing out that two appraisals are needed, one for the damaged forest and one for the forest assuming it was undamaged.

The coverage by Johnson et al. (1967) in their classic book on forest planning in many ways parallels this handbook with chapters on:

6 Principles of Forest Planning,
7 Methods of Planning,
8 Investment Criteria,
9 Costs and Benefits,
10 Risk and Uncertainty,
11 Calculation of Net Discounted Revenue,
12 Classification of Growth Potential,
13 Valuation of Land for Forestry,
31 Forestry Accounts, and,
32 Sources and Uses of Economic Data.

In Australia prior to about 1980, the valuation of forests was primarily carried out by foresters with reference to economists and some, but generally less, reference to accountants. The primary objectives of forest valuation were either to determine the value for sale, to determine the value that could be paid for land for afforestation, or to determine the value of damages that may have occurred. Over the next 20 years there was increasing interest in forestry as a business and the value of the forest enterprise became more important as financial management techniques used in other sectors were used to determine the value of forestry as an investment class compared with other investment classes.

Accounting methodologies evolved too, so that by 2000 it became mandatory for the annual change in forest value (the SGARA or biological asset component) to be included in the financial reports of any enterprise reporting under the Corporations Act. This was probably driven more by a desire by successive governments to improve taxation revenue than by any other consideration. By 2000 accountants had a far greater responsibility as they were responsible for ensuring that the figures in financial statements were correct, could be substantiated, and were being reported appropriately. In 2000 the Australian Accounting Standards Board issued AASB 1037 and AAS 35.

Since 2000, and especially since the Australian Accounting Standards Board decided to adopt international accounting standards as the basis of Australian accounting standards, the role of accountants in forest valuation has increased enormously.

Also during the 1960-80s, commercial production forestry in Australia’s native forests was reducing as National Parks were expanding and the environmental pressures were increasing. Australia’s plantation estate was increasingly being corporatised and/or sold to private investors, and the major expansion in the plantation estate was by investment companies not by government. There had been a long history of forestry based managed investment schemes such as SAPFOR (South Australian Perpetual Forests) but the covenants had not become a major asset class in their own right. The last 30 years of the 20th Century saw a rise in forestry investment companies as the government involvement declined. Forestry has evolved, and is evolving, into an asset class in its own right.

Until about 1980 almost all forest valuations were carried out by professional foresters, even in the private sector, and the involvement of accountants, economists and business managers was generally peripheral rather than central to the determination of forest value.

Given the evolution in forest ownership and changes in accounting procedures it is not surprising that the situation has changed since then.

It should be remembered though that accountants, land valuers, and investors have a relatively short history of involvement in forest valuation compared with foresters, and often have quite a different perspective. The principles developed by foresters over more than 150 years may not be clearly understood by non-foresters and are increasingly being challenged. This is not surprising, just the
result of evolution. But, remembering the historical development may help to explain why some issues that foresters treat almost as a matter of fact, because they have been shown by experience to be effective and useful over many, many years, may be considered by others to be rather weird ideas without basis. Conversely, and just as importantly, it may help explain why some issues raised by accountants or investors based on their experience with other asset classes or industries may be considered by foresters to be simply reinventing the wheel. There is a need for all to understand the principles involved, to understand the various perspectives involved, and to determine how to best apply the principles of forest valuation as the uses of forest valuation continue to evolve.

Understanding and remembering the historical development may assist in gaining a better understanding of the issues. This should assist the provision of forest valuations and forest valuation methodologies that are acceptable to all users and should also improve the general perception of forests as an asset class and as an investment.

11.3 Purposes of forest valuation

A forest valuation is required for a particular purpose. The same valuation may be appropriate for a number of purposes but there may be important differences in forest valuations for different purposes.

There can be many purposes for carrying out a forest valuation including the following.

Formal financial reporting as required by the Corporations Act 2001

The Australian Accounting Standard Board (AASB) Standard AASB 1037 made the use of the so-called Self-Generating and Regenerating Asset (SGARA) Standard mandatory for financial reporting of commercial forests by Australian entities in financial years ending on or after 30 June 2001. AAS 35 was the appropriate standard for entities not subject to the Corporations Act.

Standard AASB 141 became mandatory for annual reporting periods commencing after January 2005. This standard is based on International Standard IAS 41. This standard supersedes both AASB 1037 and AAS 35.

The ACFA (2004) standard (“An Australian Standard for Valuing Commercial Forests”) was deemed to be consistent with the then applicable AASB standards. ACFA believes that the revised version 2 of the standard (ACFA 2007) is completely consistent with AASB 141.

Although the ACFA standard has no formal status, apart from being mandatory to ACFA members, it is hoped that over time it will become regarded as a de facto standard for all forest valuations.

Financial management

Good stewardship requires that owners and managers periodically revalue and assess the past and prospective financial performance of the enterprise. In these cases, AASB standards may be quite inappropriate.

The AASB 141 standard refers to the biological asset component of the forest only whereas for financial management the whole forest asset needs to be considered.

But, equally, they may provide an appropriate methodology. For financial transactions and also for financial management the client may determine that the various standards do provide a sound base for them to use, as the bases for the forest valuation can be clearly argued and supported by the various standards.
Financial transactions

Financial transactions involving forests and plantations involve many different purposes including:

- a seller – wishing to establish a reserve price,
- a buyer – wishing to establish a maximum price or a reasonable price,
- a lender or borrower – wishing to use the forest asset as a collateral value,
- an accountant or a taxpayer – to determine a value for taxation purposes,
- an investor or company – to determine an equity value, perhaps for use as collateral,
- an insurer – to determine an insured value,
- an insurance claimant – to determine a value for a loss,
- an inheritor – to determine a value for a deceased estate,
- an testator (or legator) – to determine a value for estate planning, or,
- a forest manager – to determine the values of alternative silvicultural and management options and strategies, and so improve the profitability of an entity.

For these valuations the strict use of AASB standards may, in some cases, be misleading and quite inappropriate as the AASB 141 standard refers to the biological asset component of the forest only.

Managed Investment Schemes

Prospectuses may be prepared for Managed Investment Schemes (MIS) which involve the acquisition of forests. Forest value is an important component for determining the value of shares or units in the entity. In other cases a prospectus may be prepared for a forest venture on new land. In these cases the value of the future forest opportunity is fundamental in estimating the eventual return for an investor. In this latter case the strict SGARA or biological asset interpretation of AASB 141 is not appropriate because the forest has not yet been established, but the principles may apply. The ACFA (2004, 2007) standard provides ways to determine the forest value.

The preparation of Prospectuses, especially those for Afforestation Managed Investment Schemes, and Afforestation Investment Schemes, is a complex and costly exercise and expert legal opinion will generally need to be sought. This is beyond the scope of this Handbook.

ACFA understands that the Australian Securities and Investment Commission (ASIC) require that Prospectuses and other company information be lodged with them and be made available on their web site:

http://www.asic.gov.au

for an exposure period during which comments may be provided to ASIC about the prospectus.

ASIC provides an INFOLINE telephone service and in 2007 the service was available at 1300 300 630. The service is also available by emailing infoline@asic.gov.au or from the web address above which may provide a convenient first port of call where information can be sought and complaints made.

ACFA makes no recommendations about how prospectuses are to be constructed but does suggest methods for determining how the future expectations from the forest may best be determined by the preparer of a prospectus.

ACFA would expect that all people who provide valuations for use in forestry based prospectuses are members of ACFA who must adhere to the ACFA standard or at the very least should state that their valuation adheres to the standard. Potential investors should be somewhat wary of any valuation where such a statement is not made.
11.4 Methods of forest valuation

There are a number of approaches to forest valuation, four of which have been used in various circumstances in practice.

None of the approaches is appropriate for all circumstances.

11.4.1 Quoted price in the market

For many goods, such as goods in a Supermarket, there is a quoted price available in an active market. Such a quoted price is not available for forests. If such a price was available for forests then this would provide the most appropriate value.

11.4.2 Transaction based approaches

The transaction based approach involves the analysis of market transactions. It is theoretically the correct procedure to estimate NMV (Net Market Value) or Fair Value for a forest estate. However there are often practical difficulties.

The Australian market for forests (perhaps even more so than the New Zealand market) generally violates the perfect market in which a large number of willing buyers and sellers enter transactions where identical goods are being exchanged. Consequently the transaction evidence for forest sales should be interpreted with some caution.

Despite this, available transaction evidence should always be considered and, where appropriate, used in the valuation of a forest.

The value of a forest can be estimated by an analysis of sufficient transaction information. The analysis essentially involves an interpolation or extrapolation of the values of past sales to the forest of interest.

Even if forest value cannot be inferred from the past transactions it may be possible to infer other relevant factors from sales. For example, the implicit discount rate or log price assumptions may be estimated from market transactions.

A New Zealand example of an analysis of sales is that of Manley and Bell (1992) who developed a relationship between the prices paid for state owned plantations sold in 1990 and their underlying characteristics.

There are no known published examples of analyses of Australian forest transactions but that is expected to change over time. Individual consulting firms and other enterprises are known to have carried out such analyses but their analyses are not publicly available for commercial reasons. What is however known is that analysis of any large forest transaction is a time consuming and expensive task because there are a number of practical difficulties.

Practical difficulties

There are many practical difficulties, not unique to forest valuation, in obtaining transaction evidence, in analysing it, and in extrapolating it to the target forest.

- **Heterogeneous forests.** No two forests are identical. They may differ in terms of maturity, distance to market, species composition, terrain, site productivity, past silvicultural practice, and other factors which will influence their value. Therefore it will generally be difficult to find a recently sold forest which is directly comparable to the forest of interest. Even if knowledge of such a sale exists it must be used with care as other differences may also pertain.
• **Points in time.** Prices provide market information at a particular point in time. They must be interpreted with caution when subsequently used because the underlying market conditions may have changed.

• **Illiquid market.** There are relatively few buyers in the market, particularly for larger forests and for immature forests. Some sales may be forced (for example liquidation, matrimonial property split, deceased estate) and may not reflect a willing seller situation. Consequently they may not represent the true Net Market Value or Fair Value as defined.

• **Lack of knowledge.** Some members of ACFA believe that the transaction approach may not always provide appropriate valuations for small forests even though there may be a reasonable number of known transactions. The owners of small forest estates often lack knowledge of forestry and forest management. They lack knowledge of the true value of their forest. A market may have become established at a reduced value if a number of owners have been convinced to sell their forests. In essence the sellers are not ‘knowledgeable sellers’. The market is not strictly speaking illiquid, but the purchasing entity has been able to suggest to the owners that the price they are offering reflects the ‘true value’ of the forest. This is not strictly a valuation issue but can be considered a situation where a market has been established based on transactions that do not reflect what knowledgeable parties would consider to be the true value.

• **Scale.** There are limited transactions involving large forests in Australia.

• **Strategic factors.** Transaction evidence may incorporate strategic factors such as the wish to enter or exit a region, the advantage of possibly gaining complementary age class distributions, the provision of access to vertical integration opportunities, and advantages of increasing the size of an existing forest estate. It may be difficult to assess the effect of these factors on the past transactions and this can cause difficulties in extrapolating a known transaction to a target forest.

• **Tax considerations.** It is unlikely that any two transactions will have buyers (or sellers) with exactly the same taxation considerations, and taxation implications will commonly be part of the price considerations for a transaction.

• **Intangibles.** In some situations the price paid for a forest may reflect factors other than the crop and the land on which it is growing (for example, location, aesthetics, and the desire of the purchaser to gain other assets to complement or expand an existing forest estate).

• **Lack of publicly available information.** Forest sales information is often not available either for confidentiality reasons or because the forests represent one component of a bundled sale involving other significant assets. To be useful, disclosure is required, not just of price but of all the characteristics of the forest.

For an analysis of transactions to be useful these factors need to all be considered and their impact on the forest valuation carefully assessed.

### 11.4.3 Expectation based approaches

There are a number of variants of expectation based approaches.

**Present value (PV) or discounted cash flow (DCF) approach**

Under the expectation approach future wood volume is forecast based on some underlying silvicultural management and harvesting strategy. Log volumes are multiplied by log prices to give forecast revenue. Costs are subtracted from these revenues to give future net cash flows. These are discounted to give forest value. Variations of the expectation approach arise depending on whether;

• a single rotation or perpetual rotations are assumed, and,

• the analysis framework of an estate level or a stand level is adopted.
There is an economic school of thought that suggests that the replanting decision in forestry should be treated as a separate investment decision. Under this approach the forest valuation only captures the value of the existing crop.

The alternative viewpoint is that a forest should be valued on the basis of a going concern. Accordingly, the value of a forest should not include just the current crop but also the value of subsequent rotations. In point of fact, if land rental is based on the LEV, and if the costs and revenues of the current rotation and subsequent rotations are the same, then the crop values estimated under either assumption of a single rotation or of perpetual rotations are identical.

A variant of the perpetual rotation approach, that is appealing when costs and returns are modelled differently between rotations, is to use a very long planning horizon and to include the lump sum value at the end of that planning horizon. This has the advantage of a fixed planning horizon facilitating calculation. It also may better facilitate evaluation of alternative silvicultural strategies. Sensitivity analyses should be carried out to ensure that changing the planning horizon by say ± 10 years has a negligible effect on value. In practice this planning horizon length is approximately the length of two nominal rotations.

A characteristic of the expectation approach is that it uses price information from markets in which transactions are frequently occurring. Although the market for forests tends to be thin, there are regular transactions in the log market, and many costs can be based on open market tenders. A disadvantage is that there is no certainty that these costs and returns will pertain into the future.

Other features of the expectation approach include the following.

- The approach requires future wood flows to be forecast and future log process assumptions and cost assumptions to be made.
- The approach requires the determination of an appropriate discount rate.

**Estate based expectation value**

The estate based expectation approach values the forest as a single entity. The net cash flows of the total estate are forecast and discounted to give forest value. These cash flows are associated with an underlying management and harvesting strategy which applies to the whole estate. The strategy varies depending on a number of factors.

- Assumptions or constraints placed on the level of harvesting. At one extreme the harvesting might be unconstrained with each stand harvested at its optimum rotation age. At the other extreme total harvest (and harvest by log grades) might be constrained to be non-declining or may be fixed by contract or to meet planned wood flows.
- Assumptions about the intensity of silviculture.
- Assumptions about replanting.
- Assumptions about new land planting.

**Stand based expectation value**

This approach values the forest as a sum of the values for each individual stand. The net cash flows of each stand are forecast and discounted to give stand value. As for the estate-based expectation method, assumptions are made about the underlying management and harvesting strategy. The strategy varies depending on a number of factors.

- Rotation age. The optimum rotation can be assumed or the rotation may reflect expectations about when the stand will be harvested to fit in with broader estate considerations.
- The silvicultural regime.


- Replanting, typically the assumption of no replanting is adopted in the stand based expectation approach.

Given the same set of assumptions, the stand based approach will give the same forest value as the estate based expectation value.

**Use of Internal Rate of Return (IRR) as the discount rate**

Use of the expectation method requires a discount rate to be determined. A variation of the stand based expectation method, which has been used in the past, sets the discount rate equal to the Internal Rate of Return (IRR) of the investment which would have been applied at the time of establishment of the stand.

The argument for this approach is that the value of the forest (for example for insurance compensation purposes) should reflect the rate of return expected at time zero.

Use of IRR as the discount rate ensures that crop value equals zero at the time of planting and equals the net standing value at time of harvest. However the approach violates the economic principle that past costs are sunk costs and irrelevant to present decisions.

Another criticism is that IRR is, by definition, internal to the investment, whereas the appropriate discount rate should represent the opportunity cost of capital reflecting the rate of return available in alternative (external) investments.

**The effect of land value on the analysis**

If the PV analysis is based on infinite rotations rather than restricting the analysis to a single rotation then the value of land may need to specifically be taken into account. If the PV analysis is for a single rotation then a land rent approach may be more appropriate.

If the valuation is for accounting purposes and the PV is calculated at the end of one year, and then at the end of the next so that the change in forest value can be incorporated into the profit and loss account, then the change in land value over the same period will generally need to be taken into account. In essence the infinite rotation PV assumes land and forest cash flows and so the annual change in the land value may need to be estimated if the change in forest value is desired.

Land valuation for large forestry companies is not necessarily simple. The cost of contracting a Certified Practicing Valuer each year to carry out a valuation of the land only would seem to be prohibitive compared with the likely change in value, which after all is the figure that is required by the Corporations Act 2001.

One possible option believed to be available in all states of Australia is to use the official State Government figures used for rating and other purposes as the benchmark. The values may be consistently over or under what a forest valuer or a Certified Practicing Valuer might perceive to be sensible, but generally by no more than 10%, and it is the change in this value that is important for the determination of the annual change in forest value, and that is unlikely to be anywhere near as unstable. These land valuations are generally readily available to the forest owners as part of other information and reports and so cost little or nothing.

**11.4.4 Option based approaches**

Dixit and Pindyck (1994) developed an options based approach to investment to deal with the situation where there is the ability to delay an irreversible decision. They use option pricing to value the situation where an investor has the right but not the obligation to make an investment.

The use of option pricing theory in forest valuation has been suggested by Hughes (1987). A forest owner has the option of when to harvest a stand. In theory the owner has the option to halt log production when prices are low and increase production when prices are high. Longley et al. (1993)
suggest that the ability to defer the harvest has a value which is not captured by the expectation approach. In the forest option model of Hughes (1987), forest value is a function of future harvest volume, future harvest cost, current stumpage value, stumpage price volatility (i.e. variation), the time to harvest and the discount rate.

Hughes (1997) used this option pricing methodology to value the forest assets that the Forestry Corporation of New Zealand sold in 1996. He estimated, using a discount rate of 7.5%, that the option value was $NZ 2.075 billion compared to a PV value of $NZ 1.804 billion. The implication of this is that there was an additional $NZ 271 million, or 15%, associated with harvesting options which was not captured by the expectation value approach.

Although attempts have been made to value forests using the option pricing theory, neither ACFA nor the Working Party of the New Zealand Institute of Foresters, is aware of any practical application. See also Liley (2000).

However there are believed to be ongoing developments in this area which have potential application in the future. The approach certainly appears to be worth testing and further development.

Whether or not a forest owner has the flexibility to use this valuation approach depends on any contracts which may have been let as these contracts may reduce the timing options for harvesting.

11.4.5 Lump sum based approaches

In the lump sum approach, forest value is calculated by determining the stumpage (or royalty) value of standing merchantable volume. The underlying assumption is that all merchantable stands in a forest can be liquidated immediately and sold at current stumpage prices.

The approach has also been called the immediate liquidation approach but the term liquidation has a different connotation in the business and investment communities. It is therefore recommended that the term ‘lump sum’ value be used. Young immature forests are generally assigned zero value. The approach generally gives a conservative value but not always.

Characteristics of the method include the following.

- The assumption that a forest can all be liquidated immediately without influencing stumpage prices is unrealistic except for very small forests, and these may have to be liquidated at a discount because of their size and timing constraints.
- Assigning young stands which are not currently merchantable a zero value is unrealistic.
- No account is taken of the future value increases brought about by tree growth or of the investors time preference for funds.
- Converting a plantation back to bare land after clear felling (which some users simply by liquidation) is a cost often not taken into account.

In one unpublished study, where the valuation was based on expectation value and alternatively on the lump sum value, the two methodologies provided very similar valuations. This was presumed to be attributable to the expectation value being based on the discount rate approximately equivalent to the IRR, and also to the forest having approximately equal area in each age class, a near normal forest. This suggests that the two approaches might provide at least close to the same value for a normal forest where the discount rate is the IRR but, although this seems intuitively appealing, it is believed that it has not been formally demonstrated. It is also unlikely to be a repeatable outcome.

The following table sets out the approximate ratios of the standing volume in a large forest estate relative to the annual cut for a hypothetical long-term sustainable business.
<table>
<thead>
<tr>
<th>Forest type</th>
<th>Main product</th>
<th>Rotation (years)</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native forest (e.g., jarrah)</td>
<td>Sawlogs</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Native forest (e.g. blackbutt)</td>
<td>Sawlogs</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Pine plantation</td>
<td>Sawlogs</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Blue gum plantation</td>
<td>Pulpwood</td>
<td>15</td>
<td>7</td>
</tr>
</tbody>
</table>

The actual ratios depend largely on the number of years over which planting has been conducted in the case of plantations, or the distribution of age of size classes in native forests.

These large ratios highlight why the Tasmanian Auditor-General (McHugh 1993) inferred that valuation of the state-owned forests based on the lump sum or immediate liquidation of the volume of standing trees (or as defined in the ACFA 2004 standard, living trees), was meaningless. Such an assumption is not consistent with the disposal of an asset in a liquid and active market.

In essence the lump sum approach is a variant of the expectation approach with a zero time horizon.

11.4.6 Cost based approaches

Cost based approaches involve the accumulation of costs to provide an estimate of value. Costs based approaches have had appeal for a number of reasons.

- A preference in some cases to value young stands on the basis of replacement cost rather than future expectations.
- The influence of accounting practice and the concept of objectivity.

The fundamental weakness of these approaches is that cost generally does not equal value. As noted by Davy (1987) a high cost forest does not necessarily equal a high value forest and conversely a low cost forest does not necessarily mean a low value forest. Cost is generally a function of soil physical properties, terrain, location relative to base, current vegetation, weeds, etc. Value is generally a function of site productivity, rainfall, soil nutrient status, location relative to markets, and growth rates etc.

Examples are known where forest established on expensive land produces high productivity forest for low establishment costs compared with forest established on cheaper land that requires greater cost inputs to create even poor quality forest. If land costs are excluded from the forest valuation then the lower cost forest may have a higher value, and quite reasonably so.

Historical cost method

The historical cost method equates forest value to the sum of the historic costs incurred in developing it. Variations of the method occur over;

- what are classified as development costs,
- whether maintenance costs are accumulated, and,
- whether interest costs associated with the debt-financing of the forest are accumulated.

Characteristics of the method include;

- there is no adjustment for inflation, and,
- costs relate to the technology of the time in which the operations were carried out.
Current cost method

The current cost method accumulates the inflation-adjusted costs incurred in developing a forest. It has received limited application because of the lessening interest by the accounting profession in current cost accounting concepts.

Current replacement cost method

In the current replacement cost method, forest stand value is calculated as the sum of costs compounded forward from time of occurrence to the present day. Costs are generally expressed in current day dollars. In addition, standard costs, representing current efficient practice, are generally used for each operation.

The current replacement cost approach is similar to the current cost approach when the latter includes the accumulation of interest charges. The difference is that the compounding rate used in the current replacement cost approach represents the opportunity cost of capital as distinct from the interest rate on borrowed funds used in the current cost approach. As noted by Liley (1994) “whereas the accountant’s preference is to recognise only actual, tangible financial charges against the forest, the economist is prepared to recognise a notional cost of capital.”

The current replacement cost approach has some economic underpinning. “Its claim to validity rests on the assumption of rationality on the part of the investor. It assumes that an investor would not willingly put money into a project without a reasonable expectation of at least getting it back” (Fraser et al. 1985).

Its application to very young stands has reflected the view that “this method is most relevant in the initial development stages prior to future revenue being ascertainable” (Davy 1987).

A specific limitation of the method is the need to determine an appropriate compounding rate. Often a conservative rate has been adopted. For example, a lower rate has often been used for compounding costs compared to the rate used for discounting future revenues. This may be because of different perceptions of risk.

Under very specific circumstances the value of the crop estimated by the cost-compounded method will equal that estimated in the expectation method by discounted future cash flows. This is when the same cost, revenue, and discount rate assumptions are used, taxation is excluded, and a notional land rental charge is charged in both cases, based on the Land Expectation Value (LEV). This equivalence was first noted in 1849 by Faustmann (1995).

Insurance value

The cost compounded approach has been used for some valuations for insurance purposes.

If the insured value is based on the biological asset value then it may be an underestimate of the true replacement cost for two main reasons.

- There would be a cost for clearing the young plantation if it was killed by fire, as the salvage value would be minimal.
- The replaced forest would be some years behind the forest it is replacing and that may impact wood flows and future cash flows.

It is noted that the insured value may be based on the value of the biological asset plus the cost of any clearing and replanting. In this case the insured value would have to be adjusted to determine the value of the biological asset.

Although it may be decided to insure for the value calculated by cost compounding it would seem sensible and appropriate to advise the insurer that that value may be an underestimate of the true value to the enterprise as this may assist gaining a better premium as the risk is being shared.
11.5 Recognition of other values

This Handbook refers particularly to forests managed as commercial enterprises. The United Nations Food and Agriculture Organization (FAO 2006) has developed a Planted Forest Code that addresses 12 Principles for the development of sustainable management and utilisation of planted forests, two of which have relevance to valuing forests.

They put the commercial forest into a more holistic focus. They recognise that the value of the forest estate may be far greater than is measured by the methods described earlier and imply that there are other values that should be included in determining the total value for certain particular purposes.

They demonstrate that this Handbook and the ACFA (2004, 2007) forest valuation standard are directed at only part of the total forest value. Possibly the most important of these other values in Australia is water production, but it is by no means the only non-wood value that may need to be recognised.

**FAO Principle 4: Recognition of Value of Goods and Services**

Planted forests, whether productive or protective, must be recognized for their provision of both market and non-market benefits including wood and non-wood forest products and social, cultural and environmental services.

Attributes of the principle include, but are not limited to, the following.

- Balance of the tradeoffs between returns on investment to the planted forest investor, sustainable livelihoods, sustainable land-use and sustainable forest management (including natural forests).
- Improvement of the financial and economic valuation methods to improve the recognition and full valuation of goods and services from planted forests.
- Application of the full value of planted forests goods and services in planning, management, monitoring and reporting.
- More equitable sharing of benefits between stakeholders involved in planted forest development. Recognition of the full value of planted forests in justification for investments by Government and private sector investors (both corporate and smallholder).
- Recognition of the full value of planted forests goods and services, particularly by Governments and local authorities in setting land-use priorities.

**FAO Principle 5: Promotion of Investment**

Governments must create the enabling conditions to encourage corporate, medium and small investors to invest long-term in planted forests and yield a favourable return on investment.

Attributes of the principle include, but are not limited to, the following.

- Provision of stable and clear investment policies and laws to provide investors confidence to invest long term in planted forest development.
- Provision of direct or indirect incentives to encourage long-term investment in planted forest development, that may be justified where society as a whole will benefit.
- Avoidance of perverse incentives with adverse trade, social or environmental impacts, noting that such perverse incentives may originate in other sectors.
- Revision of incentives at periodic intervals to reflect the evolution in planted forest development.
• Avoidance of economic distortions that reduce the value of planted forests or limit the opportunities for smallholder investors.
• Promotion of equity between competing land-uses in policies and priority setting.
12 Accounting standards

Staff of the Australian Accounting Standards Board (AASB) in Melbourne assisted greatly in the development of “An Australian Standard for Valuing Commercial Forests” (ACFA 2004) and their ongoing assistance with understanding of the rapidly changing interpretations of the various standards is greatly appreciated. ACFA is very grateful for their help and considers their ongoing assistance has been crucial to the ability of ACFA to maintain currency and relevance. The revised standard (ACFA 2007) developed in parallel with this Handbook has also benefited greatly from this ongoing assistance of AASB staff.

It would seem useful to briefly discuss the evolution of the accounting standard from a forestry perspective rather than an accounting perspective, and to then address the issues raised by the need to determine fair value or market value of the forest based biological asset.

12.1 Evolution of the accounting standard from a forestry perspective

Up until about 2000 there seems to have been a general disconnect between valuing forests and accounting practice. The value of a forest asset, either for sale or purchase, was generally determined by forest resource planners and managers using a variant of a discounted cash flow or present value analysis, considering past transactions, and with limited input from economists and accountants. The price so determined was then adjusted to take into account other factors the buyer or the seller deemed appropriate.

Some forest owners reported what they considered to be the value of their forest in their financial reports, but as a note that could be used to explain increases or decreases in the annual accounts.

In the early 1980’s the Treasury and the Woods and Forests Department in South Australia developed a “sustained yield approach to forestry accounting” that treated the forest as a going concern and thus all costs and returns in any year could be considered in the annual financial statements. This would not have been appropriate to most forest enterprises because they were generally in a development phase and not in a mature phase where growth approximately equalled yield. The concerns raised by forest managers were largely ignored. In 1983 the Ash Wednesday fires destroyed about 30% of their forest estate and the approach was quietly shelved amid the chaos of the recovery programme. In essence the approach was an accounting treatment and the actual value of the forest in an open market place was not a major consideration.

In the mid to late 1990’s there was a push to include the annual change in the value of the forest assets in the financial reports. This had some general merit as it was argued that increases or decreases in sales due to variations in the market requirements for timber would be balanced, in a normal forest, by increases or decreases in the level of growing stock. The combined change should reflect the effects of management.

This seems to have led to the development of Australian Accounting Standards Board Standard AASB 1037 (and its equivalent AAS 35, basically for government entities) that was entitled “Self-Generating and Regenerating Assets”. The development seems to have been driven by accountants (Herbohn 2005a, 2005b, and see also her 1998 papers). Herbohn (2005b) reports that 8 of 10 responses to an exposure draft by forestry based organisations were positive.

It would seem that at least in some large forestry entities that the responses to the AASB exposure draft were from the accountants within the organisations and not from the forest managers and so some of the fundamental issues to forestry would appear to have been largely ignored. It is understood that the issues concerning the valuing the forest asset did not have a major impact on the responses. It would also seem that some managers thought, or perhaps hoped, that the problem would just go away.

In retrospect this attitude, apparently adopted by many forest managers, would seem to have been unhelpful.
As Herbohn (2005b) reports there were two major issues raised in the discussions;

- the difficulties of measurement of the biological asset at fair value, and,
- the recognition of changes in fair value as part of income at each reporting date.

The methodology for measuring the biological asset at fair value, or market value, is the subject of this handbook and the ACFA forest valuation standard. The difficulties of measuring fair value reliably and to an accuracy considered satisfactory by managers, auditors and accountants are well known and described in this Handbook. The subject is vitally important given the high proportion of net profit that may be represented by the change in value of the forest in the financial statement in any one particular year.

The subject of recognition of changes in fair value as part of income has been considered by many foresters as something that has been imposed externally, and something that has had to just be accepted. Herbohn recognized three reasons for the opposition, the first reason being that “the proposed treatment creates unrealized profits that may not be realized in a timely basis”. The perceived consequence of this is the development of “unrealistic expectations of distributable profits, creating pressure for entities to declare and pay dividends for which no funds are available.” The second concern was the additional volatility in reported profits and the third was that allowing recognition of estimates in income statements could result in significant adjustments in subsequent periods.

AASB 1037 and AAS 35 were made mandatory for reporting periods after June 2001 for entities reporting under the Corporations Act, and this led to the need for entities with significant forest estates having to consider the value of their forest.

At this stage ACFA observed that nothing seemed to be being done to reduce this apparent volatility and saw that there was a need for a forestry oriented standard that could interpret the AASB standard and so, hopefully, reduce the disparity in approaches and the reduce the volatility in the estimates of market value. The issue of SGARAs needed to be addressed as a matter of urgency. The issue of the recognition of the changes in the financial statements was considered something that had to be accepted and it was not considered a subject for argument or discussion.

The provision of the May 2004 “An Australian Standard for Valuing Commercial Forests” was aimed at providing guidance. By gaining the approval of staff of the AASB it was hoped that this would assist users better understand the issues and have confidence in using the standard. By making it mandatory for ACFA members to adhere to the standard it was hoped to assist credibility. All in all it was hoped that the effect would be to improve forest valuation methodology and outcomes, and it was also hoped that the volatility in forest valuations would be reduced, thus assisting to address one of the impediments to forestry investment.

By late 2005 circumstantial evidence suggested that these objectives had been at least partly been realised but it was also realised that was likely to take some years for the full benefits to become evident.

In mid 2004 the Australian Accounting Standards Board decided to adopt international standards as the basis for Australian accounting standards. This appeared to further complicate the issues and led ACFA to hastily produce Supplement 1 to the standard which was issued in January 2005 (ACFA 2005). The term SGARA was replaced by the term biological asset. The term Net Market Value was replaced by Fair Value.

### 12.2 Australian Accounting Board Standards

The Australian Accounting Board (AASB) provides a large number of standards and other documents to assist in maintaining consistent and legally binding accounting practices. The AASB decided in 2004 to adopt international standards wherever possible and this is reflected in the listing of the standards in terms of their date of operation.
The Australian Accounting Standards are Delegated Legislation (that is subject to veto by the Parliament) and as a consequence they are available free of charge. In 2007 all Australian Accounting Standards that are applicable can be accessed and/or downloaded from the AASB website: 

In 2005 the situation was still rather fluid as the AASB had decided to adopt the international standards and so there were a number of older standards that in some circumstances were still relevant, and others that had been or were about to be superseded. All the Australian Accounting Standards that were then currently applicable (pre 2005) such as AASB 1037 are also still available on the AASB website.

A number of the standards and other documents may be relevant to forest valuation including the following. As at early 2007 there was one Exposure Draft available from AASB, part of which is appropriate to forest valuation. Exposure drafts are not yet formally part of the standard and so have no formal relevance, well not yet.

### Standards applicable before 1 January 2005

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As at 2007, reformatted 2012 but no textural changes
12.3  IAS 41 – AASB 141

The International Financial Reporting Interpretations Committee (IFRIC) proposed an international standard for agriculture as released by the International Accounting Standards Board (IASB) as IAS 41 “Agriculture”.

For convenience a summary is included in this Handbook. This summary, taken from the IASB web site in May 2004 http://www.iasb.org is no longer available because some aspects have changed and no equivalent summary is yet available.

Accordingly its applicability is appropriate as at May 2004 and not thereafter but it remains a useful if not necessarily accurate description.

12.3.1  Recognition and Measurement

- “biological assets should be measured at their fair value less estimated point-of-sale costs, except where fair value cannot be measured reliably;
- agricultural produce harvested from an enterprise's biological assets should be measured at its fair value less estimated point-of-sale costs at the point of harvest. However, this Standard does not deal with processing of agricultural produce after harvest. IAS 2: Inventories, or another applicable International Accounting Standard should be applied in accounting for agricultural produce after the point of harvest;
there is a presumption that fair value can be measured reliably for a biological asset. However, that presumption can be rebutted only on initial recognition for a biological asset for which market-determined prices or values are not available and for which alternative estimates of fair value are determined to be clearly unreliable. Once the fair value of such a biological asset becomes reliably measurable, an enterprise should measure it at its fair value less estimated point-of-sale costs;

if an active market exists for a biological asset or agricultural produce, the quoted price in that market is the appropriate basis for determining the fair value of that asset. If an active market does not exist, an enterprise uses market-determined prices or values (such as the most recent market transaction price) when available;

in some circumstances, market-determined prices or values may not be available for an asset in its current condition. In these circumstances, an enterprise uses the present value of expected net cash flows from the asset discounted at a current market-determined pre-tax rate in determining fair value;

a gain or loss arising on initial recognition of biological assets and from the change in fair value less estimated point-of-sale costs of biological assets should be included in net profit or loss for the period in which it arises;

a gain or loss arising on initial recognition of agricultural produce should be included in net profit or loss for the period in which it arises;

the Standard does not establish any new principles for land related to agricultural activity. Instead, an enterprise follows IAS 16: Property, Plant and Equipment, or IAS 40: Investment Property, depending on which standard is appropriate in the circumstances. Biological assets that are physically attached to land are recognised and measured at their fair value less estimated point-of-sale costs separately from the land;

an unconditional government grant related to a biological asset measured at its fair value less estimated point-of-sale costs should be recognised as income when the government grant becomes receivable. If a government grant related to a biological asset measured at its fair value less estimated point-of-sale costs is conditional, including where a government grant requires an enterprise not to engage in specified agricultural activity, an enterprise should recognise the government grant as income when the conditions attaching to the government grant are met;

if a government grant relates to a biological asset measured at its cost less any accumulated depreciation and any accumulated impairment losses, IAS 20: Accounting for Government Grants and Disclosure of Government Assistance, should be applied.”

12.3.2 Disclosure

“The Standard includes the following new disclosure requirements for biological assets measured at cost less any accumulated depreciation and any accumulated impairment losses:

• a separate reconciliation of changes in the carrying amount of those biological assets;
• a description of those biological assets;
• an explanation of why fair value cannot be measured reliably;
• the range of estimates within which fair value is highly likely to lie (if possible);
• the gain or loss recognised on disposal of the biological assets;
• the depreciation method used;
• the useful lives or the depreciation rates used; and
• the gross carrying amount and the accumulated depreciation at the beginning and end of the period.

In addition:

• if the fair value of biological assets previously measured at cost less any accumulated depreciation and any accumulated impairment losses subsequently becomes reliably measurable, an enterprise should disclose a description of the biological assets, an explanation of why fair value has become reliably measurable, and the effect of the change; and

• significant decreases expected in the level of government grants related to agricultural activity covered by this Standard should be disclosed.”

The equivalent Australian Accounting Standard AASB 141 is directly based on IAS 41 and includes some additional Australian requirements as “Aus” paragraphs. The Exposure Draft ED 151 however indicates that the AASB is considering minimising the number of these Australian specific paragraphs and so further changes are expected in the future.

A section on the differences between AASB 141 and AASB 1037 (and effectively AAS 35) is contained in an early version of AASB 141 but has since been removed. The section noted incompatibilities between the two standards, noted areas where AASB 1037 (and effectively AAS 35) are more detailed or restrictive, and noted areas where AASB 141 disclosures are more extensive.

AASB 141 is mandatory for annual reporting periods beginning on or after 1 January 2005 and relevant changes are now being considered for the ACFA (2004) forest valuation standard (planned as ACFA 2007). It should be clearly recognised that the task of ensuring timely compatibility of all relevant standards is not trivial, and complete compatibility and correctness can never be assured. Documents such as the ACFA forest valuation standard and this handbook should always be considered as ‘works in progress’.

As New Zealand is also working towards the same use of international standards, albeit operational a year later, this suggests that there is a possibility of some convergence between forest valuation standards in Australia and New Zealand at some stage in the future.

12.4 An interpretation of AASB 141

In July 2004 the Australian accounting standard AASB 141 “Agriculture” was released based on International Accounting Standard IAS 41. This is applicable to annual reporting periods beginning on or after 1 January 2005.

The timing suggests that organisations may have needed to consider the effects of this standard in the preceding accounting period in order to be able to determine any changes in forest valuation by creating an opening balance sheet at the date of transition to Australian equivalents to International Financial Reporting Standards (IFRS). AASB 1 “First-time Adoption of Australian Equivalents to International Financial Reporting Standards” defines this as “the beginning or the earliest annual reporting period for which an entity presents full information under Australian equivalents to IFRSs as comparative information in its first Australian equivalents to IFRSs financial report.” AASB 1047 “Disclosing the Impacts of Adopting Australian Equivalents to International Financial Reporting Standards”, which is applicable for interim and annual reporting periods ending on or after 30 June 2004, requires entities to disclose a narrative explanation of the key differences in accounting policies that are expected to arise from adopting Australian equivalents to IFRSs (for 30 June 2004 and later financial reports) or any known or reliably estimable information (if available) about the impacts on the financial report had it been prepared using the Australian equivalents to IFRSs (for 30 June 2005 and later financial reports).

Consideration of IAS 41 and AASB 141 led to some interpretational difficulties. In mid 2005 some of these issues were under review by the International Financial Reporting Interpretations Committee (IFRIC) which was understood to be considering proposing amendments to IAS 41. Any changes to
that standard would only be incorporated into AASB 141 after due process has been undertaken. Therefore AASB staff were unable to suggest appropriate changes to the ACFA standard with any certainty that they would not be superseded within a relatively short space of time.

Discussions were commenced with AASB staff in order to determine how various issues might be interpreted. AASB staff advised that the IFRIC was considering proposing amendments to IAS 41 and that any changes to that standard could be incorporated into AASB 141 only after due process has been undertaken. The comments in this section must therefore be considered an interim interpretation only. Other interpretations are believed possible.

The section in the first version of AASB 141 noting the inconsistencies between AASB 141 and AASB 1037 (and effectively AAS 35) surprisingly does not identify the following paragraphs in AASB 141 (directly taken from IAS 41) as being inconsistent. The bold parts have been added to assist the discussion; they do not appear in bold in the AASB standard.

20. “The objective of a calculation of the present value of expected net cash flows is to determine the fair value of a biological asset in its present location and condition. An entity considers this in determining an appropriate discount rate to be used and in estimating expected net cash flows. The present condition of a biological asset excludes any increases in value from additional biological transformation and future activities of the entity, such as those related to enhancing the future biological transformation, harvesting, and selling.

21. An entity does not include any cash flows for financing the assets, taxation, or re-establishing the biological assets after harvest (for example, the cost of replanting trees in a plantation forest after harvest).

22. In agreeing an arm’s length transaction price, knowledgeable, willing buyers and sellers consider the possibility of variations in cash flows. It follows that fair value reflects the possibility of such variations. Accordingly, an entity incorporates expectations about possible variations in cash flows into either the expected cash flows, or the discount rate, or some combination of the two. In determining a discount rate, an entity uses assumptions consistent with those used in estimating the expected cash flows, to avoid the effect of some assumptions being double-counted or ignored.”

In 5. Agriculture-Related Definitions:

“Biological transformation comprises the processes of growth, degeneration, production, and procreation that cause qualitative or quantitative changes in a biological asset.”

For more detail about other paragraphs consult Standard AASB 141.

12.4.1 Future growth

On first glance it appears that AASB 141 is incompatible with AASB 1037 and AAS 35 in that AASB 141 appears not to permit the value from future biological transformation (in essence growth) to be reflected in determining the fair market value of a biological asset.

The wording in paragraph AASB 141:21 appears to be quite clear and unequivocal. Any discounted cash flow is to exclude any increases resulting from additional transformation and future activities such as those related to enhancing the future biological transformation. The paragraph seems though to make a distinction between what can be thought of as ‘growth’ and the ‘potential for future growth’. All this could, at one extreme, be interpreted by a forest valuer as to imply that growth is to be ignored. However, future silvicultural practices such as pruning or fertiliser application will affect future harvested yield and ignoring them would mean that the valuation does not match practice, does not match the methodologies used in the market place, and certainly makes little forestry sense.
The issue of whether to include or exclude future growth, or the potential for future growth, in the valuation of a biological asset was brought to the attention of IFRIC. In December 2003 they started considering this issue.

IFRIC is reported to have considered these issues in May 2004 and to have agreed to recommend to the IASB that the IASB should take action as follows.

- Amend IAS 41 to clarify which value in which market would be relevant to establish fair value, emphasising that the asset held must be the focal point.
- Establish a fair value hierarchy in IAS 41 that is consistent with other standards.
- Clarify that when fair value is determined by using valuation techniques an entity should incorporate assumptions that market participants would use on the basis of facts or information known or knowable at the measurement date unless impracticable.
- Retain the requirements that a recognised value of a biological asset should reflect the assets present condition and location; that is the asset should be measured at its fair value less transport costs and other costs of getting the asset to market and less other costs to sell.
- Conform the terminology in IAS 41 to other Standards.

In 2006 AASB staff advised that they still believed that IFRIC intends clarifying the meaning of fair value in the context of the required exclusion in IAS 41 of ‘any increases in value from additional biological transformation’. As at mid-late 2006 no formal announcements appeared to have been made and nothing seemed to be foreshadowed in notices of future meetings.

It is expected that IFRIC (and the IASB) will further consider the issue and will release an Exposure Draft for comment. It is likely that the AASB will also then release an Exposure Draft and provide a submission back to the IASB and the IFRIC on the issues.

In the meantime, an arguable interpretation of paragraph AASB 141:21 is that although it excludes future growth (because it is a future event) it does not exclude the potential for future growth (because it is currently controlled by the entity). AASB staff believe that this interpretation is reasonable.

### 12.4.2 Limits for the discounted cash flow analysis

Paragraph AASB 141:22 could be interpreted as not allowing cash flows related to re-establishment to be used in any valuation model. However, as noted in section 6.3.5 “Planning horizon for NPV determination” of the May 2004 ACFA forest valuation standard, if valuing trees and land as a composite asset in perpetuity, the cost of replanting would be taken into account. This thrust remains virtually unchanged in the revised standard (ACFA 2007). Paragraph AASB 141:25 specifically allows this composite approach as an option. When deriving biological assets separately from land, it is the present biological asset that is being valued. Whether re-establishment is ‘home grown from existing biological assets’ (for example coppice or natural regeneration) or ‘acquired’ (for example planted from externally raised stock) could affect the measurement of the biological asset separately from the non-biological assets. The value from ‘home grown from existing biological assets’ is a value attributable to existing biological assets. The value from ‘acquired’ is a value attributable to future biological assets. To comply with AASB 141 it would be necessary to ensure that the latter is reflected in the land value or in the value of non-current assets, not in the biological asset value.

If land is at its highest and best use as forest, then it is expected that adjacent vacant land would be valued consistently with the discounted cash flow that the land can generate in perpetuity from establishment and management as a commercial forest. Therefore the value of land at highest and best use implies that the management style adopted in a forest would be used as a basis for valuing the vacant land (or at least it should be implicit in that value). In practice use of market value is appropriate and it is reasonable to assume that it reflects highest and best use.
12.4.3 IFRIC Agriculture project

In 2004 and 2005 IFRIC was believed to be considering how to account for an obligation to replant or re-establish a biological asset after harvest. IFRIC has apparently concluded that when an entity has an obligation to re-establish a biological asset after harvest, that obligation is attached to the land and thus does not affect the fair value of the biological assets currently growing on the land. This treatment is consistent with IAS 16 (AASB 116 Property, Plant and Equipment) which requires restoration costs to be included in the value of property, plant and equipment to the extent that it has been recorded as a liability in accordance with IAS 37 (AASB 137 Provisions, Contingent Liabilities and Contingent Assets). The recognition of the obligation to replant or re-establish a biological asset as part of the fair value of land is also consistent with the concept of including the value of future growth in the land value when deriving the value of the biological asset as part of a composite asset. IFRIC has also concluded to date that the harvest is the triggering event; that is, if an entity does not harvest, there is no present liability. Therefore, an entity should recognise a liability to replant at final harvest only.

At that stage too the IFRIC observed that, in some instances, an entity may have an obligation to replant a biological asset but the entity will not always have ownership of the new biological asset created by replanting (and therefore not be able to benefit from the replanting). This could, for example, be the case in some leases of land. IFRIC noted that such an obligation would be similar to other hand-back obligations included in leasing agreements, the accounting for which should be determined by the leasing standard and general requirements for liabilities. The IFRIC therefore agreed not to consider this issue as part of its agriculture project.

These various observations by the IFRIC would seem to ACFA to be more simply resolved by valuing trees and land as a composite asset in perpetuity as noted in section 6.3.5 “Planning horizon for NPV determination” of the May 2004 ACFA forest valuation standard, and then adjust this to account for the land value and also the value of subsequent rotations, and so establish the value of the rigidly defined biological asset, the current crop only. Paragraph AASB 141:25 can be interpreted to allow this composite approach.

Further, ACFA suggests that an organisation may need to consider whether it has an ‘obligation’ to replant in the sense that IFRIC seem to imply and whether the ‘obligation’ to replant in order to meet long term wood supply contracts is or is not equivalent.

12.4.4 Fair value presumption

Paragraph AASB 141:30 states that “there is a presumption that fair value can be measured reliably for a biological asset” (see also the summary quoted earlier for IAS 41) but allows that to be rebutted if “market determined prices or values are not available”. The interpretation of paragraphs 30 and 31 implies that if the presumption can be rebutted then a cost based methodology should be used.

AASB staff reminded ACFA that the requirements in AASB 1 “First-time Adoption of Australian Equivalents to International Financial Reporting Standards” should be carefully considered as they specifically affect the application of Paragraph AASB 141.30. AASB 1 contains a requirement in its Implementation Guidance (Paragraph AIG 62.2) to the effect that an entity recognising a SGARA in full under AASB 1037 / AAS 35 must continue to recognise the asset at fair value less estimated point-of-sale costs under AASB 141 (that is the rebuttable presumption in AASB 141:30 cannot be applied). AASB 1037:5.1 and AAS 35:5.1 required a SGARA to be recognised when, and only when;

- it is probable that the future economic benefits embodied in the SGARA will eventuate, and,
- the SGARA possesses a value that can be measured reliably.
Accordingly, the only circumstances in which the rebuttable presumption would seem to able to be applied are as follows.

- When an entity did not previously recognise a SGARA under AASB 1037 / AAS 35 because it did not possess a relevant and reliable value.

- When newly acquired biological assets have not previously been accounted for under AASB 1037 / AAS 35. However, this could only be justified when the newly acquired biological assets are of a different type from other biological assets measured at fair value less estimated point-of-sale costs. This is because, before an entity rebuts the reliable measurement presumption, it must determine whether other entities with the same type of biological asset can establish a reliable measurement and therefore should recognise the asset at its fair value less estimated point-of-sale costs.

Paragraph AASB 141:32 notes that:

"In all cases, an entity measures agricultural produce at the point of harvest at its fair value less estimated point-of-sale costs. This Standard reflects the view that fair value of agricultural produce at the point of harvest can always be measured reliably".

ACFA suggests that volumes and unit values up to 20-50 years out cannot be measured, but they can be estimated, however not with the reliability accountants usually desire. Future expected volumes are estimated as precisely as they can be, and the longer the projection period the poorer the reliability of the predictions. Past trends in, for example, export sawlog prices are difficult enough to model and future trends are at best estimates, although sensible assumptions about price trends can be made and can be justified. ACFA suggests that a present value approach will commonly provide estimates of forest value that are more closely akin to fair value, or value in the market place, than a cost based approach.

It is relevant to summarise the bases of forest valuation as described in the May 2004 ACFA (also ACFA 2007) forest valuation standard, and as discussed earlier in this Handbook, in terms of the accounting standard.

The obvious thread through all the accounting standards and almost all aspects of forest valuation is the desire to measure fair value or Net Market Value (NMV), in essence the value that willing buyers and willing sellers would place on a forest entity, and therefore on the biological asset component, in an active and liquid market.

In early 2005 the IASB considered draft amendments to IAS 39 Financial instruments; recognition and measurement that included a new paragraph 48A which was subsequently adopted and is now incorporated in AASB 139. The bold section is for convenience and the bolding is not included in the standard.

"48A The best evidence of fair value is quoted prices in an active market. If the market for a financial instrument is not active, an entity establishes fair value by using a valuation technique. The objective of using a valuation technique is to establish what the transaction price would have been on the measurement date in an arm’s length exchange motivated by normal business considerations. Valuation techniques include using recent arm’s length market transactions between knowledgeable, willing parties, if available, reference to the current fair value of another instrument that is substantially the same, discounted cash flow analysis and option pricing models. If there is a valuation technique commonly used by market participants to price the instrument and that technique has been demonstrated to provide reliable estimates of prices obtained in actual market transactions, the entity uses that technique. The chosen valuation technique makes maximum use of market inputs and relies as little as possible on entity-specific inputs. It (a) incorporates all factors that market participants would consider in setting a price and (b) is consistent with accepted economic methodologies for pricing financial instruments. Periodically, an entity calibrates the valuation technique and tests it for validity using prices from any observable current market transactions in the same instrument (i.e. without modification or repackaging) or based on any available observable market data.”
The general intent of the draft paragraph is clear. It suggests that if there is commonly used methodology for the determination of fair value, then it is to be used. This would seem to support the contention by ACFA as to the most appropriate forest valuation methodologies.

ACFA considers that the question of whether forests can or cannot be considered a financial instrument is of little relevance as the comment is about fair value in a general sense. Discussions were held with AASB staff on this issue and they indicated that they support this view.

It is of passing interest to note that over 50 years ago the Society of American Foresters Forestry Handbook (1955) discussed the fundamentals of valuation and described market value in terms consistent with the above discussion.

“Market value is based on the evidence of transactions, similar in time and place, in which similar property was exchanged. The current market value of a property is the amount which a seller, who is willing and able but not compelled to sell, will accept for the property from a purchaser who is willing and able but not compelled to buy.”

It would seem that little has changed. It is only the detailed interpretations that have evolved.

12.4.5 Possible future direction of discussion of Fair Value

In February 2006 the International Accounting Standards Board (IASB) and the Financial Accounting Standards Board (FASB) of the United States of America published a Memorandum of Understanding reaffirming their commitment to convergence of both sets of accounting standards.

In November 2006 the IASB published a discussion paper on fair value (IASB 2006) that included a discussion paper as Part 1 and the USA standard SFAS 157 as Part 2. They requested comments by April 2007. As convergence discussions proceed this will obviously impact the various AASB standards in the future. It must be remembered though that at this stage the discussions and the concepts have no formal standing until revised AASB standards are promulgated.

IASB had already reached the preliminary view that SFAS 157 (IASB 2006 Part 2) establishes a single source of guidance that is an improvement on the disparate guidance in the various IFRSs. This indicates the direction that IASB might be expected to take in the future.

SFAS 157 has some interesting points including the following.

- The concept of using “exit price”, that is the value from the point of view of the seller rather than the buyer.
- The emphasis is on a market based measurement not an entity specific measurement. This may have implications for some forestry organisations who are more efficient than others for whatever reason.
- The value is basically the expected value for transfer in an orderly and knowledgeable market, and is not the amount used to settle liabilities.
- The current international standards appear to limit recognition of the difference between the initial transaction price and the value as determined by other valuation methodologies to only other observable current market transactions. The US standard would appear to be more flexible. This point will need to be considered when revising the ACFA standard in the future but only after revised international standards have been promulgated.
- The hierarchy of valuation methods described in this handbook and also the standard would need to be considered in terms of the forest valuation approaches. However at this stage it would seem likely that the changes will be minimal and of little real consequence.
- Valuing in the Highest and Best Use (H&BU) is specifically mentioned. There is an example quoted where land is currently used for commercial manufacturing but the H&BU might be as residential land. The situation is not unlike land currently managed as plantation forest,
compared with the possibility of it being sold for conversion to another use (for example dairying in New Zealand, or small acre farming). The relevant paragraph A11 states.

“In this instance, the highest and best use of the land would be determined by comparing (a) the fair value of the manufacturing operation, which presumes the land would continue to be used as currently developed for industrial use (in-use) and (b) the value of the land as a vacant site for residential use, considering the demolition and other costs necessary to convert the land to a vacant site (in-exchange). The highest and best use of the land would be determined based on the higher of those values.”

The parallels are obvious. This is the same approach as adopted in the revised ACFA forest valuation standard (ACFA 2007).

- There are likely to be changes to disclosure provisions.

It must be remembered that as at early 2007 this convergence was only under discussion and that until the AASB standards have been formally updated then the discussions can only provide indications of likely possible future changes. Change is expected to take some time.

### 12.4.6 Quoted Price in the market

If there is a quoted price in the market then this would be the most obvious valuation methodology. This is recognised in AASB 141.

“If an active market exists for a biological asset or agricultural produce, the quoted price in that market is the appropriate basis for determining the fair value of that asset. [AASB 141:17].”

However a quoted price is generally not available in Australia and so ACFA consider the method is not appropriate, although recognising that if there was such a price available then it would be an appropriate basis to use. Further, as will be commented later, the market for forests seldom meets the definition of an active market.

### 12.4.7 Transaction based approach

This is obviously the preferred approach. However it fails in practice for forest valuation in the Australian market for a number of reasons that include;

- the market is generally illiquid,
- forests are heterogeneous and two forests are almost never directly comparable, and,
- taxation implications affect Fair Value or NMV and different organisations may have different taxation implications leading to different valuations, although most organisations reporting under AASB 141 should be somewhat similar.

A major difficulty with the transaction based approach in Australia is that there is a lack of publicly available information to assess any transaction. Even if the transfer price is disclosed the various component effects are rarely available.

In essence this highly desirable approach is generally impractical for forest valuation. Known transactions should be taken into consideration in determining forest value, but transactions alone can never be used in the valuation of large forest entities in practice.

Members of the Australian Property Institute (Certified Practising Valuers) would seem to rely almost solely on a transaction based approach. However they are rarely involved with the sale of a large forest entity and then generally only in terms of the land base not the forest, the biological asset.
This would all seem to be sufficient argument to rebut the standard (paragraph AASB 141:30) and to reject a pure transaction based approach, and to thus predicate that other approaches should generally be used.

However it must be remembered that fair value is really expected transaction value. So if any transaction information is available then it should at least be used and compared with the value obtained from other valuation approaches.

### 12.4.8 Lump sum based approach

The lump sum value assumes that all the forest can be liquidated or sold at the point of valuation. It provides a useful value if the forest estate is mature and if it is small enough to be able to be harvested over a short period without affecting the market. The approach fails for a large forest because the size of the forest estate generally means that it cannot reasonably be expected to be immediately harvested without severely affecting unit prices, or because the volume harvested cannot be integrated with existing wood flows. Also, the approach generally ascribes a zero value to all young plantation stands that have yet to reach the age of the first commercial thinning operation although they are further advanced and closer to harvest than any just established plantation.

Lump sum value would seem to meet the point of paragraph AASB 141:32 in that the price at the valuation point can be measured reliably, but in fact should not be considered appropriate for anything other than small areas of forest and only then when they are approaching maturity. It would seem inappropriate for any entity reporting under the Corporations Act and using AASB 141.

The approach can be likened to valuing a farm by valuing the livestock on that farm and not by valuing the farm as an ongoing concern.

The term (or, as it is sometimes called, immediate liquidation value) is not mentioned in AASB 141 but in essence it is a simplified present value approach with clear felling at the date of valuation and therefore no discounting applied.

### 12.4.9 Present Value approach

Historically, present value or net present value methods have been used in forest valuation to determine the price that a seller may deem a minimum price or a buyer a maximum price. In valuing forests as ongoing entities the most common approaches have almost always been based on variants of Faustmann’s 1849 methodology (1995).

For a single stand it is sensible to discount the expected costs and returns to provide a value. For an ongoing forest entity it makes sense to value the land and trees combined in perpetuity and then to deduct the land (or any other non-biological asset) component to derive a value attributable to the trees, the biological asset. Wood flow considerations generally mean that stands cannot be considered separately but have to be considered together as part of an ongoing enterprise.

Further, the wood flows used in the PV approach could be either the wood flows that the models predict will be available or the wood flows that the enterprise is prepared to commit to longer term supply contracts. The latter is generally less than the former, in part to account for risk and uncertainty.

The May 2004 ACFA standard paragraph 6.3.5 “Planning horizon for NPV determination” was prepared after discussions with AASB staff (see also ACFA 2007). The phrasing recognised the concern that optimising a forest is not the same as optimising each stand in that forest. It therefore makes sense in valuing large ongoing forest estates to set one planning horizon for the whole forest rather than vary it for each stand. It is suggested that for these forests the Fair Value or NMV of the biological asset restricted by definition to the current rotation, may best be valued using PV over an infinite planning horizon and adjusting for land effects and other non-current asset effects.
PV remains the most commonly used, and seemingly most appropriate, methodology for determining fair value. PV does provide estimates of expected transaction value or, in essence, fair value.

### 12.4.10 Option based approach

The option based approach has not been widely used in forestry, and is not mentioned in any of the accounting standards. It can be considered as extension of the Present Value approach.

### 12.4.11 Cost based approach

Costs may provide a base for determining value for example for insurance purposes but they do not provide a valid base for determining a possible transaction price.

A high cost forest does not necessarily imply a high value forest and a low cost forest does not imply a low value forest, in fact commonly the opposite is true. Establishment costs are a function of soil physical characteristics, terrain, location relative to base, current vegetation, and the necessity for silvicultural treatments such as weedicide. Value is a function of site productivity, soil nutrient levels, location relative to markets, and growth rates, and prices paid for wood products. Inflating costs does not necessarily inflate value. Cost and value are only loosely related.

A cost based approach would rarely, if ever, approximate the expected transaction value in a liquid market.

The argument against the use of a pure cost based approach to determine NMV is compelling.

The earlier discussion on AASB 1 and AASB 141 should also be considered.

### 12.4.12 Particular cases

There are a number of particular circumstances that may need to be considered.

**Immature forests**

Immature forest estates and plantations often have no active or liquid market for the living trees because they are too young and the trees too small to be saleable. Present Value methods can often be applied to immature forest estates, and are generally appropriate for financial reporting.

In the event that an immature plantation of very young age has a negative Present Value, and the valuer is satisfied that the discount rate used is appropriate, the loss transfers to the Profit and Loss statement accordingly. Section 5.4.4 of the ACFA 2007 standard discusses negative values and should be considered. The client will presumably heed this when entertaining any future planting.

The current replacement cost method may be justified for insurance purposes (but not valuation of the biological asset) where written into the contract. In the case of plantations, living trees are commonly insured against fire damage up to an age at or about which they can yield saleable products, typically about 15-20 years for a radiata pine plantation depending on the circumstances. The basis of the insurance is that fire-killed non-living produce is generally unsaleable at these early ages because it is not possible to meet the strict minimum charcoal limits for chip. In this event, the insurer is generally liable for the compounded cost of establishment. Hence the compounded cost of establishment, or some agreed basis reflecting site productivity and costs, may be used to value immature plantations for insurance purposes. However this value does not take into account that any replacement forest would be considerably younger thus reducing the value of the whole enterprise.
This method should not be used for valuation of the biological assets because it does not conform to the underlying principle of determining the best estimate of fair value in an active and liquid market. This also serves to illustrate that AASB 141 is not always appropriate for all valuations.

**Intermediate cases**

Often forest estates do not meet the criterion for lump sum valuation; some because the tree size is too small, some because the biological assets cannot be harvested and sold in the space of one year, some because they are relatively newly established, perhaps in a relatively new area, and some because the age and/or size classes are not typical of the long term expectations.

Transaction data are especially lacking for these intermediate cases. The Present Value method can be applied, but on what assumptions, when no experience is available on the sale of the species in the particular area?

The tenor of AASB 141 indicates that the choice of assumptions must rest on the consultant’s judgment of the best indicator of fair value, together with sufficient disclosure of the assumptions, other than confidential data, to justify that choice.

**Privately owned native forests**

For native forests in Australia, the State agency concerned is often the dominant supplier because of the extent of publicly owned native forest managed for wood production and other uses. Markets for the sale of wood from privately owned forest might then become erratic in price and conditions because of ‘take or pay’ clauses attached to the State supply contracts or agreements. Similar problems may arise wherever one grower (native forest or plantation) dominates the market because of size of holding and contracts with purchasers.

The tenor of AASB 141 indicates that the choice of prices must rest with the valuer’s judgment of the best indicator of fair value, together with disclosure of the rationale. This may involve a reduction in price and/or a deferral of harvest from the optimum age, in order to recognise the realities of an uncertain and difficult market.

**Publicly owned native forests**

Most of the provisions pertaining to the Present Value method for large forests can be applied to publicly owned native forests managed for multiple uses that include wood production. These generally involve joint production of wood together with non-commercial uses and services and it is this mix of biological asset and non-current asset considerations that makes such valuations problematic.

**Multiple use constraints**

If the other uses of multiple use forests were commercial, there would be comparatively little problem in extending the principles already enunciated to cover the valuation of joint production of those uses. But most are not. In addition, knowledge of the inter-relationships between uses is commonly limited and it is therefore necessary to protect the supply of them by relatively arbitrary constraints and devices.

For example, in order to maintain natural genetic diversity, improved genetic stock cannot be used in many publicly owned native forests in Australia. More reliance is placed on natural regeneration or the use of planting stock raised from local seed. Rotation lengths are extended well beyond the economic optimum for wood production in the interests of maintaining a diversity of structural ecosystems and communities, and associated habitat for fauna. Silvicultural systems may be modified in places to protect scenic, habitat or conservation values, clear-felling systems being modified strongly or replaced by selections systems. Habitat or nesting trees have to be retained for
fauna protection, to the potential detriment of the growth of trees in the immediate vicinity containing or producing commercial wood. The quality of water production is protected by buffer strips in which harvesting is not allowed along streams and rivers and by amelioration measures following the completion of harvesting along snigging trails and on landings. In recent times an increasing area of previously production forest has been transferred to national park status, with an associated reduction in the volume of wood available for harvest. The aggregate quantities of wood to be removed from a region should be modified to ensure sustainability of supply.

**Present Value may be circular for publicly owned native forests**

As a result of the constraints imposed on the management of publicly owned native forests, the forest manager is no longer free to choose the most economically efficient manner of operation. The future pattern of wood production flows and cash flows do not reflect the entrepreneurial choice that might maximise the value of the forest as a producer.

Any valuation based on Present Value is therefore circular in that it simply reflects the planned pattern of regulated multiple use of that forest, not the optimum value when used for wood production alone under minimal constraints. Notwithstanding this circularity, the Present Value of wood production in a multiple use forest may provide a useful comparison over time that summarises any changes to the regulatory conditions, as well as to other conditions affecting wood production.

It does not, however, provide any useful guidance as to the return on capital investment, either singly for wood production or for other or all uses, because of the strictly derivative nature of the Present Value, given the net revenue flows.

**Disclosure of constraints for native forests**

AASB 141:Aus49.1 recognises the issue of constraints imposed on native forests, especially on publicly owned forests, and requires an explicit statement of the constraints and an additional valuation that sets out the fair value in the absence of these restriction(s). The clause states that;

> “An entity shall disclose biological assets for which an entity’s use or capacity to sell is subject to restrictions imposed by regulations or other external requirements that have a significant impact on their total fair value less estimated point of sale costs. The total and restricted amounts of those biological assets shall be disclosed, together with the details of the nature and extent of those restrictions.”

ACFA notes that AASB 141:Aus49.1 clearly requires the total and restricted values to be disclosed and ACFA recognises that determination of the total unrestricted value may be difficult. If specific inventory data are not available for the restricted areas (for example buffer strips, wildlife corridors, local reservations for endangered or area species, landscape values etc.) and trees (for example clumps of habitat trees), ACFA recommends that estimates of fair value be based on estimates of areas concerned and the annual cash flows foregone, based on those in adjacent commercial forest, adjusted for site or species differences. The restrictions placed on rotation length pose major problems of rescheduling wood flows. These, and restrictions on the scale of operation (for example coupe size), may be problematic to evaluate.

ACFA recommends that all restrictions be documented and disclosed. Given that these are generally laid out in regulations this is generally not difficult. ACFA believes that in some cases it may not be possible to reasonably quantify the unrestricted value of the forest, although the restricted value can be reasonably determined. In these cases ACFA suggests that the effect of the restrictions be noted and discussed together with a comment that this does not meet the specific wording of paragraph Aus49.1. Thus the restrictions are disclosed but not necessarily their effect on value.

ACFA has been advised that in the future the AASB believes that it is unlikely to issue specific paragraphs with the Aus prefix, relying totally on the IAS standard. If this occurs then this particular
issue may be at least partly resolved as AASB 141.49 does not specifically require the unrestricted value to be disclosed.

For most entities the issue remains only partly resolved.

**Leased forests**

Leases which effectively transfer substantially all of the risks and benefits pertaining to ownership of the land to the lessee, except actual ownership, are to be treated as finance leases under AASB 117. In effect they are treated as if the lessee had purchased the asset and borrowed the funds. The initial present value of the minimum lease payments is disclosed as an asset and as a liability in the first year of the lease and thereafter the asset value is depreciated in the normal way. The (non-current) liability is adjusted annually by a reduction equal to the implied interest expense while any remainder of the minimum lease payment is shown as a direct expense, as are any contingent rents.

Leases in which the lessor effectively retains much of the risks and benefits pertaining to the land, such as certain types of sharing and joint venture arrangements, are treated as operating leases under AASB117. These do not appear as assets or liabilities in the Statement of Financial performance of the lessee because the assets are not effectively owned by the lessee. For these, the minimum annual lease payments are recognised as a direct expense, as are contingent rents.

Thus, regardless of the form of lease, the lease payments are recognized independently of the valuation of the combined asset, which still draws its intrinsic value from both living trees and land, notwithstanding the legal separation. It is therefore appropriate to value the combined asset in the same manner, regardless of ownership, and to use the annual gain or loss in present value of the combined asset as the appropriate amount for the Income and Profit or Loss Statements.

**Joint venture and share farming forests**

In the case of joint venture forest estates, the normal method of valuation will be to deal with the forest as a whole and then to apportion the Present Value in accord with the terms of ownership in the joint venture.

Similarly for share farming, although in this case the apportionment of value between the parties will probably require individual calculation of Present Values for each party, given that the cost and revenue stream are often borne unequally and at different times.

There may be a difference between the value determined under the share farming or joint venture contract and the value that would be determined by the market if there were no such share farming or joint venture. Such differences should be detailed, discussed and documented.

**12.4.13 Summary**

In the recent past an interpretation of AASB 1037 (and AAS 35) might have been implied that if all current stands were discounted for the current crop, a PV would be obtained that was considered an appropriate proxy for NMV or Fair Value for use in determining the change figure to be reported in the Profit and Loss statement.

The May 2004 ACFA standard proposed this as an option while also suggesting that the Fair Value or NMV may also be approximated by calculating PV over infinite rotations and adjusting for land effects. In discussions held in 2004 this was considered a possible approach by AASB staff.

AASB 141 is a little more difficult to interpret and use. The ACFA 2007 standard provides guidance that might be as sound as can be achieved at present.

It would appear that an objective of introducing the international standard was to improve international understanding and facilitate comparisons, but as Herbohn (2005b) notes:
“the irony is that international harmonization of accounting standards may, in the case of IAS 41, actually decrease comparability between reporting entities because of the judgement necessary to estimate fair values of timber assets in the absence of active and liquid markets”.

Doubts have been expressed about the efficacy of applying the new standard.

Herbohn also noted (2005b) that IAS 41 (and hence AASB 141) has been criticised for being too academic, for introducing inappropriate measurement methods for biological assets, and for producing potentially misleading information. Herbohn also reported that respondents to the various draft documents had suggested that there was potential for manipulation of the information.

It is hoped that the ACFA forest valuation standard (2007) might help alleviate some concerns. ACFA believes that a practical, useful, interpretation of AASB 141 based on the generalised comment taken from AASB 141:20. might be achieved.

“In some circumstances, market-determined prices or values may not be available for a biological asset in its present condition. In these circumstances, an enterprise uses the present value of expected net cash flows from the asset discounted at a current market determined pre-tax rate in determining fair value.”

This would seem to fit with the methodology defined in the May 2004 ACFA standard, and might enable the forest value as used to determine the annual change to be accounted for in the financial reports to more closely approximate fair value or NMV as considered likely to pertain in the market place.

In mid 2004 it appeared that the implementation of AASB 141 might have created some difficulties that were incapable of resolution.

However paragraph AASB 139.48A appears to support the views of ACFA as to the most appropriate methodologies to be adopted in valuing commercial forests in that it states that:

“If there is a valuation technique commonly used by market participants to price the instrument and that technique has been demonstrated to provide reliable estimates of prices obtained in actual market transactions, the entity uses that technique.”

While that standard is not specifically relevant to forest valuation but to financial instruments, it would seem that the thrust of the paragraph is relevant and appropriate. AASB staff concur with this view.

This situation continues to evolve. In May 2004 “An Australian standard for Valuing Commercial Forests: Version 1” appeared to be completely consistent with AASB 1037 and AAAS 35. In January 2005 ACFA issued a supplement to the standard that was believed to be a satisfactory interpretation of the initial version of AASB 141; a revised version has been released. The latest version of the ACFA forest valuation standards, released in 2007, is the most current interpretation consistent with AASB 141.

Changes to AASB 141 will continue to be released. Insofar as they may impact upon the discussion in this section, and the ACFA forest valuation standard, it is considered necessary to be continually watchful.

12.5 A hierarchy of valuation methods

The AASB 141 standard provides a number of indications about the methodology to be adopted in carrying out a forest valuation.

AASB 141:30 states in part that;

“There is a presumption that fair value can be measured reliably for a biological asset” and later the same paragraph states “that biological asset shall be measured at its cost less any accumulated depreciation and any accumulated impairment losses. Once the fair value of such a biological asset becomes reliably measurable, an entity shall measure it at its fair value less estimated point-of-sale costs”.

As at 2007, reformatted 2012 but no textural changes
AASB 141:17 states that:

“If an active market exists for a biological asset or agricultural produce the quoted price in the market is the appropriate basis for determining the fair value of that asset”.

ACFA does not believe that quoted prices are available in all situations although quote prices are available from time to time for products, for example the Australian Pine Log Price Index (APLPI). ACFA recognises that such values, if available, should be used wherever possible.

The next paragraph, AASB 141:18, suggests three alternatives if an active market does not exist; the most recent transaction price, the market prices for similar assets with adjustments to reflect differences, and sector benchmarks. AASB 141:19 accepts that the values so derived from these alternatives may not be consistent and suggests that an entity needs to consider the reasons for the differences before determining fair value.

AASB 141:20-23 discusses Present Value methodology. It states that the “present condition of a biological asset excludes any increases from additional biological transformation”. Some have implied this to mean that growth cannot be allowed for. In intensively managed forests the expected growth that results from planned future application of fertiliser or thinning is considered part of the wood flow analyses and therefore the PV analysis. IFRIC is understood to have been asked to address this issue but at present no clarifying ruling has been made publicly available. Certainly an analysis that excludes these silvicultural effects would not provide expected wood flows, and hence cash flows, that would match practical forest management common sense, nor management anticipation.

ACFA recommends that future growth be taken into account, consistent with the emphasis on estimating the biological asset component of the fair value of the entity as a going concern.

AASB 141:24 states that cost may sometimes approximate fair value.

AASB 141 does not specifically mention the use of lump sum approach, sometimes called the immediate liquidation method, although it is in essence a simplified present value approach, an approach which is mentioned.

From these paragraphs ACFA observes that AASB 141 discusses a range of methods and outlines a hierarchy by the paragraph order. A hierarchy is desirable given that AASB 141:19 recognises that the various values derived may not be consistent.

AASB staff have advised ACFA that IFRIC had agreed in May 2004 to recommend to the IASB that inter alia it should establish a fair value hierarchy that is consistent with the various other standards.

At the time of preparation of the accounting standard no comments seemed to have been made available by IFRIC or IASB and so, as it would take some time for these to become part of AASB 141, it was considered that ACFA should tentatively develop an interpretation of the implied hierarchy.

The new paragraph AASB 139:48A is fully reported earlier and includes the following points.

- The best evidence of fair value are quoted prices in an active market.
- If the market for a financial instrument is not active, an entity establishes fair value by using a valuation technique.
- The objective of using a valuation technique is to establish what the transaction price would have been on the measurement date in an arm's length exchange motivated by normal business considerations.
- Valuation techniques include using recent arm's length market transactions between knowledgeable, willing parties, if available, reference to the current fair value of another instrument that is substantially the same, discounted cash flow analysis and option pricing models.

Finally and importantly the paragraph states that:
“If there is a valuation technique commonly used by market participants to price the instrument and that technique has been demonstrated to provide reliable estimates of prices obtained in actual market transactions, the entity uses that technique.”

The paragraph also suggests making maximum use of market inputs, minimising entity specific inputs, recalibrating the methodology periodically, and also periodically testing its validity.

Based on all the considerations ACFA believes that it is possible to determine an appropriate hierarchy of valuation methods.

ACFA believes that in practice almost all transactions by prospective buyers or sellers are based on PV analyses or on lump sum analyses if the forests are small in area and are mature. The following summarises the hierarchy expressed in AASB 141.

- **Quoted price method.** Not appropriate as quoted prices do not exist.
- **Transaction method.** There are few transaction method outcomes that are publicly available. Need to take into account the number and appropriateness of any available transactions.
- **Lump sum method.** Should be restricted to small forests approaching maturity. The method generally fails for large forests because the market cannot reasonably take all the wood immediately, and without impacting prices. It is recognised that this method is a special case of Present Value methods.
- **Present Value methods.** Recognises the need to document, disclose and discuss all the issues, especially discount rates, inflation considerations, and the costs and returns used. Option pricing may be relevant.
- **Cost based methods.** Should generally be restricted to young plantations. The cost of insurance may be also be an option.

In 2006 the International Accounting Standards Committee Foundation issued a document entitled “Basis for Conclusions” that included amendments up until 31 December 2005. Until this is considered by AASB and changes made to AASB 141 it has no official standing but it is of interest to note that paragraph B29 states that “The Board considered setting an explicit hierarchy in cases where no active market exists” and in paragraph B30:

“The Board concluded that a detailed hierarchy would not provide sufficient flexibility to appropriately deal with all the circumstances that may arise and decided not to set a detailed hierarchy in cases where no active market exists. However the Board decided to indicate that an entity uses all available market-determined prices or values since otherwise there is a possibility that entities may opt to use present value of expected net cash flows from an asset even when market-determined prices or values are available.”

ACFA interprets this to imply some flexibility in determining the most appropriate method to be adopted and considers that until IASB and then AASB issue a revision of the AASB 141 standard that includes a more rigidly detailed hierarchy of methods to be adopted, that this hierarchy should be considered as the basic hierarchy. An entity then determines which methodology to adopt. The higher ranked methods in AASB 141 should be considered and reasons for not using them should be clearly discussed and documented in any forest valuation report. ACFA believes that such a discussion may be brief but suggests that it is necessary in order to meet the requirements of AASB 141.

### 12.6 A possible implementation protocol

The following is an implementation protocol that would seem to be completely consistent with AASB 141 and other AASB standards, uses appropriate values for the forest (living trees or biological asset according to the strict accounting definition) and the land, allows that the land and the trees are inextricably linked in an ongoing forest enterprise, and allows for the possibility that there may be a higher and better use for that land than as forestry.

As at 2007, reformatted 2012 but no textural changes
For simplicity the description of this protocol will use a pseudo-equation approach. Now if it is assumed that;

- \( BC_{pre} \) = Value of current biological asset, i.e. current crop only, calculated pre-tax,
- \( BC_{post} \) = Value of current biological asset, i.e. current crop only, calculated post-tax,
- \( BT_{pre} \) = Value of total biological asset, including future rotations and replanting of fallow new land etc., calculated pre-tax,
- \( BT_{post} \) = Value of total biological asset, including future rotations, calculated post-tax,
- \( Lf \) = Land value as forest,
- \( Lh \) = Highest and best use value of land (\( Lh \geq Lf \)),
- \( Vs \) = Salvage value of forest if clear felled today, including clearing costs to convert to best alternative use,
- \( Iv \) = Value of intangible assets, and,
- \( Nv \) = Value of other non-current assets.

The protocol is based on a number of different premises.

- The biological asset (\( BC_{pre} \)) is defined (AASB 141:21) as the current crop only.
- The biological asset (\( BC_{pre} \)) is to be valued pre-tax according to the AASB 141 standard.
- The biological asset is to be valued at fair value (which can be interpreted as expected transaction value), and if that is not possible then Present Value (PV) as stated in AASB 141:21, or if that is not possible then it is to be valued based on cost as stated in AASB 141:24. The lump sum approach is a variant of PV.
- The protocol needs to meet the literal wording of the AASB 141 standard.
- The protocol needs to provide a fair value of the combined asset that matches expected transaction price, (or fair value or market value).
- In the protocol wood flows should be based on the silvicultural management strategy that the forest manager would currently determine as appropriate.
- The planning strategy should therefore be based on current supply contracts, planned forest management strategies and current forest expectations. This may be difficult for smaller forests.
- The protocol requires the separation of wood flows (and associated costs) into (\( BC \)) and (\( BT-BC \)) components to determine the value of both the current and subsequent rotation components. This is possible in some extant forest planning systems but if it is not currently possible then these other forest planning systems can probably be modified relatively simply.
- In general the analysis should be based on a planning horizon greater than the longest planned rotation length for the current forest. This also presupposes that the forest will be replanted as an ongoing management strategy. If this is not the case then the analysis should reflect the expected strategy, replanting or not.
- The protocol needs to consider the termination value of the forest (living trees) at the end of the planning horizon. This could use the lump sum method as the discounting period will minimise any possible distortions.

The AASB 141 standard specifically excludes expected future biological transformation but the wood flows modelled by most forest managers would normally include (for example) fertiliser responses and thinning effects from future treatment as this is what the organisation would plan as its forest management strategy. An argument could be contrived that this does not match the precise wording of the AASB 141 standard and that these effects should be excluded, but this does not make practical forest management sense and would not match expected practice. An alternative argument could
also be developed that it is impossible to determine just what “future biological transformation” means and that until AASB/IASB determine just what silvicultural management activities are considered to effect future biological transformation, and what are not, that all currently planned silvicultural activities should be considered appropriate. On balance ACFA believes that until this is clarified that the wood flows should be based on the strategy the enterprise plans to adopt.

ACFA prefers that this analysis be based on a post-tax discount rate so that the forest value better matches the expected transaction value. The analysis can therefore be used to determine BTpost. This matches the current practice for many forest enterprises of reasonable size that are in the business of ongoing forest management. The value of BCpost can then be separated out relatively simply.

The taxation effect could be estimated using a pre-tax rate on the post-tax wood flows to determine BCpre or could be determined almost arbitrarily. However the desire for the fair value to be based on post-tax analysis and the requirement that the change in value of the living trees that is to be included in the Profit and Loss statement is to be based on pre-tax analyses necessitates that taxation be considered.

Now

$$ BT_{post} = BC_{pre} + (\text{taxation component}) + (\text{subsequent rotation component}) $$

and so, in this simplified protocol, it is possible to determine the major components. The sum of the two bracketed components is probably a better estimate than the individual bracketed estimates but, as will be discussed later, this may or not be important.

**Determination of highest and best use**

In an ongoing forest enterprise the forest and the land are inextricably linked, so it is necessary to consider the value of either the combined forest and land entity or the sum of the two separate components values assuming conversion to another land use.

The valuation of an asset is based on the premise of using the highest and best use as the benchmark, as the Australian Guidance Note G2 to AASB 116 sets out “…The fair value of an asset is determined by reference to its highest and best use, that is, the use of the asset that is physically possible, legally permissible, financially feasible, and which results in the highest value...”.

The fair value of forest if managed as forest (FVf) is based on the combined forest and land asset and is therefore

$$ FVf = Lf + BT_{post} + (Iv + Nv) $$

The fair value in an alternative highest and best use (FVa) is also based on the combined forest and land asset but as two separate components, and is

$$ FVa = Lh + Vs + (Iv + Nv) $$

In this case the value of the forest component (the living trees or biological asset as defined in the ACFA 2007 standard) is the salvage value of the forest adjusted for the cost of salvage.

Now if (FVf>FVa) then the fair value is FVf, and the enterprise would expect to maintain the combined asset as forest. If (FVf<FVa) then the fair value is FVa, and the enterprise would seriously consider converting to the alternative highest and best use, or possibly selling the combined asset off at this higher value.

This protocol ensures that the selection of highest and best use is based on the highest combined value. This matches the ACFA 2007 standard. It also makes practical common sense. This approach does not appear to be contrary to anything in AASB 141 or any other AASB standard. It accepts that in an ongoing forestry enterprise the two components are inextricably linked.
Determination of Fair Value or NMV

Now the fair value (FV) of the combined forest and land entity is therefore

\[
FV \equiv NMV = \text{Max}(FV_f, FV_a)
\]

Value for the Profit and Loss statement and Other Financial Statements

There are two alternatives that must be considered depending on whether FVf or FVa is the higher figure.

If (FVf > FVa), then the assumption is that the enterprise will remain an ongoing forestry enterprise.

According to AASB 141 the annual change in BCpre is included in the Profit and Loss statement, the value being based on the current rotation only, and the analysis is carried out pre tax.

Now (BTpost – BCpre) has basically two components, the taxation component and the subsequent rotations component both of which can be treated as non-current assets, so both can be reported in the financial statements. Any error in the separation therefore has little effect on the overall financial performance.

In this gross over-simplification the non-current asset components are as follows;

- Taxation component of (BTpost – BCpre),
- Subsequent rotations component of (BTpost – BCpre),
- Iv, and,
- Nv.

The land value that is reported is Lf. It should be noted that the land value is not reported as Lh even if (Lh > Lf) as the highest and best use of the combined asset is as forest.

For completeness BCpre and BTpost can be reported in a note.

If this protocol is followed then the value reported in the Profit and Loss statement is completely consistent with the AASB 141 standard, the fair value reported is the expected transaction value, and the land value reported is the appropriate land value in the highest and best use.

The alternative consideration is if (FVa > FVf) and as the highest and best use of the combined asset is not forest then the reporting is somewhat different.

The land value that is reported is Lh.

The Profit and Loss statement could show the change as (Vs – BCpre(last year)) which could well be negative and quite considerable. This would also have taxation implications that would need to be addressed. AASB 112 may need to be considered. The financial statements would need quite detailed notes to explain the changes in management strategy and the accounting treatment. The owner would obviously consider converting or selling.

This alternative is also consistent with AASB 141 and it is based on conversion to the highest and best use based on the combined value. It also is consistent with the ACFA 2007 standard and also makes practical common sense.

Summary

The protocol appears to be completely consistent with the AASB 141 standard and is also believed to be consistent with other AASB standards. The value reported in the Profit and Loss statement matches the idiosyncrasies of the AASB 141 standard. The best estimate of fair value (or NMV or expected transaction value) will be reported in the financial statements. The land value reported will be according to the highest and best use based on either the combined land and living trees (the forest) asset if the entity is managed as an ongoing forestry asset, or as the two separate
components if the highest and best use is in some alternative use. The protocol recognises that the highest and best use of the combined land and forest asset may not be as forest. The components in the financial reports all are consistent.

The protocol avoids the difficulties with the simple deduction method where the forest value is determined by subtracting the land value from the fair value, a procedure which fails because in an ongoing forest entity the land and the trees are inextricably linked.

12.7 An alternative description of the implementation protocol

Because the forest is inextricably linked to the land, the determination of what is the highest and best use must be based on a consideration of the combined value of the land and the biological assets.

It may be necessary to determine two possible values in order to determine the highest and best use of the combined asset. One would be to value the land in an alternative highest and best use for that bare land, and to add the salvage value of the forest (based on the lump sum method) including the costs of converting the land to that alternative land use after clearing. The other would be based on ongoing use as forestry where the land value would be the land value as forest and the biological asset value would most likely be based on a Present Value analysis of the current crop and also any subsequent rotations. The highest and best use is determined by which of the two figures is the higher.

If the highest and best use of the land is as forestry then it is important to ensure that the components in the financial reports are all consistent and sensible; including the fair value or Net Market Value, the land value, and the biological asset value on which the change in biological asset value reported in the profit and loss statement is based.

One recommended approach to achieve this is as follows.

1 Optimise the present value of the combined asset by mathematical programming or simulation to determine the best schedule of wood flows over an extended planning horizon for both the current and future tree crops. This provides the fair value (or NMV) of the combined asset and approximates the expected transaction value if the asset would be sold. This should be based on post-tax analysis.

2 Segment the cash flows in (1) into those that relate solely to the Living Trees (the biological asset as defined in AASB 141) and the value of the Subsequent Rotations. This biological asset value is used to calculate the annual change in the value which goes into the income statement and hence the profit and loss statement (see also earlier). AASB 141 states that this analysis should be pre-tax, whereas ACFA believes this should be post-tax. AASB is currently reviewing this but have yet to provide a definitive interpretation. In the interim it is suggested that entities clearly document the tax basis used in their valuation analysis.

3 Determine the value of land and improvements and bring to account as a non-current asset under Property, Plant and Equipment.

4 Deduct this value from the present value of the combined asset (see (1) above) to derive the present value of the biological asset (as specifically defined under AASB 141), or the Living Trees, and also the Subsequent Rotations.

5 Deduct the value in (2) above from this to bring to account the present value of this Subsequent Rotations asset under Property Plant and Equipment.

6 If the discounting in (1) and (2) is not based on pre-tax discount rate, ensure that the taxation effects have been appropriately brought to account without double counting, see AASB 112. Where AASB 141 applies a pre-tax rate must be used.
Where the land is owned by the reporting entity, periodic revaluations of the land will be required, both in its alternative highest and best use and in its use for forestry, and these should be disclosed in notes to the financial reports but should not be shown as non-current assets under Property Plant and Equipment to avoid double counting.

This approach is, in essence similar to the previous section, it is just the description that differs. This approach is also described by Ferguson and Leech (2007).
13 Carrying out a forest valuation

The concept of value is universally well known and at the same time the exact definition is elusive. Economists deal extensively with personal and social behaviour patterns surrounding value and for them it is a target point at which individual choices are aimed. Accountants deal with tracking and presentation of value concepts and for them value is almost universally identical to historical transaction price expressed in currency terms. In forestry the long time spans and the nature of the asset mean that neither concept is appropriate on its own.

Value in the sense used in this Handbook, and in the standard (ACFA 2004) concurrently being revised (ACFA 2007), is market value or NMV, or fair value as used in AASB 141. In essence it is the expected transaction value if the entity was to be sold.

Valuation is basically the process of establishing, by conventional calculation, a single number expressed in currency that is a surrogate for the market price expected on sale of the asset. The process should contain any procedure that increases the realism of the valuation as a surrogate for market price.

AASB 141 separates the forest enterprise into the biological asset and the non-biological asset components and the accounting treatment of the two types of components is different. The expected transaction value for an enterprise incorporates both types of components. Therefore the expected use of a forest valuation is critical in determining what methodology is appropriate.

13.1 Simple economic formulae

There are a number of formulae that are basic to any economic Discounted Cash Flow (DCF) or Present Value (PV) calculation. As many calculations are carried out in spread sheets these formulae are often used without fully understanding the relatively simple mathematics that underlies the calculations. The formulae are commonly attributed to Faustmann (1849 [1995]).

Most economic calculations are carried out in spreadsheets or other packages and it is necessary to ensure that the calculations are carried out in the manner desired. One issue is whether the costs or returns should be discounted from the start or the end or the middle of each year and it is not unknown to find that a calculation should have been adjusted by one year’s discounting. Confirming the calculations is essential if the forest valuation is to be defended, especially if it may have to be defended in court.

13.1.1 Simple or compound interest

Simple interest assumes the same amount of interest is obtained each year. For example if a capital value of $100 gains 5% simple interest each year for 6 years then the asset becomes $130.00 ($100.00 + 6 * 0.05 * 100.00).

If the interest is compounded, in essence the money being reinvested, then the amount becomes $134.01, based on the calculation:

\[ \text{\$134.01 = \$100.00 \times (1.05^6)} \]

This latter method is the more appropriate. Simple interest is almost never used in forest valuation.

13.1.2 Interest rates

By convention the discount rate is normally described or depicted as 1.0i where “i” represents the percentage rate to be applied. Hence 5% is represented as 1.05, the equivalent multiplier for the calculation. If “i” is greater than 10%, for example 13%, then the rate is 1.13, not 1.013. The depiction is not strictly speaking mathematically correct but is accepted common practice.
There is a simple formula to convert a nominal interest rate to the real interest rate taking account of the inflation rate. Conversion from one to the other should be carried out by the formula;

\[ i_r = \frac{(1 + i_n)}{(1 + d)} - 1 \]

or

\[ 1.0i_r = 1.0i_n / 1.0d \]

where the rates are proportions, not percentages

- \( i_r \) = real rate
- \( i_n \) = nominal rate
- \( d \) = inflation rate

or

\[ 1.0i_n = 1.0i_r * 1.0d \]

and

\[ i_n = (1 + i_r) * (1 + d) - 1 \]

The simpler formulation

\[ i_r = i_n - d \]

or

\[ i_n = i_r + d \]

provides only an approximate result, with decreasing reliability as the product of the two interest rates (\( i_r * d \)) increases. Its use, although not uncommon, is not recommended.

### 13.1.3 Discounting formulae

To discount a cost or return to an earlier time “\( n \)” years earlier the formula is:

\[ P = \frac{V}{(1.0i)^n} \]

where

- \( V \) = the value being discounted,
- \( i \) = the interest rate,
- \( n \) = the number of years the value is being discounted for, and,
- \( P \) = the equivalent value \( n \) years before.

This simple formula can be used to derive the other formulae for discounting repeatedly recurring values (costs or returns) to any base year.

**Single value at age \( n \), one rotation**

The formula is

\[ P = V \left(\frac{1}{1.0i^n}\right) \]

**Single value at age \( n \), infinite rotations**

If the value occurs at age \( n \) in the first rotation and the rotation length is \( r \) then the formula is

\[ P = \frac{V}{1.0i^n} \left(\frac{1.0i}{1.0i^r - 1.0}\right) \]

This can be derived from first principles.

\[ P = \frac{V}{1.0i^n} + \frac{V}{1.0i^{n+r}} + \frac{V}{1.0i^{n+2r}} + \ldots \]

or

\[ P = \frac{V}{1.0i^n} \left(1 + \frac{1}{1.0i^r} + \frac{1}{1.0i^{2r}} + \ldots\right) \]
now if
\[ k = \left\{ 1 + \frac{1}{1.0^i} + \frac{1}{1.0^{2i}} + \ldots \right\} \]

then
\[ k(1.0^i) = 1.0^i \times \left\{ 1 + \frac{1}{1.0^i} + \frac{1}{1.0^{2i}} + \ldots \right\} \]

and by subtraction and reassignment
\[ k = \left\{ \frac{1.0^i}{1.0^i - 1.0} \right\} \]

and hence
\[ p = \frac{V}{1.0^m \left\{ \frac{1.0^i}{1.0^i - 1.0} \right\}} \]

**Annually recurring value, one rotation**

If each of the annual values are separately discounted then
\[ p = V \left\{ \frac{1}{1.0^i} + \frac{1}{1.0^{2i}} + \ldots \frac{1}{1.0^{i-s}} + \frac{1}{1.0^i} \right\} \]

and therefore
\[ p(1.0^i) = V \left\{ 1 + \frac{1}{1.0^i} + \frac{1}{1.0^{2i}} + \ldots \frac{1}{1.0^{i-1}} \right\} \]

now by subtraction and reassignment
\[ p = \frac{V}{i \left\{ \frac{1.0^i - 1.0}{1.0^i} \right\}} \]

**Annually recurring value, infinite rotations**

Now as \((1.0^i)^s\) increases the section in brackets approaches 1.0 and hence
\[ p = \frac{V}{i} \]

**Generalised calculation, multiple rotations**

A generalised formula is possible allowing a generalised time line for ongoing reafforestation of a site with the first rotation values being different from second and subsequent rotations.

If the time line has

- \(s\) = the number of years from the first rotation establishment year,
- \(n\) = the age into the first rotation that the value \(V_1\) occurs at, and also, the age into the second rotation that the value \(V_2\) occurs at,
- \(r\) = the rotation length,
- \(f\) = the fallow period between rotations, and,
- \(A_1\) = the annual maintenance charges to be applied to for all years from base year to the clear felling of the first rotation, and,
- \(A_2\) = the annual maintenance charges to be applied to for all years from the clear felling of the first rotation.

This time line can be represented as:

\[
\begin{array}{cccccc}
\text{yr} & 0 & 1 & 2 & 3 & \ldots \\
\text{first rotation} & s & n & r & n & \ldots \\
\text{fallow} & f & f & f & f & \ldots \\
\text{second rotation} & r & n & r & n & \ldots \\
\text{fallow} & f & f & f & f & \ldots \\
\text{third rotation} & r & n & r & n & \ldots \\
\end{array}
\]

As at 2007, reformatted 2012 but no textural changes
If this time line is appropriate then only two formulae are required

\[ P_1 = V_1 \left( \frac{1.0}{1.0^{n_f}} \right) + V_2 \left( \frac{1.0}{1.0^{n_f}} \right) \left( \frac{1.0}{1.0^{n_f} - 1.0} \right) \]

\[ P_2 = \frac{A_1}{i} \left( \frac{1.0^{n_f} - 1.0}{1.0^{n_f}} \right) + \frac{A_2}{i} \left( \frac{1.0}{1.0^{n_f}} \right) \]

and from these it is possible to carry out almost all desired calculations.

It is relatively easy to use the preceding formulae and similar derivation methods to develop formulae for any other circumstances, for example differences in the years different annual maintenance costs are applicable, and differences between second and third rotation costs.

### 13.1.4 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the interest rate or discount rate at which the Present Value (PV) of a series of costs and returns is zero.

Microsoft Excel© provides a function (IRR) which will calculate the IRR for a series of values discounted to the first element but assumes that each successive element in the vector is an exact multiple of the period (generally years) and that the discount rate has been modified if necessary to match the period. The function assumes that the period is in equal units of time.

If the costs and returns are not periodic but at particular dates then Excel provides a function

\[ \text{XIRR} \text{(range of values, range of dates, initial guess)} \]

that facilitates the calculation of the internal rate of return. The first value must be the base date for the calculation but this can be dummyed in with a zero cost/return if necessary.

The discount rate returned is the annual discount rate but, for at least some versions of Excel, the calculation assumes (see the Excel Help file) that each year has 365 days and does not allow for leap years (it should be approximately 365.25) so the function is slightly biased when used for a number of years. This may or may not be important. If this issue might be important then check the version of Excel being used to determine whether this analysis holds for the version being used and whether action might need to be taken.

One alternative to is use years as days and use an equivalent daily interest rate, but the possible confusion that the analysis might cause needs to be considered.

There is also a function MIRR that allows for reinvestment of cash returns, but this feature is rarely needed for forest valuation analyses.

If such spreadsheet or other functions are used then it is necessary to ensure that the analyst knows exactly what the calculation method is really doing in order to be able to ensure that it is being applied correctly. Often it is safer to do the calculation within the spreadsheet using first principles just to ensure that the calculations can readily be justified.

### 13.2 Some spreadsheet tips

Most simple forest valuations are carried out using spreadsheets, predominantly Excel© from Microsoft. This is probably the most used spreadsheet package. It may take some time to become proficient in the use of a spreadsheet package but the time is generally well spent.

Microsoft provides a web site for Microsoft Office Online that enables particular subjects to be searched for to determine if particular problems have been raised by others, and solutions provided, generally by a member of the “Microsoft Most Valuable Professional” group of people. The web site as at 2006 was;

As at 2007, reformatted 2012 but no textural changes
The web site below provides a forum in which questions and answers can be posted. It can provide very useful assistance.

http://support.microsoft.com/newsgroups/default.aspx

This section aims to provide some useful tips that are relevant to the use of Excel for forest valuation. It is not intended to be complete.

### 13.2.1 Useful Functions

#### Goal Seek

The “Goal Seek” function in Excel allows the outcome of a calculation, generally an equation that may be quite complicated, to be set to a particular value, allowing one of the cells involved in that calculation to be changed. This can be very useful if the discount rate to be used in a discounted cash flow is not known. In essence in this case it can provide the internal rate of return.

However it may be that the interest rate is divided into two components, one fixed and one that the analyst wants to allow to vary. Two cells can be set up with the two interest rates, which initially might be the same, but one of can then be allowed to be estimated using goal seeking by setting the result of the discounted cash flow to a particular value.

Another example is where an equation is used to calculate upper stand height (in one cell) based on age and site potential or site index (in two other cells) then goal seek can be used to determine the site index based on knowledge of the actual stand height at some (non base) age.

Goal seeking is not commonly used, but may often be the only relatively simple way of resolving a calculation dilemma in Excel.

One comment has been received that the function does not always find the true optimum. This suggests that care should be taken when using the function and sensitivity analyses may need to be carried out.

#### XIRR

The comments earlier about the XIRR function need to be considered seriously as it must be remembered that it is the responsibility of a forest valuer to provide correct calculations and be able to stand up in court and support those calculations. It is believed that it would not be a satisfactory answer to say “that is what the Excel package function IRR produced”. The support news group provides a number of examples supporting the view that the calculations may be unsatisfactory for forest valuation.

### 13.2.2 Reliance on the methodology

Forest valuers often simply use the functions embedded in a spreadsheet and assume that they do what the analyst wants them to do correctly.

Forest valuers should recognise that if they are required to justify their analyses in court that the court may assume that they understand the exact methodology used and can cogently argue and justify the case for that methodology.

This may not always be the case and it is important for forest valuers to be aware of this.

For example the difficulty raised earlier with the XIRR function assuming only 365 days in a year may or may not be important in a forest valuation analysis and blithely assuming that the spreadsheet calculates correctly may become a problem.
13.3 The importance of records

It should be self evident that it is important to maintain all the records of income and expenditure concerning a forest, and of operations performed in a forest that were not costed or charged.

However ACFA members continue to report cases where the forest owner has not had an adequate record keeping system in place and then suddenly it has become necessary to determine the value of a forest asset for some reason, perhaps as part of the valuation of an estate for probate purposes, or on a split between the owners of the forest estate. The valuation is made difficult, if not impossible, and is certainly far more costly to perform than if all the relevant information is readily available. Importantly, where income and cost data are not available and are relevant to the valuation, an estimate should be made and support data for it included in the valuation report.

13.4 Separation of biological assets from non-biological assets

AASB 141 is quite specific in that it refers to the biological asset (formerly SGARA) alone. It further specifies that only the current crop is to be considered and that subsequent rotations are not part of the biological asset as defined in the standard.

For forest valuations used to determine the change in value of the biological asset for incorporation into the financial statements as required under the Corporations Act this requires separation of the costs and returns associated with the biological asset from those associated with non-biological assets. They are treated differently under the accounting standards.

For forest valuations made to assess potential transaction value then it is highly desirable to separate the costs and returns associated with the biological asset from the non-biological assets so that the methodology used for all forest valuation is as consistent as possible. The transaction will almost always comprise both the biological and non-biological asset components.

Thus, if the AASB 141 standard is to be used to value the biological asset component then such costs and returns associated with land acquisition, leasing of land, and capital equipment must be excluded from that component but the costs and returns will probably need to be considered as part of the total valuation.

Unless this separation is carried out as the first level separation in any forest valuation then it is almost impossible to resolve the various issues with regard to land treatment and other non biological components. When it realised that land is not part of the biological asset and that AASB 141 is not appropriate then most of the difficulties that have emerged about how to treat land become much simpler.

The approach commonly stated simply as “the value under AASB 141 is the figure on the cheque if a forest changes hands” is therefore a simplification and is not necessarily true. In fact it is commonly not true. The “figure on the cheque” is for the biological asset and non biological asset components combined whereas the figure required for the Profit and Loss statement is the change in value of the biological asset alone, and this is rigidly restricted by definition to the value of the current crop alone.

13.5 Consistency in aggregate values

AASB 141:25 would seem to imply that the biological and non-biological components can be simply added to get the Fair Value or Net Market Value of the entity in the marketplace. The clause states:

“Biological assets are often physically attached to land (for example, trees in a plantation forest). There may be no separate market for biological assets that are attached to the land but an active market may exist for the combined assets, that is, for the biological assets, raw land, and land improvements, as a package. An entity may use information regarding the combined assets to determine fair value for the biological assets. For example, the fair value
of raw land and land improvements may be deducted from the fair value of the combined assets to arrive at the fair value of biological assets.”

Experience in New Zealand in valuing going concerns that have sustainable wood flows indicates that the deduction of current land value from the present value of the living trees and land, mooted as an option above in AASB 141:25, creates an estimate of the annual change in the fair value of living trees, or biological asset, that can be materially biased if reported land values change materially over the period since the previous valuation. If this option is adopted and material biases arise in the gains or losses attributable to living trees, some form of arbitrary adjustment has been suggested through the use of a reconciliation factor, or a land occupancy charge, or some other mechanism.

However, such an adjustment inevitably creates problems in reconciling the sum of the component asset values with the aggregate value of the entity and ACFA believes an adjustment should not be used.

This issue reflects the inability to separate the roles of the living trees from the land on which they grow in determining the respective values of the combined asset, a problem long recognised in forestry.

As with other estimates of fair value, a valuation of a forest entity is subject to the test of valuing in the highest and best use. If alternative uses of the various component land and forest assets sum to a higher value, then that should be used as the value of the entity.

The possible implementation protocol and the alternative description of that protocol in the previous chapter address this consistency issue which is also addressed in the revised ACFA forest valuation standard (2007). The protocol recognizes that the net market value or fair value of the forest component should ideally be based on a post-tax analysis that will generally include both the current and subsequent rotations. It recognizes the situation where the highest and best use of the land may not be as an ongoing forest estate. It also provides for the change in value of the biological asset (as strictly defined in the standard), that is reported in the profit and loss statement to be calculated based on the current crop only, and allows the analysis to be based pre-tax. In this regard ACFA considers that a post-tax analysis would be preferable. As at late 2006 it is understood the AASB are considering exactly how the AASB 141 standard should be interpreted in this regard.

The ACFA forest valuation standard and this Handbook are believed to be completely consistent with the nuances in the accounting standard AASB 141. At the same time it is possible to provide a fair value, or NMV, or expected transaction value that matches the methodologies currently used in practice when buying or selling forest assets.

The approach is internally consistent.

ACFA recognizes that the interpretation in the ACFA 2007 standard may involve difficult professional judgements. ACFA recommend that the underlying assumptions used and the effects on the various valuations be disclosed, discussed and fully documented.

13.6 Costs

For most forest valuation approaches the costs of all the various forestry activities need to be considered.

General attribution of costs

Costs can generally be attributed either to a stand in which case they are generally reported on a per hectare (ha), volume (m³) or weight basis (t) for harvesting yields. Alternatively costs may be attributed to the forest as a whole in which case they are generally apportioned on the basis of productive forest area. The separation can at times be unclear but the important thing is that all costs within an organisation should be included and that no costs should be included in the analysis more than once.
Some costs can be clearly attributed to occurring in a particular operation year or plantation year, for example ploughing, weedicide application, fertiliser application, pruning, plantation fire insurance, and these can generally be attributed to a particular area and so knowledge of the area treated and unit costs can be used to ensure that the unit cost figures are correct. The information can also be used to ensure completeness.

Some other costs cannot. These are commonly attributed to general plantation expenses and included in an annual maintenance cost. Examples include administrative overheads, firebreak maintenance, fire protection costs, research, and insurance of plant and equipment. These can be distributed to each coupe or stand on a per hectare basis.

Some costs may be able to be attributed to particular years but the administrative overheads of so doing may not be considered sensible so they may, for convenience, be included in annual maintenance costs. One example of this is forest inventory, which if carried out under contract may be attributed to a particular plantation in a particular year, but if carried out by in-house staff who carry out other activities as well are more conveniently considered an overhead and included in the annual maintenance costs.

It is critical when evaluating the costs of a plantation enterprise to ensure that all costs are included in the various identified components and, on the other hand, that costs are not double counted. Large forestry organisations can generally obtain the necessary cost information from their formal financial and accounting systems, which can be audited, but this is not always the case.

Apportioning may be inappropriate at a stand level. For example in some forest enterprises the costs of managing small areas of native forest or parks or recreation areas are included in the annual cost of managing the plantations. It may also be that annual charges should be different for highly productive or poorly productive forest. However if the totality of the costs is correct then any incorrect apportioning will have no effect on the in toto PV calculation. It may however make the calculated PV for a particular coupe or stand negative and that may require special treatment in the valuation, see section 6.3.4 of the ACFA (2004, 2007).

There are relatively few general bases for costs including;

- cost per hectare per year throughout the plantations life,
- cost per hectare in a specific year,
- cost per kilometre (for example of firebreaks) which requires total distance and area so that the costs can be apportioned,
- cost per tree, for example for pruning, and,
- costs per cubic metre or ton or piece of wood produced.

**Averaging across years**

Many forest management costs differ from year to year depending on the weather and on climatic variations. For example, a dry year generally has less requirement for weed control, but the costs for fire protection/suppression are likely to be higher. In comparison, a wet year is likely to occasion higher costs for weed control and lesser costs for fire protection requirements. Some organisations take this into account by using a rolling average to determine an average per hectare cost for various operations. One organisation uses a three year average whereas it would probably be better if it was longer, perhaps seven to ten years to more closely match the climatic cycles. But then inflation would probably need to be taken into account.

This averaging may also be desirable to account for variations in, for example, establishment costs so that the variation in establishment difficulty is averaged out. For example second rotation establishment costs are generally higher than for ex pasture sites and the proportion of each will generally vary between years.

For this averaging, costs from each particular financial year need to be indexed to a common base.
Attribution of costs to the biological asset

The specific definition of biological asset as used in the strict accounting sense causes a number of challenges for large ongoing forest enterprises, especially in determining whether costs should be attributed to the current crop or to the future crop, that is attributed to the biological asset or to the subsequent rotations.

The separation is not always clear cut.

Even what are generally called annual costs and partitioned on an area basis need to be carefully considered as some aspects are more properly considered relevant to the current crop, others to future crops. As one organisation has commented the differences can be significant and not taking this aspect into account can change the value of the biological asset by 5-10%.

For example fire protection, road maintenance, and inventory annual costs may be based on and attributable to the current crop although some per hectare costs might also need to be applied to subsequent crops. Similarly, nursery management, research into genetic improvement, and research into establishment practices are more properly attributed to subsequent rotations as there is no gain from these activities that accrues to the current crop. Perhaps these should be linked to re-establishment costs.

Some other costs are not easily aligned, and these might include office administration and training.

It is necessary to separate the costs into the two components; those relevant to the current crop, the biological asset or living trees, and those relevant to the future crops or subsequent rotations. The former are considered in the value changes reported in the Profit and Loss statement, whereas the latter can be considered a non-current asset.

One organisation that has taken some care to address this issue has reported that the delineation took a great effort but that it was necessary, as simplification and generalisation would have led to material differences in the value of the biological asset.

A further difficulty is that this separation can make it more difficult to ensure that the totality of costs is consistent with the actual experience of the organisation, making it more difficult to ensure that costs are not missed and that costs are not included more than once in the analysis.

The underlying assumptions used in any valuation must be clearly reasoned and discussed, and must be fully disclosed and documented.

Example costs

The following lists approximate plantation establishment and management costs obtained in 2006. It indicates the wide range for many component costs.

- Initial survey. $50-500 /ha
- Pre plantation site preparation. $1000-1500 /ha
- Plantation establishment, including site preparation, seed, seedlings, weedicide applications over the first few years, planting, and post-planting survey. $1000-1500 /ha
- Additional spot weedicide application. $50-200 /ha
- Pruning, first lift only, depending on number pruned. $100-400 /ha
- Pruning lifts above the first lift, depending on the number of trees pruned. $150-600 /ha
- Thinning to waste thinning at the time of pruning. $200-350 /ha
- Fire break maintenance. $100 /km/a
Roading for harvesting. $0+/km
Harvesting overhead costs not directly attributable to an operation. $0-4/m³
Later age fertiliser application, per operation. $1000-2000/ha
Annual maintenance and overheads $50-150/ha/yr

The bases of the costs used in any analysis should be clearly stated and clearly documented. This should include;
- identification of costs,
- a description of any modelled costs, for example logging costs,
- comment on the relevance of any externally sourced costs,
- provision of any reconciliation to independent sources, and,
- provision of any reconciliation of total costs.

Any cost used should be;
- consistent with costs elsewhere in the valuation,
- internally consistent, with no double counting and nothing left out,
- externally consistent, and,
- be consistent in terms of tax treatment with the discount rate and methodology used.

The costs should be complete, reliable and consistent.

13.7 Revenues

The revenues to be included in any forest valuation are generally almost completely based on log price. In Australia these are generally defined in these terms.
- **Mill Door price** The value of a log at the mill door.
- **Stumpage** This is the Mill Door price less the costs of falling, loading, haulage and other costs associated with getting the log from the forest to the mill.
- **Royalty** This is the value of the tree or log at the forest prior to harvesting. The falling, loading and haulage and other costs can then be added to obtain the Mill Door price.

If the falling, loading and haulage costs are fixed then stumpage and royalty are in essence the same. Some contracts are predicated as residual stumpage after setting the Mill Door price, while others are predicated as royalty which is independent of falling and haulage. The difference generally reflects whether the buyer or seller is to be responsible for variations in the harvesting costs and is based on the wood supply agreement. There are many alternatives possible.

Log measurement costs are generally considered an overhead for the seller, but may in some cases be netted out of revenue.

There are some examples of non log or non standard revenues. Examples include; quarry material where there may be an ongoing contract to provide material for road construction or some other use, grazing leases or agistment of stock, apiary licences, firewood, and the revenues from tourism. These are not relevant under the AASB 141 standard as they are not biological assets under the guidelines but may need to be taken into account separately. It all depends on the use of the forest valuation.

Log measurement methods

Any discussion about revenues is further complicated by log volumes being measured according to a number of different so-called standard methods and, as the differences can be as high as 10-15% for individual logs, it is imperative to know how volume is being measured or estimated or predicted.

Turland and Borough (1996) provide a summary of three methods commonly in use.
**Smalian’s formula**

Smalian’s formula uses cross sectional area at the large end of the log (B in m$^2$) and at the small end of the log (S in m$^2$), and log length (L) to estimate log volume.

\[ V = \left(\frac{B + S}{2}\right) \times L \]

See also the Annex.

**Huber’s formula**

Huber’s formula uses cross sectional area (M in m$^2$) at mid log length and log length (L) to estimate log volume.

\[ V = M \times L \]

See also the Annex.

**Japanese Agricultural Standard**

The Japanese Agricultural Standard (JAS) is used extensively for scaling sawlog exported to Japan and Korea, the two major buyers of softwood logs from the Pacific rim. In Korea it is called the Korean Industrial Standard. The principle is to determine the volume as though no taper exists, although some allowance is made for taper in longer logs. The following description is believed to be correct but users should confirm the exact methodology specified in any contracts before relying on the accuracy of this description as some variants are believed to exist.

If

\[ V = \text{Volume (m}^3\text{)} \\
D = \text{Shortest small end diameter (cm)} \\
L = \text{Length (m)} \\
L' = \text{Length to nearest whole metre (not rounded down)} \\
\frac{(L' - 4)}{2} = \text{derived taper factor} \]

then if logs are less than 6.0 m in length

\[ V = \left(\frac{D^2 \times L}{10000}\right) \]

and if logs are greater or equal to 6.0 m in length

\[ V = \left(\frac{(D + \frac{(L' - 4)}{2})^2 \times L}{10000}\right) \]

The length of sawlogs specified excludes the required 0.1 m overcut in log length.

Small end log diameter measurement is also specified. For logs with a small end diameter less than 14 cm it is measured across the centre of the small end of the log (not the pith). For logs of 14 cm and larger small end diameter there are several steps. First the shortest small end diameter is measured inside bark through the centre of the log and rounded down to the nearest 2 cm class interval. Then the diameter is measured at right angles to this measurement. This is required to make an adjustment for out of round logs. If the shortest measurement is less than 40 cm then 2 cm is added to the shortest diameter for every 6 cm difference between the two diameter measurements and this adjusted small end diameter is used in the volume calculations. If the shortest small end diameter is greater or equal to 40 cm then 2 cm is added for each 8 cm difference.

The Japanese Haakon-Dahl measurement is often cited in the literature and is similar to the JAS but uses imperial measurements.

**Comparison**

The Annex to this Handbook also defines other formulae such as Bruce’s formula, the Centroid formula and Newton’s formula none of which is commonly used in Australia.

Turland and Borough (1996) provide some worked examples comparing logs measured by the commonly used rules; Huber, Smalian and JAS. In general if the taper along the log is quite low and logs are round then the various measures are quite similar. Huber’s formula is slightly less than Smalian’s formula if taper is uniform, but if log taper varies along the log then this generalisation may
not hold. However the JAS formula is commonly highly variable when compared with the other two. It is simply not possible to determine an average correction methodology that would facilitate conversion from one measure to another.

The Turland and Borough (1966) paper also includes a table demonstrating how woodchip price per tonne can be converted back to a stumpage, specifying the various steps in the process.

Examples

One source of example stumpages from around Australia is the Forestry Market Reports of the Australian National University prepared by Dr U.N.Bhati. These are available (in 2007) from the web site:

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

However in a letter to the Editor of Australian Forest Grower published in the winter 2005 edition U.N. Bhati announced that further Market Reports had been put on hold.

The examples below are obviously not complete but may form a useful starting base if no other information is available.

Australian Pine Log Price Index

The Australian Pine Log Price Index (APLPI) is compiled by KPMG using data provided by five Australian softwood growers; Forestry Plantations Queensland (formerly DPI Forestry), ForestrySA, Hancock Victorian Plantations, Forests NSW (formerly SFNSW) and ACT Forests.

The index, updated to June 2005, is provided in two forms; one of which is generally available. In 2005 KPMG made that version available from their web site and the .pdf file was available in 2007 by following the links through; industries > energy & natural resources > forestry and then the report can be downloaded.

Information is provided as stumpages not royalties and is updated biannually. Data are available from 1995 but the report index also shows the index trend using the January-June 1998 period as a base of 100.

The tables quote the maximum, minimum, weighted average value, and the total volume, for four general sawlog sizes (small, intermediate, medium and large), and for preservation material, pulp log and salvage log. Export sawlog and pulp log volumes are also quoted. The information is also presented graphically.

Given that for the six months from January to June 2005 the sawlog volume was some $2.3 \times 10^6 \text{ m}^3$ the figures provided have some broad credibility. The table for that period is reproduced below.

<table>
<thead>
<tr>
<th></th>
<th>Minimum $/\text{m}^3$</th>
<th>Maximum $/\text{m}^3$</th>
<th>Average $/\text{m}^3$</th>
<th>Volume $\text{m}^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small sawlog</td>
<td>5.80</td>
<td>41.08</td>
<td>35.26</td>
<td>723,447</td>
</tr>
<tr>
<td>Intermediate sawlog</td>
<td>12.35</td>
<td>66.18</td>
<td>47.43</td>
<td>830,020</td>
</tr>
<tr>
<td>Medium Sawlog</td>
<td>38.91</td>
<td>91.86</td>
<td>68.17</td>
<td>559,602</td>
</tr>
<tr>
<td>Large sawlog</td>
<td>44.76</td>
<td>113.85</td>
<td>80.15</td>
<td>212,472</td>
</tr>
<tr>
<td>Preservation log</td>
<td>14.37</td>
<td>25.54</td>
<td>22.65</td>
<td>104,427</td>
</tr>
<tr>
<td>Pulp log</td>
<td>0.07</td>
<td>16.67</td>
<td>9.27</td>
<td>1,340,779</td>
</tr>
<tr>
<td>Salvage log</td>
<td>7.42</td>
<td>26.76</td>
<td>23.49</td>
<td>70,650</td>
</tr>
</tbody>
</table>

For practical use in a particular forest valuation these figures must be adjusted for any expected variations in harvesting and transportation costs from the average which may or may not be available. There are other factors which may also not be consistent between reporting agencies.

The trend information may also be very useful in forest valuation. It could be that an analyst might use a proportion of these average figures, perhaps for example, 90% of the average. Whatever it is decided to use it is important to justify the choice, document the reasoning, and disclose all details.
South Australia

The details in the table below, which is reproduced from Bhati (2001), were provided by ForestrySA for radiata pine sawlog for that year. This table provides an indication of the effect of diameter on log value.

<table>
<thead>
<tr>
<th>Class</th>
<th>End Diameter</th>
<th>$/m³ 2000-01</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;150 mm</td>
<td>17.52</td>
</tr>
<tr>
<td>2</td>
<td>150-200</td>
<td>19.42</td>
</tr>
<tr>
<td>3</td>
<td>200-250</td>
<td>30.35</td>
</tr>
<tr>
<td>4</td>
<td>250-300</td>
<td>40.44</td>
</tr>
<tr>
<td>5</td>
<td>300-350</td>
<td>50.57</td>
</tr>
<tr>
<td>6</td>
<td>350-400</td>
<td>60.60</td>
</tr>
<tr>
<td>7</td>
<td>400-450</td>
<td>69.61</td>
</tr>
<tr>
<td>8</td>
<td>450-500</td>
<td>76.89</td>
</tr>
<tr>
<td>9</td>
<td>500-550</td>
<td>79.10</td>
</tr>
<tr>
<td>10+</td>
<td>&gt;550 mm</td>
<td>81.32</td>
</tr>
</tbody>
</table>

Bhati demonstrated graphically that in the period 1978-2000 the price of a class 5 sawlog approximately followed the Consumer Price Index (CPI).

Sawlogs are measured at each end under bark and the log diameter is assumed to hold for that half the log length.

Victoria

Bhati (2001) quotes an example radiata pine second commercial thinning (at age 22) stumpages in 2000 as $17 /tonne for sawlog, $13 /tonne for pulp wood.

He also quotes cypress (*Cupressus macrocarpa*) at age 78 in 2000 as $53.50 /tonne.

Bhati (2003) quotes pine in 2003 at $27.80-37.40 /m³, preservation products $17.20 /m³ and pulp log at $12.20 /m³.

In the same report he quotes hardwood in 2003 as $13.26 /m³.

Western Australia

For plantations Bhati (2003, but also 2001) provides some examples.

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Log type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue gum</td>
<td>2001</td>
<td>Age 9-10</td>
<td>$20.30 /tonne</td>
</tr>
<tr>
<td></td>
<td>2002</td>
<td>Thinnings</td>
<td>$25.43 /tonne</td>
</tr>
<tr>
<td>Spotted gum</td>
<td>2003</td>
<td></td>
<td>$23.00 /tonne</td>
</tr>
<tr>
<td>Radiata pine</td>
<td>2003</td>
<td>Saw log</td>
<td>$26.47 /tonne</td>
</tr>
<tr>
<td>Pulp log</td>
<td>2003</td>
<td></td>
<td>$10.24 /tonne</td>
</tr>
</tbody>
</table>

For native forest in 2003 Bhati (2003) quotes:

<table>
<thead>
<tr>
<th>Log type</th>
<th>Species</th>
<th>Region</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip log</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First grade</td>
<td>Jarrah</td>
<td>Swan, SW region</td>
<td>$23.91 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warren region</td>
<td>$25.74 /tonne</td>
</tr>
<tr>
<td></td>
<td>Karri</td>
<td>Warren region</td>
<td>$37.52 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$39.52 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$46.80 /tonne</td>
</tr>
</tbody>
</table>

As at 2007, reformatted 2012 but no textural changes
For the native forest log the average increase over a 9 year period varied from 3.6-4.5% compared with the CPI of 2.4%. The graphs show a greater rate of increase in the period 1994-2000 than 2000-2003.

The Forest Products Commission also publishes stumpage values on their web site [www.fpc.wa.gov.au](http://www.fpc.wa.gov.au) and update these regularly. They provide another independent source of stumpages for different mid diameter saw logs and different products, for both softwood and hardwood.

### Tasmania

Bhati (2002b but also 2001, 2003) provides information based on Forestry Tasmania data.

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Year</th>
<th>Log type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantation</td>
<td>2002</td>
<td>Blue Gum thinnings</td>
<td>$27.50 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Softwood saw log</td>
<td>$70.09 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Softwood pulp log</td>
<td>$50.33 /tonne</td>
</tr>
<tr>
<td>Native Forest</td>
<td>2000-01</td>
<td>Sawlog category 1&amp;3</td>
<td>$73.24 /m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sawlog category 2&amp;8</td>
<td>$55.08 /m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sawlog category 1,2,3,8</td>
<td>$67.91 /m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulp log</td>
<td>$48.95 /tonne</td>
</tr>
<tr>
<td></td>
<td>1999-2000</td>
<td>Messmate/swamp gum saw log</td>
<td>$ 7.00 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alpine ash saw log</td>
<td>$30.00 /tonne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alpine ash pulp log</td>
<td>$11.00 /tonne</td>
</tr>
</tbody>
</table>

Bhati (2002b) provides graphical evidence that the stumpages for pine followed the CPI for the period 1980-1998. For eucalypts the stumpages rose in excess of the CPI during the same period but it has been suggested that this may reflect a catching up from historically low stumpages.

It should be noted that weight includes bark but volume is volume under bark.

Candy and Gerrand (1997) quoted stumpages for sawlogs and pruned logs for shining gum but these are understood to be based on radiata pine stumpages and are believed to be optimistic.

<table>
<thead>
<tr>
<th>SED (cm)</th>
<th>20-25</th>
<th>25-30</th>
<th>30-35</th>
<th>35-40</th>
<th>40-45</th>
<th>45-50</th>
<th>&gt;50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pruned $/m³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>150</td>
<td>160</td>
</tr>
<tr>
<td>Sawlog $/m³</td>
<td>45</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
</tr>
</tbody>
</table>

### New Zealand

Bhati (2003) provides New Zealand stumpage ranges for a number of radiata pine products. These have been converted to Australian dollars and are as at June quarter 2003. The domestic prices are at mill door, and can be approximately converted from tonnes to m³ at 1.0. The export prices are FOB. The New Zealand Ministry of Agriculture and Forestry collects the data from the major suppliers and presents the information as a range. The figures below are therefore based on a large sample unlike some of the Australian examples.
Export FOB

<table>
<thead>
<tr>
<th></th>
<th>$/JAS m³</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pruned peeler (300+ mm)</td>
<td>136-204</td>
<td></td>
</tr>
<tr>
<td>Unpruned A grade (200-340 mm)</td>
<td>77-94</td>
<td></td>
</tr>
<tr>
<td>Unpruned J grade (200-260 mm)</td>
<td>68-90</td>
<td></td>
</tr>
<tr>
<td>Unpruned K grade (200-260 mm)</td>
<td>62-76</td>
<td></td>
</tr>
<tr>
<td>Pulp log (100+mm)</td>
<td>35-46</td>
<td></td>
</tr>
</tbody>
</table>

Domestic mill door

<table>
<thead>
<tr>
<th></th>
<th>$/tonne</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 pruned (400+ mm)</td>
<td>131-168</td>
<td></td>
</tr>
<tr>
<td>P2 pruned (300-399 mm)</td>
<td>97-135</td>
<td></td>
</tr>
<tr>
<td>S1 unpruned (400+ mm)</td>
<td>73-93</td>
<td></td>
</tr>
<tr>
<td>S2 unpruned (350-400 mm)</td>
<td>74-83</td>
<td></td>
</tr>
<tr>
<td>L1 &amp; L2 unpruned (300+ mm)</td>
<td>44-63</td>
<td></td>
</tr>
<tr>
<td>S3 &amp; L3 pruned/unpruned (200-299 mm)</td>
<td>44-69</td>
<td></td>
</tr>
<tr>
<td>Pulp log (100+ mm)</td>
<td>30-34</td>
<td></td>
</tr>
</tbody>
</table>

As New Zealand exports much of its radiata pine produce it provides a useful window on world export prices compared with the Australian Log Price Index where the prices are generally from domestic sales.

Another source of New Zealand log price information is available in 2007 at a fee from:

http://www.agri-fax.co.nz/forestry.cfm

Trends in expected future log revenues

The examples above refer to historical information but what is really needed for most analyses is the expected trend in future log revenues.

In New Zealand log prices are much more closely aligned with the world export market prices and there has been a slow but steady decline in relative log prices over the past 10-15 years. This contrasts with Australia where the market is predominantly internal and limited circumstantial evidence would suggest that real log prices (discounted for inflation) would seem to have been steady or perhaps even slightly increasing.

The Australian Log Price Index enables trends from 1995 to be obtained.

The likely future trend in log prices needs to be considered, incorporated into the analyses, reasoned and documented, even if the simple conclusion is just that they will remain constant in real terms.

13.8 Environmental and other effects

In commercial forests the overall general objective is to manage for profit and therefore the ACFA (2007) standard is appropriate for formal financial reporting under AASB 141. However in most cases there are small components of the overall forest estate that are managed for environmental and other purposes. These include stream reserves, heritage sites, and also recreation sites. These create a difficulty for valuation in that the AASB 141 standard is not necessarily appropriate as it applies specifically to the biological assets that are managed for profit, and a separate valuation is strictly speaking necessary for both other biological asset and non-biological asset components.

One commonly suggested approach is to assume that the whole forest estate is being managed for profit and so these other costs can be considered appropriate for the valuation of the overall forest. This may be appropriate if these other effects can be considered minimal, and the definition of minimal is likely to vary between organisations.
The choice of approach depends on the relative effects of these effects compared with the productive commercial forest.

Whatever the decision and methodology used it should be clearly stated, described, reasoned and documented.

**Non-wood values**

Non-wood forest values are not commonly quantified in Australian forest valuation. However they may, in some cases, be a significant component of value.

The United Nations Food and Agriculture Organization produces a bulletin “non-wood NEWS” available free in hard copy and also (in 2007) from their web site.


The bulletin provides a comprehensive summary of non traditional forest products and may be a useful reference for entry to other sites, journals and organizations.

**Landscape and aesthetic values**

This is another area generally ignored in Australian forest valuation. It is an area of interest in many other countries including the United Kingdom. An article by Grayson (2004) briefly describes four studies, including the web references from which the studies can be downloaded.

### 13.9 Contingencies

A contingency is defined as a potential obligation or benefit that arises as a consequence of some earlier transaction or activity, and,

- its occurrence is possible but not probable, or,
- the associated cost or value cannot be measured with reliability.

The New Zealand Forest Valuation Standards (NZIF 1999) provides a useful table.

<table>
<thead>
<tr>
<th>Can quantify</th>
<th>Cannot quantify</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probable</td>
<td>Not a contingency</td>
</tr>
<tr>
<td></td>
<td>Include in forest valuation</td>
</tr>
<tr>
<td></td>
<td>Contingency</td>
</tr>
<tr>
<td></td>
<td>Disclose as a note, using sensitivity analysis</td>
</tr>
<tr>
<td>Possible</td>
<td>Contingency</td>
</tr>
<tr>
<td></td>
<td>Disclose potential financial effect as a note</td>
</tr>
<tr>
<td></td>
<td>Contingency</td>
</tr>
<tr>
<td></td>
<td>Disclose existence as a note</td>
</tr>
</tbody>
</table>

Examples of contingencies include the following.

- Uncertainty over land tenure.
- Provisions for public access that have the potential to constrain forest management.
- Areas of possible historical or cultural or environmental significance that may be subject to management restrictions at some time in the future.
- Areas that may be subject to prospecting rights that might lead to some future mining activity.
- Areas covered by mining licences that may permit the removal of tree cover.
• Provisions that potentially constrain forest management at some later point.
• Existence of a new disease for which the full potential impact cannot be determined at present.
• The impact of draft regional planning documents that may affect zoning and land management status at some time in the future.
• Contractual obligations that could influence the way prices are adjusted, may control future harvesting levels, or may otherwise limit forest management flexibility.

Another way, seemingly preferred by some accountants, is to allow for contingencies as risks and to include them in the β or risk factor in the discount rate. In the opinion of ACFA risks and contingencies should more properly be handled separately and generally handled differently.

ACFA considers that the table above provides appropriate guidance.

One difficulty with including contingencies in risk, and also in assessing risk itself, is that such allowances that are made are commonly greater than a detailed, reasoned analysis would indicate. In essence this builds in an allowance for uncertainty and lack of knowledge that may be quite inappropriate.

Another possibly useful way of looking at risk is the approach of Knight (1921) who separated risk and uncertainty. With risk he suggested that you can tame the randomness with probabilities whereas with uncertainty you do not even have knowledge of the probabilities. Uncertainty can therefore be treated as a contingency whereas risk can be quantified. However as von Neumann and Morgenstern (1944 [1953]) commented, even ignorance gets quantified in practice thus blurring the differences between risk and uncertainty.

### 13.10 Risk

In many valuations carried out using discounted cash flows risk is commonly included in the discount rate that is used. This inclusion of all the risk allowance in the discount rate is generally not appropriate for forestry investment.

The general perception is that forestry is a risky business and so accountants often seek to use higher risk factors than are considered appropriate for other industries that they understand better. They may select a higher than appropriate risk adjusted discount rate simply because they do not understand how risk is managed as part of the overall forest management strategy. Forest managers are used to managing risk and managing forests to lessen the effects of any event that might diminish future expectations. For example in South Australia when some 30% of the radiata pine forest was burnt in one event in 1983 the effect on the wood flows was approximately 10% and then only for a relatively short period of time. The issue is how should this be accounted for in forest valuation?

Liley (2000) provides a good summary of risk treatment in forest valuation citing some practical examples. He suggests that, in a Present Value framework, there are two basic broad alternatives, including an allowance in the derivation of future cash flows and including an allowance in the discount rate. As Liley notes, the problem is succinctly summed up by Clutter (Clutter et al. 1983) who stated:

> “First, use of a risk-adjusted discount rate assumes risk is compounding over time. Second, no specific guidelines are available on how to determine the appropriate adjustment factor.”

Manley (2005) in surveying the discount rates used for forest valuation in New Zealand asked what specific allowances respondents made for risk. Of the 22 respondents seven said that they adjust yields, which may be by reducing area as well as volume, especially if there was no fire insurance. Ten respondents reported that they adjusted the discount rate and examples are given of the sort of adjustments made. The remaining five made adjustments to the cash flows for example by including fire protection and surveillance costs. It could be argued that simply providing this survey will
encourage forest valuers to consider their methodology and that, over time, a more consistent methodology for allowing for risk will evolve.

Risk does not always increase with plantation age nor increase over time and so the use of a risk adjusted discount rate (the approach commonly adopted by accountants) would seem to be quite inappropriate. For example, the cost to an enterprise of a major fire may be greatest for plantations approaching the first commercial thinning when salvage is difficult and there may be considerable costs returning the site to production, compared with very early ages when the costs are less and late ages when salvage values may be high. Another example is wind damage which may be greater at young ages and immediately after any pruning or thinning operation. In neither case is risk a simple function of plantation age as assumed by the use of a risk adjusted discount rate.

Liley provides (2000) some examples of how wind and fire risk has been modelled including examples of stochastic modelling. This is the area of forest management modelling that would seem to benefit most by stochastic modelling approaches and it is somewhat surprising that there are not more examples detailing where and how it has been used. However as Liley notes, stochastic modelling techniques such as Monte Carlo simulation are increasingly being used.

In forest management practice risk may also be accounted for by the use of arbitrary allowances on projected wood flows, and/or by limiting contracts (see Leech 2002). Some risk may also be accounted for by taking out explicit fire insurance, and/or by increased investment in fire protection, or research into insect and other potential ecological effects. Some investment enterprises deliberately plant more area than is sold thereby making an allowance for at least part of the risk. This has the advantage of being readily demonstrated as risk mitigation.

It should be noted that market uncertainty is not a reason for adjusting the discount factor as the outcomes may be better or worse than expected.

There are many different sources of risk.

In valuing a forest enterprise it is necessary to consider how that enterprise manages risk and to make allowances for this in any determination of an appropriate analytical method and also in any determination of the risk factor that should be built into the discount factors.

In all this it is vital that double accounting for risk should be avoided.

It is also important that ignorance of available knowledge should not be built into risk.

### 13.10.1 Force majeure

In any wood supply contract there is generally a force majeure provision to cover the situation where unexpected devastating events occur that render a contract inoperable and cause the contract to be suspended. Examples of the reasons include; riots, civil commotion, earthquake, fire, catastrophe, Acts of God, changes in Government regulations or decrees, and any circumstance beyond the control of the affected party which could not be reasonable foreseen.

It could be argued that fire can be foreseen by managers and so the effect on the ability of a forest owner to supply timber under a wood supply contract might seem to not be covered by a force majeure provision in a contract. However a very large fire such as occurred in South Australia in 1983 which burnt some 30% of the forest was basically considered by all parties to be “unexpected” and all contracts were ignored although every attempt was made to come to a reasonable arrangement for the provision of timber. Nobody had foreseen a fire of that magnitude.

When assessing risk the existence of a force majeure provision may need to be considered because in essence it allows for some of the more extreme risk. Such allowances may not have to be incorporated into the valuation itself.
13.10.2 Contingencies

Contingencies are discussed earlier but it is common in a general discussion of risk to make allowances for some of the risk concerns that are more properly treated as contingencies.

Care should be taken not to include an allowance for contingencies in the consideration of risk.

Care should be taken not to double count any factors.

13.11 Discount rates

The discount rate to be used in the valuation of a forest enterprise may or may not be fixed and set in the terms of reference supplied to the valuer. If it is in fact set then this might be considered to be affecting the independence of the valuation. Experience of ACFA members and others suggests that when a discount rate is provided by a client for use in a valuation it may or may not be an appropriate rate. This suggests that the discount rate should always be discussed in any forest valuation.

In essence the discount rate should be the market determined rate.

It is prudent for anyone carrying out forest valuations when the Terms of Reference direct what rate should be used to review the discount rate and, if desirable, to suggest possible alternatives. Examples of extreme cases are known where a valuer declined to carry out the forest valuation at all, although this is not believed to be common.

ACFA members experiences suggest that discussions of the various aspects that should be considered in determining the discount rate generally resolve the issue and enable a credible and acceptable rate to be determined.

13.11.1 Real or nominal discount rate

By convention the discount rate is normally applied to real cash flows and so the discount rate is expressed in real terms. Conversion from the nominal to the real rate should be by the formula;

\[ i_r = \frac{(1 + i_n)}{(1 + d)} - 1 \]

where the rates are proportions, not percentages

\[ i_r \] = real rate

\[ i_n \] = nominal rate

\[ d \] = inflation rate.

The simpler formulation

\[ i_r = i_n - d \]

provides only an approximate result, with decreasing reliability as the inflation and nominal rates increases. Its use, although not uncommon, is not recommended.

Long term Government bond rates and inflation

The New Zealand Forest Valuation Standards (NZIF 1999) quotes the arithmetic and geometric means for New Zealand, the United States of America and the United Kingdom, of the long-term Government bond rates, inflation rates, and the long-term Government bond rates, inflation adjusted. This suggests that for the USA and UK the means are 1.16-2.23% and for New Zealand 0.19-0.58%, although the standard deviation of these figures is high at 9-15%.

If a real discount rate is to be used then it is suggested that a low base value determined by the long term Government bond rate is appropriate.
An inspection of the Australian figures published by the Reserve Bank of Australia for the 30 years to 1997 suggest that for fixed 3 month deposits and the long term Government bonds the average inflation adjusted rate is about 1.2-1.9% although a number of different interpretations are possible depending on which figures are used. This is consistent with the quoted overseas figures. From late 1993 to mid 2004 the average 10 year Treasury Bond rate was 6.7% and equivalent average CPI (Consumer Price Index) was 2.7 suggesting that a inflation adjusted figure of about 4.0 would be equivalent.

The simple conclusion is that a figure as low as 4% might be justified as the risk free real rate of return in the determination of a suitable interest rate to be applied to any forest valuation analysis.

13.11.2 Period conventions

In discounting, different results arise depending on whether the cash flows are assumed to arise at the beginning, middle or end of each period.

The most common approach is to assume that all costs and returns occur in the middle of the year. Particular circumstances may make this assumption inappropriate.

It is possible, but rare, to discount at intervals greater than a year.

It is more common to discount at intervals less than a year, generally a simple multiple so that the annual rate is not prejudiced. If this greater precision is desired then it is necessary to be rigorous in determining the discount rate to be applied to each period. If the annual discount rate is “i” then the discounting factor is defined as (1+i). If there are “n” periods within a year the discount rate to be applied to each period is not (1+i/n) but {(1+i)\(^{1/n}\)} as this latter formulation will give consistent results for different numbers of equal length periods within a year.

13.11.3 Simple capital asset pricing model

In the simple CAPM or Capital Asset Pricing Model (Brearley et al. 2000), the discount rate for equity capital (\(R_{\text{CAPM}}\)) is calculated as follows:

\[ R_{\text{CAPM}} = R_f + \beta \left[ E(R_m) - R_f \right] \]

where

- \(R_{\text{CAPM}}\) denotes the opportunity cost of capital,
- \(R_f\) denotes the risk free rate of return,
- \(\beta\) denotes the systematic risk of the equity, and,
- \(E(R_m)\) denotes the expected rate of return on the overall market portfolio.

The risk free rate of return is generally measured from the 10-year United States Treasury bond rate because it is accepted as the most stable rate. This has generally been in the range 4 to 5% in the decade to 2003. All rates cited here are in money values.

For forestry enterprises, values of \(E(R_m)\) would seem to be anywhere between 5% and 25% although the higher end figures would seem to often be a desired objective rather than a practical reality. If the opportunity cost of available capital is considered then a range from 6-11% would seem more sensible for use in practice.

The values of \(\beta\) vary for different industries and major entities (McKinsey & Co., Inc. at al 2000), from about 0.3 to 2.0. Those for major forest products companies are generally accepted as being in the range 0.6 to 1.3. The New Zealand Forest Valuation Standards (NZIF 1999) quotes the values of \(\beta\) from some 10 sources ranging from 0.5-0.8, with most being 0.6-0.75.

This latter lower range reflects, at least in part, the fact that in forestry enterprises there are a number of allowances for risk (see earlier) and so it is plausible, and indeed sensible, to use lower
values of $\beta$ so as to not “double count” risk. The use of $\beta$ values as low as 0.3-0.7 would appear quite sensible for ongoing forestry enterprises.

If the above ranges are accepted then values of $R_{\text{CAPM}}$ in the range 4-10% would result.

Inflation in Australia has, for the years prior to 2006, been in the vicinity of 2-3%. Hence the real values of the opportunity cost of capital that perhaps should be used by major forestry investors could be in the realm of 6-13%.

There are alternative, more complicated formulae that may be more appropriate than the one above, or may be mandated for use in certain circumstances. It is important that whatever methodology is used it must be clearly documented.

### 13.11.4 Extension of the CAPD model

In most cases the discount rate to be used is sensibly determined either by using the simple capital asset pricing model or by direct application of a particular discount rate as directed, but in some cases a more detailed method may be desirable.

A possible extension to the simple capital asset pricing model described above, and described in a number of texts, is to include:

- the long term inflation rate,
- the perceived market value of the business,
- the equity value,
- the value of any debt, and,
- the borrowing margin.

The Equity $\beta$ ($E\beta$) can be derived from

$E\beta = \beta (1 + (D/M))$

The cost of equity ($CE$) and cost of debt ($CD$) can be derived from

$CE = R_f + E\beta (R_m - R_f)$

$CD = R_f + B$

now $R_{\text{CAPM}}$ can be calculated and adjusted for the long term inflation rate by

$R_{\text{CAPM}} = \frac{1 + CE (V/M) + CD (D/M)}{(1 + i) - 1}$

Obviously this method requires more inputs to be defined but it does allow for the interest rate to vary as the business becomes more mature and the debt relative to market value changes.

The New Zealand standard (NZIF 1999) suggests that

$\text{Asset } \beta = \frac{\text{Equity } \beta}{[(1 + (1 - \text{tax rate}) * (D/M))]}$

and provides a good detailed review of various discount rate approaches.

### 13.11.5 Discussion

It has been suggested that the WACC/CAPM approach is appropriate for the determination of discount rates for forest valuations. WACC is the Weighted Average Cost of Capital and CAPM is the Capital Asset Pricing Model described earlier. In practical use the calculation requires consideration of the following inputs;

- Debt equity ratio, base debt level and debt premium,
- Tax rate,
- Risk-free rate,
- Market risk premium,
- Beta factor,
- Imputation credits, and,
- Inflation rate.

A beta factor relates the performance of the relevant industry sector (or individual company) to the performance of all listed companies of all types and is therefore a measure of the asset’s exposure to non-diversifiable risks such as changes in interest rates, inflation rates, tax rates and other macro-economic policy changes.

To select a beta factor and gearing ratio, beta factors and gearing ratios of companies with similar resources are generally averaged. One difficulty is that there are relatively few listed companies engaged in pure-play forestry on a world-wide basis, and even less in Australia, that have the ability to set the beta factor for their enterprise without external considerations being imposed on them. A number of forestry related companies either have vertically integrated operations with their processing operations accounting for a substantial part of the business or are operators of Managed Investment Schemes (MIS). These types of forestry related companies have substantially different exposures to macro-economic risks compared to companies purely involved in forestry. Therefore, the utility of their beta factors for forest valuations is questionable.

A further problem is that the performance of forestry related companies apparently bears little relationship to the overall market’s performance. In fact the relationship is not significant for most of the companies that could possibly be used to derive an average beta factor. This makes invalid a fundamental assumption of this approach; that there is a consistent relationship between the performance of the asset and the overall market.

The discount rate derived in this way only takes into account ‘external risks’. In order to apply such a derived rate, the cashflow must be adjusted to fully account for industry and project specific risks (diversifiable risks) such as loss due to pests and disease, and fluctuations in log markets. This adjustment is difficult to do.

The result of this lack of accounting for the full risks faced by an investment is, as noted above, one reason why the WACC/CAPM derived rates for forest projects tend to be less than those rates derived using a transaction analysis approach.

See also the ACFA 2007 standard in the section on Definitions and Explanations.

### 13.11.6 Example discount rates

In the earlier discussion on the simple capital asset pricing model it is suggested that the real values of the opportunity cost of capital could be in the realm of 6-13%.

There is only limited evidence from within Australia but New Zealand would seem to be consistent with this range of 6-11% narrowing down the range somewhat. Manley (2003) reports the results of survey of discount rates used in 2003 in New Zealand and the range applied to post-tax cash flows was 7-9.5%, with the pre-tax rate higher. The average rate used by the sub-set of 13 valuers who responded to the 2001 survey indicated that the rate remained virtually unchanged over that period. The latest survey available (Manley 2005) shows a slight decreasing trend in the post-tax discount rates being used and a more marked decrease in the pre-tax rates. However over the survey period the rates used have remained relatively stable.

As at 2007, reformatted 2012 but no textural changes
The information is graphed for convenience.

One published rate is a pre-tax rate of 7.4% used by Carter Holt Harvey (2005) in their Target Company Statement prepared in response to a takeover bid. No real discussion is provided as to why the rate was selected. The rate is a ‘real’ rate, and does not take inflation into account. The report also publishes the sensitivity of the valuation to a change of 0.5% in the discount rate.

In Australia there has been no similar surveys to those Professor Manley carried out. An informal review carried out in 2005 indicated that the range of interest rates used by a group of about 15 ACFA consultants was generally in the range 5-10%.

Considering the available evidence a narrower range of 8-8.5% would seem to be a reasonable base discount rate that can be adjusted depending on circumstances.

13.12 Taxation

13.12.1 General discussion

Taxation implications provide sources of confusion. A pre-tax discount rate would generally be understood to imply a rate which ignores taxation effects and which will be applied to forest cash flows which similarly avoid any inclusion of taxation. This would result in a pre-tax present value (PV).

A post-tax discount rate is considered by some to be that rate which would be applied to cash flows which explicitly recognise and net out taxation. It therefore is a discount rate which is applied to post tax cash flows. Others would consider that a post-tax rate includes adjustments for the effect of taxation. When applied to pre-tax cash flows it is intended to provide the same result. The discount rate contains a surrogate adjustment for tax effects. It is important that any valuation report states quite explicitly just which rate is being used, and it is preferable to also include a statement as to why that particular rate was selected.

The terms pre-tax and post-tax should not be applied to the discount rates but rather to the cash flows modelled.

In essence in the pre tax alternative the cash flows are discounted at a particular rate (i) to determine a PV, and in the post-tax alternative the cash flows are decreased by taxation implications and then discounted at a different discount rate (i’) to provide the same PV. Thus \( (i) \geq (i’) \) holds.

Brealy and Myers (1988) authoritative text book indicates that there is no way to determine a universal adjustment to relate (i) to (i’), and that it is preferable to model the effects of taxation explicitly.

This also implies that as the taxation implications will differ between organisations involved in forest estate transactions, it may be impossible to unravel the taxation effects from past transaction evidence. This would further undermine the use of transaction approaches to forest valuation or, at the very least, make them more difficult.

The use of a post-tax approach also requires definition of the appropriate tax rate. It could be modelled explicitly for a particular purchaser or seller, or a generalised construct could be used for potential purchasers. The former approach is more rigorous and a more commercially astute potential purchaser may therefore be better placed than another potential purchaser. The latter more general approach has some appeal but may be inapplicable to any of the possible purchasers.

One simple survey of ACFA members suggests that the post-tax rate is about 2% below the pre-tax rate, and that the discount rates referred to as examples earlier may be more appropriate to pre-tax rates.

In discussions with AASB staff it was commented that whether pre-tax or post-tax analyses are carried out the result is the same as the discount rate should be different and should take the tax effects into account. This is true if the cash flows do not change but the matter is equivocal for most
forestry enterprises where the wood flows that determine the cash flow are generally determined by a linear programming analysis that optimises forest value at a set discount rate, subject to a number of constraints. In these circumstances the two approaches are unlikely to provide similar results.

13.12.2 Taxation and the AASB standards

When prepared, the forest valuation standard ACFA (2004) was believed to be completely consistent with standards AASB 1037 and AAS 35 of the Australian Accounting Standards Board. Section 6.3.8 “After-tax basis” recommended using a post-tax basis for the valuation of a forestry asset.

Part of the reasoning was that using a pre-tax basis might well not provide the best indicator of net market value (NMV) of the forest enterprise as a going concern because the value of the return on any asset is generally determined after taxation effects have been assessed. It was further suggested that for most ongoing business entities after tax revenues are generally not difficult to define.

Further, Brealey and Myers (1988) in their authoritative text book are unequivocal on the subject. “You should always estimate cashflows on an after-tax basis. Some firms do not deduct tax payments. They try to offset this mistake by discounting the cashflows before taxes at a rate higher than the opportunity cost of capital. Unfortunately there is no reliable formula for making such adjustments to the discount rate.”

It is also accepted that in many cases the decision as to whether a pre-tax or post-tax basis should be used may be mandated in the valuers Terms of Reference and so, strictly speaking, choosing the taxation basis may not be an issue. The basis used should be disclosed in any report.

The ACFA (2007) standard also recognises that in less formal valuations (appraisals) pre-tax valuations may be appropriate, depending on the use to which the valuation is to be put, as the client can always then superimpose the appropriate tax considerations.

However in spite of the Brealey and Myers (1988) comment above, AASB 141:20 requires that: “an entity uses the present value of expected net cash flows from the asset discounted at a current market determined pre-tax rate in determining fair value”.

This use of a pre-tax rate is inconsistent with the ACFA (2004) standard. The revised ACFA (2007) standard is consistent with AASB 141.

In AASB 141:4 the table explicitly includes forestry so it is not possible to argue that forestry is not a form of agriculture. The IAS 41 “Agriculture” standard includes the same wording.

The concerns expressed about the appropriateness of the valuation as a reasonable estimation of Fair Value or Net Market Value will however remain.

See the earlier section on a possible implementation protocol and also the ACFA (2007) forest valuation standard, both of which are believed to be completely consistent with the current accounting standards.

13.13 Planning horizon

The determination of the planning horizon to be applied in any forest valuation analysis depends on the proposed use of the forest valuation.

The discussion and limitations here refer to biological asset based valuations for formal financial reporting. For valuations that are not required for formal financial reporting then this section provides sound guidance, but there is no implication of it being accepted as mandatory.
13.13.1 Single stand, or few stands

If the valuation is required for a single stand or a manageable number of stands then the most appropriate methodology would be to adhere to the strict definition of a biological asset in AASB 141 and use discounted present values (PV) over the life of the current crop. This also implies that the wood flows from that forest enterprise are determined to be the optimum for the owner and that balancing wood flows over years between different stands is not a consideration.

Any costs at clear felling of the current crop that can be attributed to the cleaning up of the site, for example the regular returning of logging debris within the compartment or coupe boundary and keeping fire breaks and access tracks clear of debris for access purposes, can be included. Costs that should more appropriately be treated as part of the next crop should not. This may mean, for example, that a slash heaping and burning contract has to be divided arbitrarily into two components; fire break maintenance and rehabilitation, and heaping the slash to assist the planting of the next crop. When professional judgement is required, whatever is determined should be clearly documented in the valuation report.

If a forest crop is to be a single rotation and the land is to be sold after clear felling then the inclusion of any of the costs necessary to return that land to a state suitable for sale would appear to be appropriate. This is appropriate if the highest and best use is determined to be other than as forestry.

13.13.2 Ongoing forest estate

For an ongoing forest enterprise managed for profit that includes a number of stands, the planning horizon should generally be a full rotation plus transition into the next. So for a forest managed on a nominal rotation length of say 35 years then a planning horizon of 50-70 years would be quite appropriate.

This enables wood flows to be adjusted and harmonised by varying clear felling ages. AASB 141 implies that each stand is a biological asset and that the value for each stand is to be that determined from the optimum treatment of that particular stand. This implies that a lumpy, uneven, set of wood flows can be marketed in practice. This may or may not be a satisfactory assumption, but is generally quite unsatisfactory for large forestry enterprises. Most forest enterprises plan to optimise the forest and not to optimise each individual stand as that is neither sensible nor practical.

It is a general operations research truism that the optimum for each component is not the same as the optimum for the complete entity. This is also true for forests.

The initial interpretation of the SGARA standard by many people valuing forests was that the classic Faustmann (1995 [1849]) approach was not acceptable but detailed discussions with AASB staff led to an alternative and generally more appropriate interpretation that is formally detailed in Section 6.3.5 of (ACFA 2004), the approved forestry standard, that was considered consistent with AASB 1037 that preceded AASB 141.

Discussions with AASB staff in 2004 had led to the interpretation that although the biological asset is defined as living trees, and therefore only refers to the current rotation, the fair value or net market value (NMV) of that biological asset may be best determined by using the present value (PV) over infinite rotations. An appropriate approximation can be the PV over an extended planning horizon with implicit recognition of the terminal value of the trees and land at that point in time. This method values land and forest, and so includes biological asset and non biological asset components so it is necessary to take out, at a minimum, the land value changes when determining forest value changes for incorporation into the profit and loss account. The method requires consistent land valuations year on year which may be available from the official government valuations or are better obtained from valuations by a Certified Practising Valuer (CPV) of the Australian Property Institute (API).
Under this approach it is possible to use infinite rotation PV but generally a finite fixed planning horizon will be used as it assists calculations. If this latter method is preferred then it is essential to include the termination value, generally the lump sum value at the end of the planning horizon. The long discounting period will ensure that this has a negligible effect but it is desirable for consistency and to better facilitate comparisons between valuations of alternative future silvicultural strategies. Alternative analyses should be undertaken to ensure that changing the planning horizon by a short period (say ±5-10 years) has a negligible effect on the change in forest valuation. These analyses should be documented and disclosed in any report.

There are two real advantages of this methodology. First it is the commonly used Faustmann (1995 [1849]) approach as has generally been used in forestry. Second, it generally more closely matches the likely transaction value if an enterprise is to be traded.

In the previous chapter an implementation protocol was described which addresses the need for consistency when considering the various components of a forest valuation. The protocol uses the above methodology to determine the net market value or fair value of the forest and separates this into the value of the biological asset, as defined in the AASB 141 standard as the current crop only valued pre-tax, and the other components including the value of subsequent rotations and, optionally, taxation effects. It considers that the highest and best use of the land should be based on the highest and best use of combined land and forest. It provides the value of the biological asset so that the change can be incorporated into the profit and loss statement.

Note that this discussion is strictly speaking relevant only for valuations used for formal financial reporting under the Corporations Act, or for valuation of a biological asset, although it may be appropriate for other valuations too.

13.13.3 Other possible considerations

There are a number of other possible considerations about planning horizon or rotation length that may confuse and may need resolution before a forest value can be determined.

It must be stressed that in these rarer cases, such as discussed in this section, and where the forest valuation procedure cannot be clearly defined, professional judgements have to be made. In such valuations especially, the procedures used must be clearly defined, adequately documented, and supported where possible by external documentation.

Coppice

There may be some difficulties with coppice forest under the AASB 141 standard. The strict biological asset (or SGARA) definition of a forest implies that after clear felling, a replanted crop is not part of the biological asset. However if the first crop is harvested with higher stump heights and the second crop is re-established as coppice then it has been argued that strictly speaking clear felling has not taken place.

For example two 12 year rotations of blue gum (Eucalyptus globulus), one replanted after clear felling at age 12 and the other harvested differently to facilitate coppicing at age 12 could be considered to have quite different time horizons when determining their relative value as biological assets.

More importantly, if the valuation is made during the life of the first crop then the silvicultural management specified may be open to either option being used in the future depending on the future circumstances. Given too that if coppice regeneration fails for any reason, it is a very sensible and valid silvicultural option to kill any coppice that does occur and to replant. This proposed silvicultural flexibility is simply prudent forest management but it does appear to conflict with the strict AASB 141 definition.
Given that section 6.3.5 of the ACFA (2004) standard (also restated in ACFA 2007) can be applied it is feasible to adopt a consistent planning horizon for the two options. However that can only be considered appropriate if there are many stands, and the enterprise can be considered an ongoing forest estate. The difficulty remains if there is only one such stand, or a few such stands, and the strict definition of a biological asset has to be applied.

Discussions with AASB staff in 2004 suggested that it may be quite appropriate to use a consistent planning horizon, probably the longer planning horizon - the two full rotations. Whatever it is decided to do however should be very clearly documented, and reasons for that decision should be well argued and incorporated in any report. Alternative valuations may need to be presented so that the magnitude of any such alternative interpretation can readily be assessed.

**A prospectus may state two rotations**

Some forest investment prospectuses clearly state that they are for two crops, the second of which is planned to be established by coppice, or if that re-establishment is considered unsatisfactory then the second crop may be established by planting. This could be considered two rotations under the strict biological asset definition.

The valuation of such a forest should however more sensibly include the two rotations as that is the period of the lease contract. It also is more likely to match any estimate of fair value that might be obtained in a possible transaction.

It is necessary to know whether the valuation is required to meet the AASB standards, including AASB 141, or not.

Most investors invest in very few units of a larger investment and so the consideration above of using PV over the two rotations, as it is part of an ongoing enterprise, may not be appropriate to them individually but may be appropriate to the parent company.

Discussions with AASB staff in 2004 suggested that it may be quite appropriate to use the two rotations as the planning horizon, or to use the land lease period. Whatever it is decided to do however should be very clearly documented, and reasons for that decision should be well argued and incorporated in any report. Alternative valuations may need to be presented so that the magnitude of any such alternative interpretation can readily be assessed.

ACFA considers that the issue is not yet completely clear and this interpretation may change as the international standard becomes more readily interpreted.

**Group selection – infinite length rotation?**

Given that group selection might be practiced, with gaps created by selective tree felling to enhance regeneration, it may be difficult to determine the boundary of the rotation as implied by the strict definition of the biological asset as the current crop only.

It is a perfectly sensible and reasonable forest management practice to manage some forest types on a group selection basis which might be considered an infinite rotation length forest management. It may be quite impractical to map each group which would be necessary if the strict definition of valuing the current crop only is to be applied.

An individual tree selection system create an even more difficult situation as it would appear to be necessary to predict the year in which each tree is to be felled if the strict definition is to be applied.

The issue is unclear and no guidance can reasonably be given at this time. The infinite rotation approach discussed earlier does provide a consistent interpretation. However this would provide a sound estimate of fair value but the derivation of what is and what is not an appropriate base for calculating the change in biological asset value for incorporation into the profit and loss statement is problematic.
Given the pressure from the conservation lobby for more single tree and group selection silvicultural systems to be used in order to avoid what is perceived by some as unacceptable clear felling then this issue may become much more important.

The issue has been raised with AASB staff but no clear guidelines can be issued at present. It is recommended that forest valuers use professional judgement and common sense and that the methodology they decide to use be clearly documented, and argued, in any valuation report required to meet the AASB 141 standard.

## 13.14 Valuing the land

Foresters are not generally certified to value land.

This may cause some difficulties with forest valuation where land value is a requirement, but this may be resolved by contacting members of the Australian Property Institute (API) whose members are also Certified Practicing Valuers (CPV).


provides details of the organisation and the various state divisions should be able to provide, on request, a list of practitioners.

API and PINZ (Property Institute of New Zealand) Professional Practice Manual 5th Edition was available in mid 2006 from the API web site in hard copy for $187 and on CD for $77. API also produces the Australian Property Journal. The practice manual especially may be a useful document for some forest valuers.

It should be remembered that API members generally value properties based purely on transaction information and that they rarely have any understanding of the principles used in valuing the forest component of the joint asset. However collaboration and cooperation may be extremely useful.

Manley (2005) summarises how land is accounted for in valuing tree crops in New Zealand concluding that the “range of approaches being used reinforces the need for the NZIF Forest Valuation working party to provide greater guidance to practitioners on this subject.”

## 13.15 Other

### 13.15.1 Carbon credits

AASB standard AASB 141 as compiled in May 2005 does not include any reference to Carbon credits or any other environmental credits. However in the now superseded earlier version released in December 2003 there is a section that notes the incompatibilities between AASB 1037 and AASB 141. In this section the subject of Carbon credits is specifically mentioned.

“A1 Scope

The scope of AASB 141 is narrower than the scope of AASB 1037, in that AASB 141 excludes from its scope:

- Non-human living animals and plants that are not agricultural activities such as:
  - An investment in a forest as a carbon sink which gives rise to carbon credits that can be either sold or used to offset pollution caused by an entity,”

Although this version of the standard has been replaced it would seem quite unequivocal.

ACFA believes that forest investment will very rarely, if ever, be solely justified on its potential as a carbon sink. This would seem to suggest that an investment based even in part on its role as a carbon
sink and the gaining of carbon credits would need be handled quite differently and the mechanisms are not clearly defined or understood at present.

It is hoped that the apparent incompatibility can be resolved as soon as possible.

Discussions with AASB staff suggest that one option is to value the forest ignoring the effect of the carbon credits. The change in value of the carbon credits can then be determined separately and then used to adjust the change in forest value. This adjusted change in forest value can then be incorporated into the Profit and Loss statement and the carbon credit issue can be handled separately. This treatment would seem to be necessary in order to meet the requirements of AASB 141.

The forest valuer may have to rely on information about carbon credits being provided by the forest manager and so it is highly desirable that any consideration of carbon credits be noted in the forest valuation report.

ACFA strongly recommended that any forest valuation disclose whether carbon credits were considered, and how they were considered. Even if they were not considered at all then it is recommended that a statement to that effect be included in all forest valuations.

**Further General References on Carbon Credits**

Bhati, U.N. (2000)  [Very general comment on Carbon Credits]

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### 13.15.2 Other environmental credits

Carbon credits are not the only form of environmental credit that may be relevant to forest management in a particular set of circumstances, especially in the future. These other environmental credits are considered by some to be likely to become far more important than at present.

It is difficult for a forest valuer is to know exactly what environmental credits may be relevant to a particular valuation, let alone know what the value may be.

Just as for carbon credits it is recommended that any forest valuation disclose whether any other environmental credits were considered, and how they were considered. Even if they were not considered at all then it is recommended that a statement to that effect be included in all forest valuations.

### 13.15.3 Social and environmental values

Rivas Palma (2005) provides cogent reasons for asserting that “The value of forest ecosystems is usually underestimated if only the direct immediate commercial value of timber and timber products is considered”. Aspects that may need to be considered include; air quality, biodiversity, carbon, climate regulation, erosion control, nutrient cycling and water regulation.

The first question this raises is how to quantify these indirect values? The second question is whether these indirect components should or should not be included in any forest valuation? Certainly there is little doubt that they increase the total value of the forest but by how much?

AASB 141 may or may not be relevant for a particular forest valuation, but it is explicit in stating that it applies only to forests established for profit. However, even if AASB 141 is relevant, it can be argued that even if the forests were established for profit these indirect values are also relevant and should be considered.

The understanding and quantification of these issues will continue to evolve.

At present they might simply be considered a generally positive risk that might be used to offset the other negative risks perceived by many forest valuers. Consideration of these indirect increases in value may well provide a further argument for reducing the value of β for risk used in determining the discount rate using the simple capital asset pricing model described earlier.
13.15.4 Lease payments

The subject of lease payments has always been a difficult area for forest valuers to interpret as it would seem reasonable for the forest component of the asset to be similarly valued whether or not the land is leased or owned.

In an early version of AASB 141 there is a section that notes the incompatibilities between AASB 1037 and AASB 141. Sections A.2 and A.3 are reproduced here as they may assist.

“A.2 Leases of non-human living assets other than biological assets

Non-human living assets, other than biological assets, held under a lease are subject to AASB 117 Leases, such that where:

- the item is subject to a finance lease, the lessee recognises a lease asset and lease liability, measured at the inception of the lease at a lower of the fair value of the leased property and the present value of the minimum lease payments (AASB 117:12); or
- the item is subject to an operating lease, it continues to be lessor-controlled property and the lessor applies the measurement requirement of AASB 116 Property, Plant and Equipment, together with the AASB 117 requirement that such assets be presented according to their nature.

Where exclusive rights to non-human living assets other than biological assets are obtained under a finance lease, AASB 1037 (paragraph 2.1(b)) requires a lessee to recognise and measure the right at its net market value, as if that right is itself a non-human living asset other than a biological asset. Similarly, where such an asset is subject to an operating lease, the lessor applies AASB 1037.

A.3 Operating leases of biological assets

Under AASB 117.25 a lessee of a biological asset does not recognise an asset but instead recognises the operating lease payments as an expense. In contrast, where an ongoing lease gives the lessee an exclusive right over SGARAs, AASB 1037 (paragraph 2.1(b)) requires the lessee to recognise and measure that right at its net market value, as if that right is in itself a SGARA.”

It would still seem sensible to treat a valuation of forest on leased land and owned land separately for many forest valuation purposes. However for financial reporting the exact nature of the lease impacts on the accounting treatment that should be applied and so ACFA suggests that it is advisable to consult a suitably qualified accountant or accountancy firm in this regard.

Further General References on Leases

Bhati, U.N. (2000b) [Discusses leases and quotes some indicative rentals]

13.15.5 Government grants

AASB 141 specifically addresses the accounting treatment for government grants. It requires (AASB 141:34) that unconditional Government grants be recognised immediately as income, but only when the government grant income is received. AASB 141:35 similarly recognises conditional Government grants to be recognised immediately as income, but only when the conditions attaching to the grant are met.

It is recommended that AASB 141 (Paras 34-38, A.5) be consulted if there are any Government grants that have to be considered in a forest valuation.
13.15.6 International examples of forest valuation

The United Nations Food and Agriculture Organization has a web site http://www.fao.org/forestry/valuation that, in 2005, included some 95 examples from Africa, Asia and Latin America. The data base contains short summaries of each study, the outputs valued, the methodologies used, and the value estimates produced.

13.16 Other possible considerations

13.16.1 Rotation length

One of the basic requirements in forest management is to determine, or define, the rotation length in the case of plantations or cutting cycle length for natural forest. Rotation length can affect forest value quite considerably. Rotation length must always be considered together with the objects of management of the forest.

Plantations

The diagram below shows a theoretical yield curve together with its pai (periodic annual increment) and mai (mean annual increment) curves with the increment curves scaled to make the trends more obvious. Note that the pai curve crosses the mai curve when the mai is at a maximum.

This age is the age at which yield is maximised and historically was one of the determinants of rotation length. It may be more appropriate to consider yield of a product or a group of products rather than total volume yield because different products have different values.

However as forestry is a business the rotation length is generally determined on economic grounds and not simply set to maximize yield. This economic approach can better reflect the relative values of different products.

Clutter (Clutter et al. 1983) provides a good starting point for a discussion on rotation length. In the Australian context Leech (1993) discusses rotation length for radiata pine in South Australia.

If economic analyses are to be used to determine optimal rotation length then great care needs to be taken to ensure that the correct discounting rate is used as the PV analysis is very sensitive to discount rate.

Native forests

The rotation may be very long in native forest. It may be indeterminate as there is commonly no prediction of the time that it takes for seedlings and saplings to be recruited into the smallest diameter class measured at time of inventory, and it is certainly not constant for all trees, especially in a mixed species forest.
In the case of regrowth forest it can generally be determined precisely and similar analyses to plantation species are then possible.

The more common consideration in native forest is the cutting cycle (equivalent to thinning interval in plantations) the interval between successive harvests. One of the better known silvicultural systems is used in the management of Teak (*Tectona grandis*) in Myanmar where trees greater than 7'6" girth (ca 75 cm dbhob) are removed every 30 years and this regime was shown as early as the late 19th century to provide merchantable yields that could be achieved sustainably.

The determination of rotation length in native forests may be influenced by water yield and other characteristics as well as volume growth. Clarke (1994) suggests that water yield is highest at early ages and at later ages and so if water yield is considered an important aspect in determining the forest management strategy to be adopted then this may influence the selection of rotation length.

### 13.16.2 Certification

Many forest organisations have sought and obtained certification under various schemes for forest certification.

The information required to ensure certification is maintained may provide soundly based, auditable information of use in carrying out a forest valuation.

### 13.17 Comparisons between forest entities

Most forest enterprises want to be able to compare their financial performance with the financial performance of other similar enterprises as part of a general policy of prudent financial management. The diversity of methodologies used for current forest valuations makes this problematic.

The earlier discussion indicates that there are a wide range of aspects that need to be considered when carrying out a forest valuation and indicates how quite different values might be placed on the same entity, depending on which assumptions are made.

The assumptions that have been made by different enterprises need to be continually borne in mind when comparing the financial reports, or forest valuations, of different enterprises because it may affect the conclusions. A difficulty is that the information needed to make such comparisons may not be readily available. It can be extremely difficult to achieve consistency.

### 13.17.1 An example by the Productivity Commission

One published comparative analysis is that of the Productivity Commission (2005) which compared the five largest forestry-based Government Trading Enterprises (GTE).

It is understood that some analysts have made quite scathing comments about this analysis but the purpose of this discussion is not to take issue with any particular aspect of the Productivity Commission (PC) analysis, nor to suggest what the “correct” analysis might be, but to indicate some of the reasons why differences in interpretation might occur.

Since 2000 the annual change in forest valuation appears directly in the financial reports, even though the revenue cannot be realised. This amount is generally a very significant amount and in some cases is the largest component. For any comparison to be meaningful then the forest valuations for the enterprises being compared should be made on the same basis and ideally any year on year fluctuations should also be dampened by using a longer term trend.
The Productivity Commission (PC) report acknowledges that:

“DPI Forestry in Queensland, the FPCWA and Forestry Tasmania used different approaches to estimating the NPV of timber assets. ForestrySA used current market prices, though ‘pre-commercial’ stands of timber (those aged less than 15 years were valued at current costs. SFNSW used market price to assess softwood plantation and native forest timber but valued hardwood plantations on the basis of historical cost due to difficulties in determining market prices for this asset.”

Of the five GTEs three used different variants of the PV approach and the other two used the lump sum approach with one using a current cost basis for young plantations and the other a historical cost basis for all hardwood plantations. Note that DPI Forestry is now Forestry Plantations Queensland and that FPCWA is the Forest Products Commission of Western Australia.

It can only be concluded that the five GTEs each used different valuation approaches.

Simply by comparing the five GTEs the Productivity Commission analysis seems to imply that because each enterprise believes that it uses and interprets the AASB 141 standard correctly that the forest valuations are comparable.

This implication needs to be treated with considerable caution. The difficulties of getting at the base information to ensure that any such comparison is meaningful should also be recognised and a reader must accept that it may not be possible to get comparable information from the published or available information across the five government enterprises, or for that matter across any commercial forestry enterprises.

Difficulties also occur when an organisation, for whatever reason, makes an extraordinary adjustment to its accounting methodology. Some organisations would seem to smooth out the forest valuations, perhaps by the use of the particular valuation approach they use, whereas others would seem not to.

For example the report indicates that for Forestry Plantations Queensland, formerly DPI Forestry, the increment in market value of the standing timber assets for 2001-02 to 2003-04 was $156 million, $334 million and $2 million respectively. It has been suggested that the major component in this fluctuation is the changes in the Weighted Average Cost of Capital (WACC). It is also believed that Forestry Plantations Queensland has since reviewed their methodology for calculating the WACC in order to reduce the large year on year swings in asset valuation. The variation that this one component alone can occasion is somewhat disturbing but not totally surprising. Note also that the revenue is stated as having fallen by $335 million, almost totally (ca 99%) due to the difference in the change in value of the standing timber component! Given that this revenue cannot be realised the year on year fluctuations in forest valuation need to be analysed with considerable care.

There are also believed to be differences in the way revenues are determined and are treated in the financial reports between forestry enterprises although this cannot be confirmed as this information is not readily available.

These differences in the way the various accounting standards seem to be being treated can only add to the difficulties when attempting to compare forestry enterprises.

It can be concluded that until forest valuations are more consistent and follow a consistent methodology and until accounting standards are interpreted consistently, that such cross enterprise comparisons, while highly desirable, can be quite problematic. Great care is needed in their interpretation.

Simply, it is just this general concern that led ACFA to the development of the Forest Valuation Standard and this Handbook!
Part V  CASE STUDIES AND CHECK LISTS

14  Case studies

Although the valuation standard and this handbook provides information useful in the carrying out a forest valuation examples are provided of some of the applicable methods for valuing forests.

As no two studies are exactly the same and this section provides a range of examples to enable the reader to assess what may or may not be appropriate for their particular forest valuation.

14.1  A possible classification of forest valuations

Earlier it was stated that there is no one method of forest valuation that is appropriate for all circumstances.

ACFA suggests that before a method of forest valuation can be selected and applied, a number of pertinent issues must be considered. The following simple classification may be useful.

Forest valuers should apply the ACFA (2004, 2007) standard and the approximate classification below is to be used as a guide only. The discussion here is indicative rather than definitive and is provided to assist valuers consider the possible approaches that might be desirable.

Forest size
- Few stands
  Can generally value each stand separately and combine the values as with few stands there are generally no complex yield scheduling considerations. For valuing a forest that includes a few stands the most appropriate approach is generally PV, although if nearing maturity the lump sum approach may be relevant.

- Many stands
  Whether the area is being managed as a forest or as a series of separate stands can be a matter of semantics and opinion. For valuing a forest that includes many stands the most appropriate approach is generally PV.

Age class
- Young / immature
  Compounded costs may be the most appropriate if the valuation is for insurance purposes. However discounted PV may be more appropriate for other purposes. It depends on the reason for the valuation being carried out.

- Mature
  If there are only a few stands then lump sum value may be appropriate providing access to markets is available and assured. As the discounting period is likely to be small PV approaches will generally provide similar values.

- All age classes
  If a forest consists of all age classes then it is generally better not to value each stand separately as the overall management of the forest impinges on the management regimes to be applied to each stand. It is better to determine an overall management strategy, apply that to each stand in the forest and then sum the separate values. One simple indicator is whether the forest is expected to provide a near constant stream of wood
flows. Discounted PV is generally the most appropriate approach, applied across the whole forest.

Reason for valuation

- **Financial reporting**
  Whether or not the owner is required to report under the Corporations Act is an important consideration. The ACFA (2004, 2007) standard suggests that in most cases PV will be the most appropriate method although analysis of past transactions is important. The valuation must meet the appropriate AASB standards.

- **Insurance**
  If the forest is young or immature then the best approach may be compounded costs of establishment. If valuing a forest with a wide range of age classes then PV is generally more appropriate. The choice may depend on the methodology required by the insurance broker.

- **Sale**
  Ideally transaction approaches should be used, but as discussed earlier transactions may be limited and difficult to interpret. PV approaches are generally used. If the prospective owner desires to clear the land then it may be sensible to get tenders to determine the lump sum value (or sometimes called the immediate liquidation value) and subsequent clearing costs. Consideration of AASB standards may not be required but may be appropriate.

- **Investment**
  PV is probably the most appropriate. However taxation considerations often are the primary concern of the investor and may even drive the investment decision.

- **Financial management**
  PV is probably the most appropriate.

- **Other**
  The choice of methodology will depend on the reason for the valuation.

Some of the other more important considerations

- **Are AASB accounting standards relevant?**
  If they are then this may limit the range of valuation options that are appropriate. It may also require detailed explanation of why the particular forest valuation methodology was accepted.

- **Is ASIC relevant?**
  If it is then this may also limit the range of valuation options that are appropriate.

- **Are there taxation implications?**
  If there are then this may need direction from the client commissioning the valuation.

- **Terms of Reference**
  The valuation may be limited by conditions set by the entity in the Terms of Reference. This is likely to impact whether pre-tax or post-tax analysis is required.

- **Are there any contracts in place?**
  If there are then they may affect the valuation for other than accounting purposes under AASB standards. If long term wood supply contracts are in place it may limit the use of option pricing.
Environmental considerations
These may affect the valuation depending on the reason for carrying out the valuation.

Contingencies
Must be considered.

Is the valuation likely to be used for other purposes?
If there are any other likely uses for the valuation then care should be taken to specify exactly why the valuation was being made and what the assumptions are in the analysis in order to limit the possibility of it being used in circumstances that are not appropriate. This is almost impossible to ensure, but the danger of misuse should be minimised.

This list is not exhaustive, but each of these aspects ought to be considered because, as has been shown elsewhere in this Handbook and in the ACFA forest valuation standard (2004, 2007), they can impact the selection of the methodology to be used.

14.2 Case study 1 – a single stand

The simplest example of a valuation is a theoretical analysis of a single plantation stand with costs and returns detailed below.

In the example below there is a fixed establishment cost, another fixed cost at age 3 (for example a treatment for insect attack or a fertiliser application), annual maintenance costs which in this case are considered to occur for each of the years after establishment, and a return at age 10 when the stand is clear felled.

<table>
<thead>
<tr>
<th>Year</th>
<th>Costs $/ha</th>
<th>Annual costs $/ha</th>
<th>Returns $/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1000</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>50</td>
<td>10 000</td>
</tr>
</tbody>
</table>

This is provided as a simple example, which can be expanded to meet more typical single stand valuations.

PV at age 0

If the real interest rate is set at 7.0% then the discounted components to age 0 are:

- Costs \((-1000 - 100 / 1.07^3)\) $ - 1081.63

---

\(^1\) To calculate the total of the series of annual costs
if total = \[50 \times (1.07^3 + 1.07^2 + 1.07 + \ldots + 1.07^9 + 1.07^{10})\]
and if series = \[0.07 \times (1.07^3 + 1.07^2 + 1.07 + \ldots + 1.07^9)\]
then series (1.07) = \[1.00 - 1.07] / 0.07
and by subtraction series (1.07 – 1.00) = \[(1.00 - 1.07^{10}) / 0.07\]
or series and therefore total = \[50 \times (1.00 - 1.07^{10}) / 0.07\]

As at 2007, reformatted 2012 but no textural changes
• **Annual costs**  \((-50 / 1.07 - 50 / 1.07^2 - ... 50 / 1.07^{10})\)
  
  or  
  \((-50 (1.00 - 1.07^{10}) / 0.07)\)  
  $\rightarrow 351.18$

• **Returns**  \((+10000 / 1.07^{10})\)  
  $\rightarrow 5083.49$

**Total**  $\rightarrow 3650.68$

### PV at other ages

If the same stand is valued at another age, say 6, and if it is assumed that the annual maintenance costs for year 6 have already been paid, thus leaving four years costs to be discounted, then the discounted components are:

• **Annual costs**  \((-50 / 1.07 ... 50 / 1.07^{10-6})\)
  
  or  
  \((-50 (1.07^{6} - 1.00) / 0.07)\)  
  $\rightarrow 169.36$

• **Returns**  \((+10000 / 1.07^{4})\)  
  $\rightarrow 7628.95$

**Total**  $\rightarrow 7459.59$

If the assumption is made that the annual maintenance costs for that sixth year have not been paid then the value is decreased by $50.00 to $7409.59.

It is a relatively simple matter to extrapolate these calculations to cover various costs and returns in various years, or even by adjusting the calculation method detailed in the footnote, calculating recurring costs every 2, 3, or any other interval of years.

Most spreadsheet programs have functions that readily enable such calculations to be made but care must be taken to ensure that the calculation method is being interpreted correctly.

### Compounded costs

If it is desired to value the stand at age 6 for insurance purposes then it may be more appropriate to value the stand based on the cost of replacement.

Discounting forward the comparable components are:

• **Costs**  \((-1000 \times 1.07^6 - 100 \times 1.07^{6-3})\)  
  $\rightarrow 1623.23$

• **Annual costs**  \((-50 \times 1.07^5 - 50 / 1.07^5 ... - 50 / 1.07^{5-5})\)
  
  or  
  \((-50 (1.07^5 - 1.00) / 0.07)\)  
  $\rightarrow 357.66$

**Total**  $\rightarrow 1980.89$

Note that if the PV of the plantation at age 0, $3650.68, is compounded forward 6 years at 7% interest the value is $5478.69, and this is the same as the PV at age 6 of $7459.59, less the compounded costs of $1980.89, apart from rounding error.

This cost compounded method is an underestimate of the true replacement cost for two main reasons.

• There would be a cost for clearing the age 6 plantation if it was killed by fire, and at that age the salvage value would be minimal.

• The replaced forest would be six years (or more) behind the forest it is replacing and that may impact wood flows and future cash flows if this stand was one stand amongst many managed by an entity.

Although it may be decided to insure for the value calculated above it would be sensible to advise the insurer that that value is an underestimate of the true value to the organisation as this may assist gaining a better premium as the risk is being shared. In general insurance parlance this is not true replacement value but a lesser value that enables the crop to be replanted, but at some, possibly considerable, cost to the organisation in terms of delayed wood flows.
14.3 Case study 2 – a blue gum plantation

This case study was provided with the approval of the company commissioning the forest valuation. ACFA gratefully acknowledges the contribution and consent of both the company and its consultant who produced this modified version of the report which shall be treated as an example only. The detailed figures must not be used for any purposes whatsoever.

The valuation was carried out in 2003 prior to AASB 141. Some changes have been made to the report to reflect its use as a Case Study rather than as a valuation report.

The brief

A Fictitious Investment Company Pty Ltd (FIC) requested a consultant, as forest valuer, to value its plantation assets. The financial statements of FIC were required to be audited and the auditors required a valuation of the plantation. The forest valuation to be included in the accounts was to be prepared in accordance with AASB 1037 but given that the plantation was not material to the FIC’s net assets, the precision of the valuation was not critical. The final report was required within six weeks.

The client advised that the plantation comprised 214 ha of Tasmanian blue gums planted 6.4 years previously. The client provided a copy of the title.

The plan

An enquiry to the local valuer’s office confirmed that there was no suitable transaction evidence of the value of plantations in the region.

To generate the value of the plantation required calculation of the lump sum value of the plantation and the PV of future cash flows. These calculations required the following;

- the net effective area of plantation,
- the average standing volume,
- the average stumpage value of the plantation, and,
- projections of plantation growth and stumpages into the future.

Given that a high level of precision was not required by the client and that there was no existing information about the variability of the plantation, it was decided to measure randomly located fixed area plots (0.02 ha circular plots).

Data gathering

The forest valuer obtained copies of an aerial photograph of the property and cadastral information on the title boundaries. The corners of boundary fences and plantation boundaries and gaps (retained native vegetation and dams) were mapped using non-differential Global Positioning System (GPS) travelling within 2 metres of the edge of the plantation. Having entered this information into a MapInfo Geographic Information System (GIS) the Gross Area on the property was calculated to be 259 ha and the Net Effective Area of the plantation was calculated to be 194 ha.

During the mapping exercise, and from inspection of the aerial photographs, it was observed that the plantation was fairly uniform. Only minor edge areas showed significant variation from the overall plantation. Stratification of the plantation into high, medium and low yielding classes was considered unlikely to provide much improvement in sampling precision.

The terrain was quite flat and soils were sandy duplex soils common in the area. Trees were observed to have been planted in straight rows running north-south 5 m apart with trees 2 m apart within the rows. Access through the plantation was easy.

An objective survey entailing 44 randomly located sample plots was used to gather information on the plantation stocking and size of the trees. Plots were allocated by random number generated map...
grid coordinates and located objectively in the field. Each was a 7.98 m radius (0.02 ha) circular plot. For each plot the following data were recorded:

- the map coordinates (easting and northing) using GPS,
- species,
- tree diameter at breast height over bark (DBHOB) using a girth tape, and,
- the height of the three largest diameter trees of good form, using a clinometer.

Information on current log prices and harvesting and haulage costs was gathered from local traders and contractors.

Results and analysis

Measurements were analysed using the Farm Forestry Toolbox (FFT4) (Private Forests Tasmania 2004), verified by the forest valuers own spreadsheets, and projections were made on the basis of several published models of blue gum growth.

The summary results of plot measurements as processed using the consultants’ spreadsheets are presented in Table 1 below. Detailed results by plot are presented as an Annex at the end of this report

<table>
<thead>
<tr>
<th>Stocking (stems/ha)</th>
<th>Average Dbhob (mm)</th>
<th>Basal area (m²/ha)</th>
<th>Height (m)</th>
<th>Volume (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of all 44 plots</td>
<td>826</td>
<td>134</td>
<td>12.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Standard error</td>
<td>25</td>
<td>2</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Confidence level (95%)</td>
<td>50</td>
<td>4</td>
<td>0.7</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The Farm Forestry Toolbox estimated there was 4 tonnes/ha residue in stumps and tops of trees. The estimated standing saleable volume of pulpwood was 53 tonnes/ha on 194 ha or 10 200 tonnes with 95% confidence limits of 800 tonnes (9 400 tonnes to 11 000 tonnes).

Projections

Future growth of plantations is very uncertain because models available for this work are imperfect and because of agricultural risk. Models assume the continuation of average conditions but future growth will be determined by climatic and environmental conditions which can vary widely from average.

These results were projected using the models in FFT4 and using algorithms developed by Wong et al. (2004). The results of projections are presented in Table 2 below.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Standing volume</th>
<th>Projected volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FFT4</td>
<td>Wong et al.</td>
</tr>
<tr>
<td>Standing volume</td>
<td>6</td>
<td>57</td>
</tr>
<tr>
<td>Projected volume</td>
<td>10</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>234</td>
</tr>
</tbody>
</table>

The forest valuer adopted the view that these represented the high and low estimates of future volumes and that a reasonable estimate was the mean of these estimates. That is, the mean estimates of future volumes were 155 tonnes/ha at age 10 years with potential for growing on to 207 tonnes/ha by age 12 years. Harvesting losses of 7 tonnes/ha at age 10 and 8 tonnes/ha at age 12 were expected. The saleable yields for the plantation were therefore projected to be 148 tonnes/ha (132–164 tonnes/ha) or 28 700 tonnes (25 600–31 800 tonnes) at age ten. If the trees were grown on...
to age 12 years the projected yields were 199 tonnes/ha (171–226 tonnes/ha) or 38 500 tonnes (33 200–43 800 tonnes).

**Timber value**

The plantation was established with the objective of growing pulpwood products to sell into the export market as woodchips. Pulpwood was likely to be sold on a stumpage basis, that is, the residual value of the pulpwood after deducting from the Mill Door Price the costs of harvesting and transporting the logs to the woodchip mill.

There was currently only one mill purchasing blue gum pulpwood within an economic haul distance of the plantations. It was likely other purchasers would become active in the future and this has since eventuated. The 2003 Mill Door Price was $52 /tonne delivered which increased to $65 /tonne delivered in 2005.

The cost of harvesting depends on the harvesting system and the stem sizes being handled. If the trees were harvested using the currently available harvesting systems the forest valuer estimated the harvesting costs to be $30 /tonne (range $28–35 /tonne) but it would have been difficult to find contractors willing to take on the operation at age 6.

At age 10 years the forest valuer estimated harvesting would cost approximately $17 /tonne (range $16–18 /tonne) and at age 12 years $16 /tonne (range $15–17 tonne) including an allowance of $1.50 tonne for roads and ancillary costs. Delivery (load and transport) costs over the 38 km to the woodchip mill were predicted to be approximately $6.00 /tonne ($±0.50 /tonne).

Therefore, in current day (real) prices in 2003 the residual stumpage values of the pulpwood sold was estimated to be $16.00 /tonne ($10.50–18.50 /tonne) as at the reporting date (age 6), $29.00 /tonne ($27.50–30.50 /tonne) delivered at age 10 years or $30.00 /tonne ($28.50–31.50 /tonne) delivered at age 12 years.

**Plantation yields and revenue**

If the plantation was to be harvested immediately the lump sum value of the timber could be based upon 194 hectares yielding 53 tonnes /ha (49–57 tonnes/ha) or 10 200 tonnes (9 400–11 000 tonnes) at $16.00 /tonne ($10.50–18.50 /tonne) for a total value of $163 200. The low estimate was $98 700, the high estimate $203 500.

If the plantation was maintained for a further 4 years and harvested in mid 2007 at age 10 then in current (2003) values the projected timber yields would be 194 ha at 148 tonnes/ha (132–164 tonnes/ha) or 28 700 tonnes (25 600 tonnes to 31 800 tonnes) at $29.00 /tonne ($27.50 /tonne to $30.50 /tonne) giving revenue (2003 values) of $832 300 (range $704 000 to $969 900).

If the trees were grown on to be harvested 12 years after planting then the projected yields would be 194 /ha at 199 tonnes/ha (171–226 tonnes/ha) or 38 500 tonnes (33 200–43 800 tonnes) giving revenue (2003 values) of $1 155 000 (range $946 200–$1 379 700).

**Future costs and discounted cash flows**

In determining the projected values three scenarios were evaluated:

1. a medium (the expected) scenario,
2. a high cost and low returns scenario, and,
3. a low cost and high returns scenario.

Historical costs for the last two years indicated the only costs incurred were local government rates of approximately $10.00 /ha which was used in the high value estimates. For the medium value the forest valuer allowed for other maintenance costs of $10.00 /ha to allow for firebreak maintenance and monitoring. For the low value regime the costs of a high maintenance regime were evaluated, including costs of $50.00 /ha each year to cover rates, firebreak maintenance, control of weeds and

As at 2007, reformatted 2012 but no textural changes
feral animals, regular inventory, contributions to fire protection agencies and equipment, contributions to research agencies and participation in industry groups.

The costs of preparing the land for a second rotation or return to agriculture were not included. This is consistent with the accounting standard AASB 1037:5.3.2(c) and also ACFA (2004) in that related cash flows should not include outflows for re-establishing a SGARA (Self Generating and Regenerating Asset) after harvest because those outflows are related to future SGARAs.

Insurance of the plantation against loss caused by fire and wind storm was available and was included to reduce some of the risk of the venture. Actual insurance costs were 0.97% of the insured value of $400 000 ($2061/ha/year). A known plantation insurance scheme had premium rates of 1.4% of scheduled medium values of $4066/ha (6 year old) with a no claim continuity discount of 21%. Insurance costs in the medium and low return high cost regimes were included. For the high value low cost regime half the insured values and a premium rate of 0.97% were applied.

The inflation rate was 3.4% inflation (CPI March, ABS) and the market 10 year bond rate was 5.2% (1.7% real plus inflation).

The forest valuer considered that there was relatively low risk in the venture at this stage. The trees were well established and growing satisfactorily. The cost of insurance against fire and wind damage had been accounted for. The market was established and demand was likely to strengthen rather than weaken. Uncertainties prevailed regarding the future growth rates, the effect on price of increasing supplies and the effect on price of a strengthening Australian currency. Therefore the risk in the plantation crop was considered similar to the risk in traditional agricultural cropping such as grains, (climatic risk such as drought, rain, frost, wind and hail, fire risk, risk of flooding, insect and pathogenic risks). The current (specified) bank five year term secured loan variable interest rate was 8.25% (4.7% real). An alternative bank indicator lending rate was 8.25%.

A real discount rate of 4.7% which, with 3.4% inflation, was equivalent to a market rate of 8.25% was adopted.

The future pre-tax cash flow for the medium value scenario plantation grown to age 12 years was projected in real values as shown in Table 3.

<table>
<thead>
<tr>
<th>Age</th>
<th>$ (real values in 2003)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Costs</td>
<td>3 880</td>
</tr>
<tr>
<td>Insurance</td>
<td>8 724</td>
</tr>
<tr>
<td>Revenues</td>
<td>1 155 000</td>
</tr>
<tr>
<td>Net cash flow</td>
<td>-12 604</td>
</tr>
</tbody>
</table>

Discounted at a real rate of 4.7% this cash flow had a Present Value of $743 000 at the date of valuation.

Sensitivity to the low yields, values and high costs scenario, and the high yields, values and low costs scenario indicates the range of projected outcomes at 4.7% real discount rate. This was estimated on a twelve year and ten year rotation. Details of our analysis of alternative scenarios were attached with a summary below.
Table 4 Summary of scenario analysis

<table>
<thead>
<tr>
<th>Harvest age</th>
<th>Units</th>
<th>Low value estimate</th>
<th>Medium estimate</th>
<th>High value estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Standing t/ha</td>
<td>53</td>
<td>57</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Yield t/ha</td>
<td>49</td>
<td>53</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Yield t</td>
<td>9400</td>
<td>10200</td>
<td>11000</td>
</tr>
<tr>
<td></td>
<td>Stumpage $/t</td>
<td>10.50</td>
<td>16.00</td>
<td>18.50</td>
</tr>
<tr>
<td></td>
<td>Revenue $</td>
<td>98700</td>
<td>163200</td>
<td>203500</td>
</tr>
<tr>
<td></td>
<td>PV @ 4.7% $</td>
<td>98700</td>
<td>163200</td>
<td>203500</td>
</tr>
<tr>
<td>10</td>
<td>Standing t/ha</td>
<td>139</td>
<td>155</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>Yield t/ha</td>
<td>132</td>
<td>148</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Yield t</td>
<td>25600</td>
<td>28700</td>
<td>31800</td>
</tr>
<tr>
<td></td>
<td>Stumpage $/t</td>
<td>27.50</td>
<td>29.00</td>
<td>30.50</td>
</tr>
<tr>
<td></td>
<td>Revenue $</td>
<td>704000</td>
<td>832300</td>
<td>969900</td>
</tr>
<tr>
<td></td>
<td>PV @ 4.7% $</td>
<td>469000</td>
<td>596000</td>
<td>741000</td>
</tr>
<tr>
<td>12</td>
<td>Standing t/ha</td>
<td>179</td>
<td>207</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td>Yield t/ha</td>
<td>171</td>
<td>199</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>Yield t</td>
<td>33200</td>
<td>38500</td>
<td>43800</td>
</tr>
<tr>
<td></td>
<td>Stumpage $/t</td>
<td>28.50</td>
<td>30.00</td>
<td>31.50</td>
</tr>
<tr>
<td></td>
<td>Revenue $</td>
<td>946200</td>
<td>1155000</td>
<td>1379700</td>
</tr>
<tr>
<td></td>
<td>PV @ 4.7% $</td>
<td>558000</td>
<td>743000</td>
<td>958000</td>
</tr>
</tbody>
</table>

These analyses indicated the most profitable scenario was to grow the plantation out to 12 years. This was true at real discount rates of up to 15.5% for the medium scenario, 12.5% for the low value scenario and 18.5% for the high value scenario.

The present value of the timber should be taken as the highest present value of the various management scenarios. The forest valuer concluded that the Present Value of the timber on the plantation is $743,000 with a range of estimates $558,000 to $958,000.

Disclaimer
This report was provided for the purpose of assessing the subject plantation and providing advise on potential management options.

The forest valuer has relied upon information provided by the client as detailed in the report.

The author acknowledges that projections of plantation growth are unreliable because of imperfect models, unpredictable climatic and other environmental conditions. The models must not be applied as errors contained in them are potentially significant.

Future market prices and costs of harvesting and haulage are affected by unpredictable factors including currency exchange rates and various economic factors. The authors claim no expertise in relation to these factors.

Annex: Plot measurement results

[Eastings and Northing were recorded as columns 2 and 3 but have been deleted from this example to preserve confidentiality.]
<table>
<thead>
<tr>
<th>Plot</th>
<th>SPH</th>
<th>Average DBHOB (mm)</th>
<th>Basal Area (m²/ha)</th>
<th>Predominant Height (m)</th>
<th>Standing Volume (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>750</td>
<td>143</td>
<td>12.3</td>
<td>13.5</td>
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</tr>
<tr>
<td>5</td>
<td>900</td>
<td>124</td>
<td>11.2</td>
<td>12.4</td>
<td>46</td>
</tr>
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<td>6</td>
<td>800</td>
<td>144</td>
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<td>66</td>
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<td>12.6</td>
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<td>13.1</td>
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<td>10.6</td>
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<td>14.6</td>
<td>85</td>
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<td>43</td>
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<td>1000</td>
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<td>13.5</td>
<td>59</td>
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<td>800</td>
<td>136</td>
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<td>16.0</td>
<td>67</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>0.3</td>
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<td>2</td>
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<tr>
<td>Confidence level (95%)</td>
<td>50</td>
<td>4</td>
<td>0.7</td>
<td>0.3</td>
<td>4</td>
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</table>
14.4 Case study 3 – choice of cashflows; pre-tax or post-tax?

Both pre-tax and post-tax cashflows may be used in deriving market values. If discount rates appropriate to the cashflow type are used, either approach should lead to the same value for the tree crop providing the wood flows remain the same.

Post-tax cashflows are generally preferred as rates implied by analyses of sales price using post-tax cashflows tend to show more consistency than when pre-tax cashflows are used. There is no fixed relationship between the discount rates appropriate for a pre-tax cashflow and for a post-tax cashflow of the same resource. This is due, in a large part, to the variable effects of the cost of standing timber deductions on forests with different maturity profiles.

A difficulty with the use of post-tax cashflows is the need to make an assumption regarding the potential purchaser’s tax situation. A common approach is to assume the company tax rate applies and that all tax deductible expenditure and credits can be deducted from revenue in the year that they occur. It is also common to assume that the tree owner has 100% equity.

This case study was provided by a consultant and is based on realistic assumptions. It is not possible to directly apply the conclusions to particular circumstances but the results are indicative.

Cost of standing timber deduction

Section 124J of the Income Tax Assessment Act 1936 allows the price paid for trees or the right to fell standing timber to be deducted from later revenue arising from those trees. This is known as the cost of standing timber deduction.

There is no ‘cost of standing timber’ if the tree owner planted the trees themselves (the development costs will have been largely claimed against other income in the year that they were incurred).

A purchaser of both land and trees needs to clearly identify the portion of the purchase price that is attributable to the trees. Although the amount relating to the trees does not need to be specifically stated in the contract, there should be documentary evidence that part of the purchase price is attributable to the trees.

The value of the cost of standing timber deduction in a year is the proportion of the price paid for the trees that is attributable to the timber felled during the particular year of income. Taxation Ruling 95/6 by the ATO describes the two methods available to calculate the cost of standing timber deduction; one is volume based and the other is tree number based. The selection of the most tax-efficient treatment will depend on the quantity and timing of thinnings planned and it will generally be necessary to evaluate both alternatives before deciding which method to adopt.

1 If the standing crop will undergo little thinning before clearfell, the volume method is likely to provide the most tax efficiency. The method involves estimating the proportion of the standing volume at the time of purchase accounted for by the harvest in each year.

2 If a significant production thinning programme is planned, the tree-number approach is likely to result in larger early deductions.

The value of the cost of standing timber deduction remains set in historical terms. In a real cashflow where values are all expressed in current dollar terms, the historical purchase price needs to be adjusted for the erosion of value due to inflation.

Illustration of the difference between pre-tax and post-tax analyses

Table 1 shows a simplified real cashflow for a tree crop resource consisting of a nearly mature long rotation crop on leased land. The resource is assumed to be harvested over two years, starting one year after purchase.

As at 2007, reformatted 2012 but no textural changes
Table 1
Case study of a nearly mature long rotation crop on freehold land

<table>
<thead>
<tr>
<th>(Year beginning 1st July)</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest Production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clearfelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total forest area</td>
<td>ha</td>
<td>200</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Total area clear felled</td>
<td>ha</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Yields/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All merchantable grades</td>
<td>m³/ha</td>
<td>200</td>
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</tr>
<tr>
<td><strong>Total production</strong></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>m³</td>
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</tr>
<tr>
<td><strong>Clearfell log revenues</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average delivered log price</td>
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<td>50.00</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$/m³</td>
<td>25.00</td>
<td>500,000</td>
<td>500,000</td>
</tr>
<tr>
<td><strong>Stumpage Revenue</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>500,000</td>
<td>500,000</td>
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<td><strong>Forest Operating Costs</strong></td>
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<td>Annual overheads</td>
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<td>20,000</td>
<td>20,000</td>
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<tr>
<td>Land lease</td>
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<td>36,000</td>
<td>18,000</td>
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<tr>
<td><strong>Net Operating Revenue</strong></td>
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</tr>
<tr>
<td></td>
<td>$</td>
<td>-56,000</td>
<td>444,000</td>
<td>462,000</td>
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<tr>
<td><strong>Tax calculation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Proportion of standing volume at time of purchase</td>
<td></td>
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<tr>
<td>attributable to clearfell</td>
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<td>50%</td>
<td>50%</td>
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<tr>
<td>Historic cost of timber</td>
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<td>354,295</td>
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<td>Inflation rate</td>
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<td></td>
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<td>Deflated Cost of Timber Tax Credit</td>
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<tr>
<td>Assessable income</td>
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<td>Tax</td>
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<tr>
<td>Post tax cashflow</td>
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<tr>
<td>Present Value of Tree Crop</td>
<td>708,590</td>
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<td></td>
</tr>
<tr>
<td>Real discount rate applied to post tax cashflow</td>
<td>8.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-tax cashflow</td>
<td>$</td>
<td>-56,000</td>
<td>444,000</td>
<td>462,000</td>
</tr>
<tr>
<td>Present Value of Tree Crop</td>
<td>708,590</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required discount rate for pre-tax cashflows</td>
<td>12.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All harvesting, annual and lease costs are assumed to be tax deductible. The cashflow is a real cashflow with all figures in 2006 dollars. Therefore, the value of the ‘cost of standing timber’ deduction is deflated over time. The ‘historic cost of timber’ is the assumed purchase price of the tree crop; this equals the calculated present value of the tree crop.

The present value of the tree crop assuming an 8% discount rate on the post-tax cashflow is $708,590. In order to produce the same present value from the pre-tax cashflow, a 12% discount rate is required. Such a difference between the pre-tax rate and post-tax rate is outside the range typically used by forest valuers undertaking valuations of Australian resources.

**An alternative example analysis**

Another quite different analysis of a short rotation pulpwood crop scenario investigated the impact on pre-tax and post-tax discount rates of changing the number of years between the date of purchase and the date of harvesting. This is summarised in Figure 1. In each case, the present value of the tree crop investment has been calculated using a post-tax cashflow and an 8% discount rate. Then the discount rate required to produce the same present value from the pre-tax cashflow has been calculated. The discount rates are specific to the assumptions made in the scenario but show that the relationship between post-tax and pre-tax discount rates depends on the age class structure of the estate being valued.
In the long rotation, mature crop analysis the difference between the pre-tax interest rate and the post-tax rate required to produce the same Present Value was 4% whereas for the short rotation crop it varies from 4% to 7% depending on the number of years between purchase and clear fell. This demonstrates that the difference between the pre-tax and post-tax rate is not a simple constant but will vary depending on the specific circumstances.

These differences are higher than the average of the surveyed range of interest rates as used in New Zealand that is described earlier (see Manley 2003, 2005), which was about 2%. The Manley survey had a number of respondents and probably covers a wider range of analyses.

The simple conclusion is that great care should be taken as analyses will likely result in different pre-tax rates for any given post-tax rate.

14.5 Case study 4 – a large plantation estate

This is not strictly speaking a case study but a series of steps in a valuation methodology. The detailed calculations for any large profitable forest estate would just be too great to include in this Handbook and would be “corporate in confidence” anyway and so it is most unlikely that the information would ever be available for publication.

This example is for a large plantation organisation that uses stand models rather than tree models and prefers to predict the growth of basal area and upper stand height rather than predict volume growth directly.

Spatial information, generally available from a Geographic Information System (GIS).

- Certificate of Title details.
- Base survey maps showing net plantation outlines.
- Soil and vegetation maps.
- Site productivity maps.
- Historical records of past logging.
- Historical records of past silvicultural operations.

Inventory, generally available from a computerised data base.
- Plots covering all areas that have been thinned commercially.
- For areas that have not been thinned it is possible to use the site productivity survey, or if that has not yet been carried out because plantations are too young, then potential site productivity can be estimated from the geology, soil and/or past vegetation.
- Areas to be planted can be similarly defined.
- For each stratum (stand, coupe and potential harvesting area) this information is combined with the spatial information to provide the area and attribute information at the date of inventory, whether based on plots or just expected site potential, and initial stocking.

Biometrics.
- Either;
  - basal area growth model,
  - upper stand height growth model,
  - model to predict volume from basal area and upper stand height,
  - or
  - volume growth model.
- Model to predict the amount of mortality that can be expected at any time.
- Model to predict how this mortality will affect increment.

History.
- Historical records of past harvesting operations.
- Historical records of past fertiliser applications.
- Records of significant historical events.
- Historical records of plantation establishment.

Future.
- For each stratum a schedule of proposed silvicultural operations;
  - plant status (seedlings, cuttings etc.),
  - silvicultural spacing,
  - pruning regime,
  - commercial thinning (age of first thinning, thinning interval, stocking after each thinning, thinning type for each thinning, and expected age of clear falling),
  - fertiliser application, and,
  - any other proposed treatment.

Costs.
- Most large forest organisations have detailed formal accounting systems from which the unit costs of operations can be extracted.
• This enables the unit costs to be determined and also enables all costs not directly applicable to specific activities to be included in the general bucket commonly called “annual administration charges”.

• It is also generally possible to independently audit these cost figures and so assist improve the credibility of the forest valuation.

Revenues.
• Many organisations have appropriate stumpage figures that can be used.

Processing system.
• This takes the inventory information for each stratum and predicts future outturn by size and product class for each operation, taking account of historical information and also the planned schedule of silvicultural events.

• This can also provide the necessary economic information for analysis.

• It is also possible to use this information in a detailed optimisation analysis.

For a large commercial plantation forest this activity is not a trivial exercise and it cannot be completed in a very short space of time. Because it is necessary to take a snap shot of the forest at the base point in time this means that all ongoing operations will need to be divided into two sub-strata:

1. one for the completed area, and,
2. the other for the area yet to be completed.

Further, the growth model may be quite complicated to allow, for example, the prediction of the mortality likely to occur and then the effect of this mortality on subsequent growth.

14.6 Other particular issues

The objective of this section is to highlight and discuss some of the quandaries that have been encountered during the experiences of some ACFA members.

Is a valuation economically viable? Example 1

A potential client requested a valuation of the forestry assets of a deceased estate. The assets included about 15 ha of woodlots in an investment project. The difficulty was that the constitution of the project includes a pooling mechanism. Although the investor owns particular forestry lots that can be demarcated on the ground, the future revenues will be determined as the average of the investment pool. Thus any valuation of the asset would require the assessment of the value of the total pool involving many thousands of hectares.

This is not an uncommon practice.

The consultant had to advise the potential client that the cost of valuing this pool would be high relative to the value of his particular asset of only 15 ha. This is a wholly unsatisfactory state of affairs.

One forest management enterprise that has operated in this manner for some years is known to provide, as a service to unit holders, the valuation of each unit, made by their own foresters. This is believed to be at least partly independently audited and can provide a valuation that can be used in some circumstances, although it cannot be considered truly independent.
Is a valuation economically viable? Example 2

One of the more difficult decisions is to balance the cost of doing a valuation with the size or overall value of the forest being valued and the use of that valuation. There can be no certainty that the valuation will not be used for purposes other than that originally intended and some users believe that a valuation is not biased at all and is completely precise. This ideal can ever be achieved and the smaller the forest enterprise being valued the less money can be justified for its valuation and the greater the imprecision and chance of bias.

In one known case the beneficiaries under a will agreed that they would accept the value advised by a consultant who simply drove around the woodlot and walked into it in one or two places and then made a professional judgement of its value. This was quite satisfactory for the purpose intended.

14.7 Other examples

The superseded AASB standards AAS 35 and AASB 1037 provided an example of how a forestry valuation can be handled from a strictly accounting viewpoint. It was not a good forestry example but the notes do provide useful accounting assistance.
15 Check list and example paragraphs

This chapter provides a check list of some items that should be considered. It also provides some draft provisions that might be included in a service contract to provide services. More practically, it provides examples of paragraphs that could/should be, incorporated into a valuation report.

The objective is to provide some possible alternatives disclaimers that might be considered useful by a forest valuer.

ACFA does not warrant that these provisions and example/sample paragraphs shall be legally effective, and strongly recommends the advice of an appropriately qualified legal practitioner be obtained in their regard and generally.

15.1 Check list

This check list provides an indication of aspects that should be considered in any forest valuation or appraisal.

The check list should not be considered complete or binding but an indication of the aspects that ought to be considered in reporting any forest valuation or forest appraisal. For forest appraisals many of the items are likely to be irrelevant. However consideration of these items should assist ensure completeness.

1 The formal agreement or requirement to undertake the forest valuation.
   1.1 Letters or instructions.
   1.2 The Terms of Reference.
   1.3 The contract.
   1.4 Any background information important to the valuation and referred to in the Terms of Reference or the contract

2 The objective(s) and/or intended use of the forest valuation. This should be clear and unambiguous so that any future use of the forest valuation can be assessed to determine whether it is an appropriate use or not. The forest valuer should not provide advice to the client on the Terms of Reference for the valuation.

3 The land title information, survey and ownership.
   3.1 Tenures, easements, other constraints or factors that may affect the forest valuation. These may be recorded on the title.
   3.2 Proof of ownership or control of the biological asset.
   3.3 Any other known land based factors that could affect the forest valuation.
   3.4 Location of the area.
   3.5 Map and cadastral information
   3.6 Aerial photography or satellite or other imagery.
   3.7 Physical description of the land.
   3.8 Limitations imposed by federal, state or local authorities that might affect land use or the valuation.
   3.9 Any other known limitations, such as customary rights or public access.
   3.10 Confirmation that the land as demarcated on the ground matches the title.
   3.11 Land area.
### 3.11.1 Stratified as desirable; generally into total area, planted area, fallow area, stocked and unstocked area, and other classifications that can include roads and firebreaks, water, environmentally sensitive areas, and aesthetic areas.

### 3.11.2 Method of area measurement.

### 3.11.3 Probable accuracy of area information.

### 3.12 Land value, if required.
#### 3.12.1 Basis for land value.
#### 3.12.2 Was it valued by a Certified Practising Valuer (CPV) of the Australian Property Institute (API)?
#### 3.12.3 Definition of what is, and what is not, included in the land valuation.
#### 3.12.4 Consideration of whether the value is appropriate for forest valuation.
#### 3.12.5 Date of land valuation.

### 4 Stand history.
#### 4.1 Source of available records.
#### 4.2 List of available records.
#### 4.3 Completeness and reliability of available records.
#### 4.4 Any known deficiencies in the available records.
#### 4.5 Known changes in ownership.

### 5 The inventory data used, if any.
#### 5.1 The inventory design.
##### 5.1.1 Sampling strategy; including random, stratified random, systematic sampling and other.
##### 5.1.2 Plots, point samples.
##### 5.1.3 Layout.
#### 5.2 Any stratification used, its basis, and why it was used.
#### 5.3 What measurements were taken and why.
##### 5.3.1 Plot measurement standards used.
##### 5.3.2 Plot size and shape, layout.
##### 5.3.3 Dbhob measurements.
##### 5.3.4 Tree height measurements.
##### 5.3.5 Upper stand height definition adopted, and measurements.
##### 5.3.6 Volume measurements made, if any.
##### 5.3.7 Audits including independent audits that can verify the measurements.
#### 5.4 Estimated precision of the measurements.
#### 5.5 Estimated sampling precision of the inventory.

### 6 Coupe and/or compartment definition.
#### 6.1 Objective and purpose of coupes and/or compartments.
#### 6.2 Rules applied for aggregation.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>Procedures to ensure all areas have been included.</td>
</tr>
<tr>
<td>6.4</td>
<td>Procedures to ensure that no area has been included more than once.</td>
</tr>
<tr>
<td>6.5</td>
<td>Whether any coupes are so unusual that models may not be appropriate.</td>
</tr>
<tr>
<td>7</td>
<td>The models used to compute the volumes from the inventory data, and their basis.</td>
</tr>
<tr>
<td>7.1</td>
<td>The taper equation(s) used, if any.</td>
</tr>
<tr>
<td>7.2</td>
<td>The tree volume equations used, if any.</td>
</tr>
<tr>
<td>7.3</td>
<td>How size and product information were obtained.</td>
</tr>
<tr>
<td>7.4</td>
<td>Consideration of degrade, including breakage when harvesting.</td>
</tr>
<tr>
<td>7.5</td>
<td>Validation of models, determination of their appropriateness for the valuation.</td>
</tr>
<tr>
<td>8</td>
<td>The methodology used to “grow” the forest inventory in time to provide estimates of wood flows.</td>
</tr>
<tr>
<td>8.1</td>
<td>The computer software system used, if any.</td>
</tr>
<tr>
<td>8.2</td>
<td>The models used to define the future silvicultural and management regime.</td>
</tr>
<tr>
<td>8.2.1</td>
<td>Early aged silviculture to be applied (for example site preparation, weed control, planting stock, early aged fertiliser)</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Pruning regime to be applied.</td>
</tr>
<tr>
<td>8.2.3</td>
<td>Thinning prescription; age first thinning, thinning intervals, thinning type, extraction row interval.</td>
</tr>
<tr>
<td>8.2.4</td>
<td>Late age fertiliser applications.</td>
</tr>
<tr>
<td>8.2.5</td>
<td>Clear felling age.</td>
</tr>
<tr>
<td>8.2.6</td>
<td>Fallow period between rotations.</td>
</tr>
<tr>
<td>8.3</td>
<td>The models used within the calculation procedures.</td>
</tr>
<tr>
<td>8.3.1</td>
<td>Growth models, regional or soil influences.</td>
</tr>
<tr>
<td>8.3.2</td>
<td>Size and product assortment models.</td>
</tr>
<tr>
<td>8.3.3</td>
<td>Modelling stand density effects.</td>
</tr>
<tr>
<td>8.3.4</td>
<td>Modelling pruning responses.</td>
</tr>
<tr>
<td>8.3.5</td>
<td>Prediction of mortality and how it is modelled.</td>
</tr>
<tr>
<td>8.3.6</td>
<td>Other risks (for example fire, insects, droughts, wind, market availability for predicted wood flows).</td>
</tr>
<tr>
<td>8.4</td>
<td>Land acquisition strategy.</td>
</tr>
<tr>
<td>8.4.1</td>
<td>Land changes modelled.</td>
</tr>
<tr>
<td>8.4.2</td>
<td>Is there a history of revocations that should be modelled.</td>
</tr>
<tr>
<td>8.4.3</td>
<td>Have small fires and lightning strike effects been considered and if so how.</td>
</tr>
<tr>
<td>8.4.4</td>
<td>Has any allowance been made for the effect of large fires.</td>
</tr>
<tr>
<td>8.5</td>
<td>The start and end point in the planning horizon.</td>
</tr>
<tr>
<td>8.6</td>
<td>The status of the forest at the end of the planning horizon and how it is handled in the modelling.</td>
</tr>
</tbody>
</table>
| 8.7     | It needs to be clearly stated whether the wood flows are the predictions of future outcomes or have been adjusted to represent wood flows that the enterprise plans
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 Costs and revenues.</td>
<td></td>
</tr>
<tr>
<td>9.1</td>
<td>The costs used, their timing, and their basis for use.</td>
</tr>
<tr>
<td>9.2</td>
<td>The timber yields used in the valuation and their timing.</td>
</tr>
<tr>
<td>9.3</td>
<td>The stumpage or royalty values used; by products, the price points, and the basis for their use.</td>
</tr>
<tr>
<td>9.4</td>
<td>Other revenues used, their timing and the basis for their use.</td>
</tr>
<tr>
<td>9.5</td>
<td>Procedures for ensuring consistency, completeness and avoidance of double counting.</td>
</tr>
<tr>
<td>9.6</td>
<td>Consideration of reliability and reconciliation with other sources.</td>
</tr>
<tr>
<td>9.7</td>
<td>Consideration of long term trends in costs and revenues.</td>
</tr>
<tr>
<td>9.8</td>
<td>Any procedures for auditing the costs and revenues.</td>
</tr>
<tr>
<td>10 The basis for any economic analysis.</td>
<td></td>
</tr>
<tr>
<td>10.1</td>
<td>If transaction based.</td>
</tr>
<tr>
<td>10.1.1</td>
<td>Summary of relevant transactions.</td>
</tr>
<tr>
<td>10.1.2</td>
<td>Justification for any adjustments to known transactions.</td>
</tr>
<tr>
<td>10.2</td>
<td>If lump sum based.</td>
</tr>
<tr>
<td>10.2.1</td>
<td>Why was the lump sum approach (sometimes called the immediate liquidation approach) considered feasible.</td>
</tr>
<tr>
<td>10.3</td>
<td>If cost based.</td>
</tr>
<tr>
<td>10.3.1</td>
<td>Compounding rate, and explanation of the basis for its use.</td>
</tr>
<tr>
<td>10.3.2</td>
<td>Were current costs or historical costs used, and why.</td>
</tr>
<tr>
<td>10.4</td>
<td>If based on discounted cash flows.</td>
</tr>
<tr>
<td>10.4.1</td>
<td>The discount rate used in the calculations and explanation of the basis for its use.</td>
</tr>
<tr>
<td>10.4.2</td>
<td>How was inflation treated. Were the cash flows real or nominal.</td>
</tr>
<tr>
<td>10.4.3</td>
<td>Were long term trends used to modify the discount rate. What is the basis.</td>
</tr>
<tr>
<td>10.4.4</td>
<td>The period for discounting used, especially if not annual.</td>
</tr>
<tr>
<td>10.4.5</td>
<td>Planning horizon used, how the end of the planning horizon is handled.</td>
</tr>
<tr>
<td>10.4.6</td>
<td>Treatment of taxation effects.</td>
</tr>
<tr>
<td>10.4.7</td>
<td>Whether pre-tax or post-tax analysis, and why.</td>
</tr>
<tr>
<td>10.5</td>
<td>Other considerations.</td>
</tr>
<tr>
<td>10.5.1</td>
<td>How land has been treated.</td>
</tr>
<tr>
<td>10.5.2</td>
<td>Consideration of contingencies.</td>
</tr>
<tr>
<td>10.5.3</td>
<td>Consideration of risk.</td>
</tr>
<tr>
<td>10.5.4</td>
<td>Non-wood values.</td>
</tr>
<tr>
<td>10.5.5</td>
<td>Landscape and aesthetic values.</td>
</tr>
<tr>
<td>10.5.6</td>
<td>Environmental considerations, especially regulations.</td>
</tr>
<tr>
<td>Section</td>
<td>Content</td>
</tr>
<tr>
<td>---------</td>
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</tr>
<tr>
<td>10.5.7</td>
<td>Lease or contract conditions affecting valuation.</td>
</tr>
<tr>
<td>10.5.8</td>
<td>Carbon and other environmental credits.</td>
</tr>
<tr>
<td>10.5.9</td>
<td>Government grants.</td>
</tr>
<tr>
<td>10.6</td>
<td>Any client specific requirements, or departures from the standard methodologies, or specific assumptions.</td>
</tr>
<tr>
<td>10.7</td>
<td>Any sensitivity analyses should also be reported.</td>
</tr>
</tbody>
</table>

**11** Comments on the accuracy (precision and possible bias) of the models used, and of the forest valuation. Comments on any limitations that ought to be placed on the use of the information.

**12** Standards.

12.1 Whether or not the forest valuation adheres to the ACFA forest valuation standard, and if not why not.

12.2 Whether or not the forest valuation adheres to the appropriate AASB standards, and if not why not, or why AASB standards were not considered appropriate.

12.3 Were ASIC, ACCC or the ATO considerations. If so why, and how did the considerations affect the forest valuation.

Forest valuation can be provided at a wide range of levels of accuracy and the procedures can be quite diverse in order to meet these wide ranging requirements. It is therefore necessary to ensure that the basis for undertaking any forest valuation be reported and be sufficiently detailed to be obvious if it is used for purposes other than for which it was intended or for which it is appropriate.

### 15.2 Desirable paragraphs in a forest valuation report

There are so many different approaches to carrying out a forest valuation that it is necessary to very carefully document all the assumptions that have been made, document and detail the reasons and bases for those assumptions, and describe the methodology used. This is especially the case where it might depart from the strict interpretation of the ACFA standard (2004, 2007) or the various AASB standards. It is also necessary to clearly separate factual evidence from professional judgement.

In considering this, the commonly used separation amongst ACFA members of forest valuations from forest appraisals may be useful. The fundamental difference between forest valuations and forest appraisals is a matter of degree, a matter of precision, and a matter of time and effort expended, which in turn depends on the Terms of Reference given to the forest valuer, cost of the valuation, and the planned use of the valuation or appraisal.

### Accuracy; precision and bias

A comment is needed about the accuracy of the forest valuation, and especially about likely sources of error.

The various data sources need to be described in detail. If the data were from external sources to the forest being valued then this should be stated and a comment made about their appropriateness.

This is even more important for the various models used in the analysis. Generally the models will not be from the subject area and even if they are, they may not be completely appropriate. For example the models might have been developed for plantations established using one silvicultural regime but the forest being valued may have been established with a completely different regime.

Professional judgement may be needed to assess the appropriateness of data and models, and the comments on accuracy may be qualitative rather than quantitative, or ideally a judicious mix of both.
Limitations of the forest valuation

It is essential to clearly state the objectives in carrying out the forest valuation.

This may be of the form “The objectives set by (owner or person requiring the valuation) are detailed in a letter of (date) and this is appended in (Appendix 1).”

Every forest valuation is limited to some degree. The known limitations should be described in some detail as this is probably the most important information users need to be able to assess the relevance of the forest valuation for their particular circumstances. Some other limitations may be suspected, and these should at least be mentioned and a value judgement made about their likely relevance.

There needs to be a clear statement about the dangers in using the results of a forest valuation for purposes for which the study was not intended.

There is also a need to comment on the extent of professional judgement in the report.

Reference to standards

Some questions that need to able to be answered by anyone reading a forest valuation report are as follows.

- Was the current ACFA forest valuation standard used, which version, and if so why, if not why not?
- Which AASB standards were considered, if any?
- Were there any particular requirements to use them?
- Were other standards used and if so why?

These points should be the subjects of paragraphs in any forest valuation report, although they may be very brief.

15.3 Example of contract provisions and disclaimers

This section includes a set of draft provisions and disclaimers that might be used as a base for contracts to undertake a forest valuation.

Care needs to be taken to ensure that all avenues are covered. Note that these clauses cannot be considered complete or comprehensive.

In this section each subject will be considered separately. There will be comments on applicability, comments on known potential difficulties, and then some example provisions that users may care to consider.

Some of the clauses described are between a Consultant and an unnamed organization (called XYZ Corporation), whereas others are between two parties. Persons considering these clauses must consider whether or not the clause is appropriate and must make necessary changes to the wording. This is generally likely to entail seeking legal opinion. ACFA can take no responsibility that the examples provided are legally appropriate for any particular use at all. The examples are provided to assist a valuer to determine what may be necessary.

Intellectual property

This needs to be carefully considered as the general clauses commonly provided may have some undesirable and unexpected consequences. The thrust of the provision is to ensure that ownership of the intellectual property is clearly defined. Generally any intellectual property developed by the

As at 2007, reformatted 2012 but no textural changes
Consultant is the property of the company paying for the service to be provided, but this may not always be the case.

If the Consultant uses particular procedures that their organisation developed specifically for general use, for example special macros in Excel, special statistical packages and the like, then these may implicitly be included in the contract provisions and may be reassigned from the Consultant to the vendor. This may be quite contrary to the intentions of either party.

Example.

- The title to and ownership of all intellectual property in data sheets, survey results, analysis, reports and other documents prepared for the purposes of this Agreement vests in XYZ, and the Consultant must ensure that those documents are used, copied, supplied or reproduced only for the purpose of this Agreement.

Applicable law

It may be necessary to define the basis of law to be applied. This is especially important if there is an overseas component in the work but there may be important differences between Australian states and territories.

Examples.

- The Parties agree that his Agreement is governed by and construed in accordance with the law for the time being in force in the [ABC State/Territory of Australia].

  The Consultant must ensure that the Work done under this Agreement complies with the laws from time to time in force in the State or Territory in which the Work, or any part thereof, is to be performed.

- This agreement will be governed by and construed in accordance with the law of ABC and the parties submit to the jurisdiction of the courts of that State/Territory.

Termination

A mechanism is generally needed to facilitate termination of any contract and should encompass and define responsibility and payment details.

Example.

- XYZ may, by written notice, terminate or constrict this Agreement or any part of the Agreement for reasons other than the default of the Consultant in performance of the Work, and upon such notice being given the Consultant must cease or reduce work according to the tenor of the notice and must forthwith immediately do everything possible to mitigate consequential losses.

  In that event, the Consultant may submit a claim for compensation and XYZ must pay to the Consultant such sums as are fair and reasonable in respect of any loss sustained by the Consultant as an unavoidable consequence of the termination, however:

  (a) The Consultant is not entitled to compensation for loss of prospective profits; and,

  (b) XYZ is not liable to pay any sum which, in addition to any amounts paid or due or becoming due to the Consultant under this Agreement, would together exceed the Fee which would have been payable under this Agreement had it not been terminated or constricted.

Assignment and subcontracting

It is common to consider the assignment of work to others and/or the use of sub contractors.
Example.

- The Consultant must not assign or sub-contract any part of the work without the written approval of XYZ, which shall not be unreasonably withheld.

Any permission to assign all or part of the work does not discharge the Consultant from any liability in respect of this Agreement, and extends only to the permission actually given, and not so as to prevent any proceedings for a subsequent breach of this clause; and all rights under this Agreement remain in full force and will be available as against any such subsequent breach.

**Insurances**

Evidence of current appropriate insurance is usually required.

Some organisations require Public Liability Insurance (PLI), some do not. It may be possible to negotiate this as part of the terms and conditions. Most insurance providers will not provide PLI for anything less than a year, but one, QBE Mercantile Mutual, is known to provide cover for shorter periods, primarily to cover seasonable workers such as tree planters, and vineyard workers. Often larger organisations have standard levels of insurance and it may be appropriate to negotiate a lower level if the risk to the organisation is demonstrably lower. The cost of obtaining additional insurance can often be justifiably added to the contract price.

It is common to require a level of Professional Indemnity Insurance.

It has been noted that some organisations have a formal and general requirement for standard levels of insurance, regardless of the nature of the contract, and it is not uncommon for these levels to be unreasonably high and quite inappropriate for the task at hand.

Example.

- The Consultant must effect and maintain in a form appropriate to the Consultant’s activities with an insurer acceptable to XYZ:
  
  (a) Professional Indemnity Insurance (PII) for an amount of not less than [define the amount] in respect of any single occurrence for liability arising from the breach of professional duty in performing the Work, whether owed in contract, tort or otherwise or by reason of any act or omission by the Consultant;
  
  (b) Public Liability Insurance (PLI) for an amount of not less than [define the amount] in respect to all actions, claims, demands, costs, losses or expenses of whatsoever nature arising out of or in connection with loss of life or injury to persons or loss of or damage to property or environmental damage caused by any negligent act or omission of the Consultant or other persons engaged in any capacity by the Consultant in performing the services or in performing matters incidental to the services.
  
  (c) Workers’ compensation insurance in accordance with the applicable awards or legislation, and also insurance against common law liability, to any person employed by the Consultant in connection with performance of the Work; and
  
  (d) Insurance against the loss of or damage to original designs and any other documents.

**Disclosure of information - confidentiality**

It is common for an organisation to require a consultant or a provider or a service provider to sign a confidentiality clause.

Examples.

- The Consultant will not without first obtaining the written approval of XYZ disclose to any person, firm or company, or make public any information or material acquired or produced by the Consultant in connection with or by virtue of the performance of the work. Except to the extent
that disclosure has been authorised, any documents or reports acquired or prepared by the Consultant for the purposes of this Agreement remain the confidential property of XYZ.

- The Contractor will treat as strictly confidential all information acquired by it from or about the XYZ Company for the purposes of this Agreement, and will not disclose such information to any person without the prior written consent of the XYZ Company.

- The [Recipient/Consultant] covenants with XYZ that it will:
  
  a) preserve, and will procure that its Affiliates preserve, the confidentiality of the Information and take proper and adequate precautions at all times (and enforce such precautions) to preserve the confidentiality of the information and, in particular, but without in any way limiting the generality of the foregoing, will take all action reasonably necessary to prevent any unauthorised person obtaining access, as result of action or inaction by the [Recipient/Consultant] or any of its Affiliates, to the Information by direct or indirect exposure thereto or otherwise;
  
  b) not in any way, without XYZ prior written consent, use the information for any purpose whatsoever other than in connection with the Project, or in any way which may injure or cause loss to, or be calculated to injure or cause loss to, XYZ or its related companies or which may otherwise be directly or indirectly detrimental to the interest of XYZ or any of its related companies;
  
  c) confine the distribution of the information to those of its Affiliates (and to such extent) as shall be absolutely necessary for the purpose of the Project, and will advise XYZ of the names of such persons and shall cause such person to give, if so required by XYZ a written confidentiality undertaking to XYZ in such form as XYZ may require;
  
  d) be wholly responsible and liable for the acts and defaults of its Affiliates in respect of any Information disclosed to them;
  
  e) upon request from XYZ return promptly to XYZ all Information (including all copies or reproduction of the same) in the possession or control of the [Recipient/Consultant] and its Affiliates together with all information and documentation containing, compromising or relating in any way to the Information or, where return of certain information is impractical, erase or destroy such information and confirm in writing to XYZ the completion of this process;
  
  f) indemnify and keep indemnified and hold harmless XYZ and each of XYZ related companies from and against all action, claims, costs, demands, expenses, liabilities, losses, payments and proceedings whatsoever incurred or suffered by them which arise from or by virtue of the unauthorised disclosure or use of the Information by the [Recipient/Consultant] or any of its Affiliates or any such persons otherwise being in breach of any of the provisions of this undertaking or any further undertaking of the nature referred to in clause 3(c); and
  
  g) not, and will procure that none of its Affiliates:

  i) subscribe for, purchase or sell or enter into an agreement to subscribe for, purchase or sell any securities;

  ii) procure any third person to subscribe for, purchase or sell, or to enter into an agreement to subscribe for any securities; or

  iii) communicate any Information to any person in breach of section 1002G Corporations Law.

Exclusions

Any information which is clearly and demonstrably:

a) independently acquired or developed by the [Recipient/Consultant] without the benefit or use of any of the Information;
b) publicly known or which becomes publicly known after the date of this undertaking other than through breach or non-performance by [Recipient/Consultant] or any Affiliate of any obligation under this undertaking or under any further undertaking of the nature referred to in clause 3(c);

c) lawfully received by the [Recipient/Consultant] from a third party not owing (directly or indirectly) any obligation of confidentiality to XYZ or any related companies, shall not be or, as the case may be, shall cease to be, subject to the restrictions contained in this undertaking.

Service of notices

A clause is desirable that can assist if things go wrong. One unsatisfactory clause noted included the provision that a letter would be deemed to have been received on the date it was claimed to have been posted. When this anomaly was pointed out the company accepted that it was quite unreasonable and a revised provision was inserted.

Example.

- Any notice in writing required to be given under this Agreement is deemed to be properly served by one party on the other party if it is delivered personally to the other party’s Project Officer or forwarded by prepaid post (or prepaid registered mail) to the other party’s address shown on this Agreement, and a notice sent by post is deemed to have been given at the time when it ought to be delivered in due course of post. Receipt of the letter must be confirmed in writing.

Variation to the agreement

There needs to be a formal mechanism for varying any agreement. Without such a clause both parties may find themselves bound by an agreement both believe to be quite inappropriate.

Example.

- No agreement or understanding that varies or extends this Agreement and would result in an increase in the moneys payable by, or other liability of XYZ is legally binding upon either party unless in writing and signed by both parties.

- The Principal may by notice require the Consultant to vary the Consultancy services in nature, scope or timing.

  Without limiting the generality of the above clause, the Principal may direct the Consultant to:

  (a) increase, decrease or omit any part of the Consultancy services;

  (b) change the character or content of any part of the Consultancy services;

  (c) change the direction or dimensions of any part of the Consultancy services; and

  (d) perform additional work.

  Where the Principal requires a variation to the Consultancy services, the parties will negotiate in good faith a variation of the fees and the time for completion and failing agreement, the fees and time for completion will be determined. The Consultant will not commence work on the variation to the Consultancy services without the Principal’s consent and the written agreement of both parties to the varied fees and time for completion.

Resolution of disputes

A provision is needed to assist in the resolution of any dispute that might arise. This will be found essential if things go wrong and must be agreed before the contract is signed so that an amicable resolution can readily be arrived at.
Example.

- If a dispute arises between the parties in relation to any matter the subject of this Agreement (the “Dispute”), any party seeking to resolve the Dispute must do so strictly in accordance with the provisions of this clause.

1 Compliance with the provisions of this Clause is a condition precedent to any entitlement to a claim, relief or remedy, whether by way of proceedings in a Court or by arbitration proceedings or otherwise, in respect of the Dispute.

2 A party (the “Notifying Party”) seeking to resolve a Dispute must notify the existence and nature of the Dispute to the other party (the “Notification”).

3 The Notification must be given to the other party by the Notifying Party before the Dispute is made the subject of legal, arbitration or mediation proceedings by the Notifying Party (or by any person acting on behalf of the Notifying Party) and a reasonable period and opportunity for negotiation must be given before any such proceedings are initiated by either the Notifying Party or the other party.

4 Upon receipt of a Notification the parties must negotiate in good faith to resolve the dispute, and, if necessary or desirable to obtain a resolution of the Dispute, involve the Chief Executive Officers of the parties directly in those negotiations.

5 If a Dispute has not been resolved by negotiations under this Clause within a reasonable period, either Party may refer the Dispute to mediation, and must do so before initiating proceedings in arbitration or a Court to resolve the Dispute.

6 For the purposes of Clauses 4 and 5 a period of 30 days will, in the absence of clear evidence to the contrary, be deemed a reasonable period.

7 Any dispute which is referred to mediation under Clause 5 must be referred to (and name the body, but for example it could be) the Australian Commercial Disputes Centre Limited in Sydney (ACDC) and be conducted in accordance with the Conciliation Rules of ACDC in force at the date of this Agreement.

Severance

This clause considers what should be done if any part of the Agreement is found to be illegal or unenforceable.

Example.

- If any part of this Agreement is held to be illegal, void, or unenforceable, such determination shall not impair the enforceability of the remaining parts of this Agreement which shall remain in full force; provided that if the effect of any such determination will be substantially to reduce the benefit, or substantially to increase the burden of this Agreement to a Party, that Party may terminate this Agreement on giving twenty one (21) days written notice to the other Party.

Conflict of interest

If there is a conflict of interest, or potential conflict of interest then it must be declared. This point is often misunderstood, but it is inimical to ethical consulting and hence ethical forest valuing.

An example was given to ACFA of a situation where a consultant believed that there was no conflict of interest with the company but, during the consultancy, the company was taken over by another company with whom the consultant did have a conflict of interest. When this was explained to the new owner they, and the consultant, agreed a new course of action.
Examples

- The Consultant warrants that at the date of entering into this Agreement no conflict of interest exists or is likely to arise in the performance of its obligations under this Agreement. If, during the term of this Agreement, any conflict or risk of conflict of interest arises, the Consultant undertakes to notify XYZ immediately in writing of that conflict or risk.

- The Consultant warrants that, to the best of its knowledge, it does not, and is not likely to have any conflict of interest in the performance of this agreement. If a conflict or risk of conflict of interest arises (without limitation, because of work undertaken for any person other than the Principal) the Consultant will immediately give notice of the conflict of interest, or the risk of it, to the Principal.

  The Consultant will take all reasonable measures to ensure that its employees, agents and subcontractors do not engage in any activity or obtain any interest which is in conflict with providing the Consultancy services to the Principal fairly and independently. The Consultant will immediately give notice of any conflict of interest relating to the activities or interests of any of its employees, agents or subcontractors to the Principal.

  If the Principal is given notice of a conflict of interest pursuant to the above two clauses, the Principal may proceed to terminate this agreement.

Force majeure

Force majeure clauses cover the situation where unexpected devastating events occur that render a contract inoperable and cause the contract to be suspended. Examples of the reasons include; riots, civil commotion, earthquake, fire, catastrophe, Acts of God, changes in Government regulations or decrees, and any circumstance beyond the control of the affected party which could not be reasonable foreseen.

It can be argued that fire can be foreseen by managers and so the effect on the ability of a forest owner to supply timber under a wood supply contract might seem to not be covered by a force majeure provision in a contract. However a very large fire such as occurred in South Australia in 1983 which burnt some 30% of the forest was basically considered by all parties to be “unexpected” and all contracts were ignored although every attempt was made to come to a reasonable arrangement for the provision of timber. Nobody had foreseen a fire of that magnitude.

In assessing the risks attendant in a forest valuation a force majeure provision in any supply contract is likely to at least cover major risks, and so such allowances may not explicitly have to be incorporated into the valuation itself.

Example.

- If either Party is prevented by fulfilling its obligations under this agreement by riots, strikes, lockouts or other civil commotion, or by war, Act of God, earthquake fire damage to plant, or other catastrophe, or by Government regulation or decree or circumstances beyond the control of the Party affected which could not have been reasonable foreseen, the Party wholly or in part so prevented shall promptly notify the other of the situation which makes it impossible to carry out in whole or in part its obligations under this Agreement. Any loss of damage to, or delays in, or failure of performance of either Party under such conditions does not constitute default under this Agreement or give rise to any claim for damages.

  Notwithstanding anything in the preceding clause, the Party to whom performance is owed but to whom it is not rendered because of an event of force majeure as so contemplated has the right, after the passage of ninety (90) days, to declare the Agreement terminated forthwith.
Completeness

This clause considers that any Agreement should be entire in itself and should supersede any and all preceding Agreements.

Example.

- This Agreement together with the attached Schedules and Project Proposal constitute the entire, full, and complete understanding between XYZ and the Consultant and supersedes all previous representations, warranties, understandings, or agreements between the Parties relating to the Work. If there is any inconsistency between these terms and any other instruction or order given by the Parties these terms shall prevail unless otherwise agreed in writing.

Goods and Services Tax (GST)

This provision considers the Goods and Services Tax.

Example.

- In this clause, “GST,” “supplier”, “tax invoice” and “input tax credit” have the same meaning as defined in A New Tax System (Goods and Services Tax) Act 1999 (Commonwealth), the GST legislation.

  The Consultant acknowledges that in terms of the GST legislation it will, under the Contract, be a ‘supplier’ and may be required to remit GST to the Commissioner of Taxation.

  The Consultant will ensure that all tax invoices rendered to the XYZ under the Contract are in a format that identifies the GST exclusive value, the GST inclusive price and any GST separately, and which permits XYZ to claim an input tax credit.

  The parties agree that the prices for Goods or Services under the Contract are GST inclusive prices where applicable, and that the amount payable under the Contract shall not be varied by the amount of the GST.

Miscellaneous

There are many other provisions that a forest valuer may consider.

Examples.

- The Parties acknowledge that they were not induced to enter into this Agreement by any representations or warranties of the other Party, except those (if any) which are expressly contained herein.

  The Parties enter into this Agreement in reliance on their own judgement and, before entering this Agreement, have had the opportunity of obtaining independent advice.

- No failure, delay, or indulgence by either Party in exercising any power or right conferred on that Party by this Agreement shall operate as a waiver of such power or right. Nor shall a single exercise or partial exercise or any such power or right preclude further exercises of that power or right or the exercise of any other power or right under this Agreement.

- The fact that the Consultant is under the terms of this Agreement to be engaged in performing the Work for XYZ is not to be construed in any way to imply that the Consultant is an employee of XYZ.

  The Consultant must not represent itself, and must ensure that its employees do not represent themselves, as being employees or agents of XYZ.

- The Consultant will not -
  (a) represent itself or allow itself to be represented as an employee or agent of the Principal; or,
  (b) by virtue of this agreement be or become an employee or agent of the Principal.
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<td>54, 55, 56, 122, 147</td>
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<td>Tree:</td>
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<td>129, 143</td>
</tr>
<tr>
<td>Woollybutt:</td>
<td>27</td>
</tr>
<tr>
<td>Yield:</td>
<td>19</td>
</tr>
<tr>
<td>YTGen:</td>
<td>129, 137, 138</td>
</tr>
</tbody>
</table>
ANNEX 1: Code of Forest Mensuration Practice

The “Code of Forest Mensuration Practice: A guide to good tree measurement practice in Australia and New Zealand” was prepared by Research Working Group No.2 in 1999. The primary work was done by Dr Geoff Wood of the Australian National University and the work was completed by Drs Brian Turner and Cris Brack.

As at 2007 the document was maintained as a web based document by Dr Brack and is available from the URL:


although the document as published in hard copy in 1999 states the URL as


but this latter site transferred to the first site as the organisational structure of the Australian National University (ANU) had changed in the interim.

At the November 2004 meeting of RWG2, approval was kindly given to ACFA to reproduce the document as an Annex to this handbook. ACFA are very grateful to receive this formal approval.

There are a few points about this Annex reproduction that should be noted.

- The references quoted in this Annex are detailed at the end of the Annex and only selected references are detailed in the reference section of this Handbook.

- There are some slight differences in emphasis between this Annex and the text in the body of this Handbook but none of the differences are considered critical to forest valuation.

- Because this version of the code has been reformatted from the web based document it is not completely consistent with the 1999 printed version. Since 1999 Dr Brack has made some small changes to improve the web based document and when this Annex was being prepared a few other minor editorial changes were made.

- ACFA has reproduced this work as faithfully as possible, but ACFA does not, and cannot, accept responsibility for its accuracy.

- During the reproduction a number of relatively minor errors in positioning of statements was observed and a number of sections were noted where the wording could be improved and brought up to date. Given that ACFA were accorded the right to reproduce the document it was not considered appropriate to revise the content, that should more rightfully be the responsibility of the authors and Research Working Group No.2 Forest Measurement and Information.
Code of Forest Mensuration Practice


URL: http://www.anu.edu.au/Forestry/mensuration/rwg2/code.htm

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ISBN  0-7315-3309-7 (Disk/CD)
ISBN  0-7315-3308-9 (Book)
Research Working Group #2 (1999) Code of Forest Mensuration Practice:
A guide to good tree measurement practice in Australia and New Zealand.
Wood, Turner and Brack (Eds.)

URL: http://www.anu.edu.au/Forestry/mensuration/rwg2/code.htm

The members of Research Working Group #2 (Forest Measurement and Information) developed this guide to assist forest and natural resource managers to measure tree and forest stands in a consistent, reliable and useful manner.

Research Working Group #2 is the peak body of researchers in Australia and New Zealand who have responsibility for measuring and inventorying forest resources. The Working Group is responsible to the Research Priorities and Co-ordination Committee (RPCC) who in turn report to the Standing Committee on Forestry.

G.B.Wood, a member of RWG #2 until 1994, edited major drafts of this Code. B.J.Turner and C.L.Brack, members of RWG #2 representing the Australian National University, undertook final editorial work.

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CHAPTER 1

UNITS OF MEASUREMENT, SYMBOLS, SIGNIFICANT DIGITS AND Rounding-off

1.1 UNITS OF MEASUREMENT AND SYMBOLS

Australia is a signatory of the Metric Convention. Thus, when measuring forest trees and their components, and when reporting data, we are committed to use the International System of Units (SI for short). The SI system is progressively being adopted by 'metric' countries of long standing and it is the required system for almost all international journals. It has seven base units and two supplementary units (Table 1.1).

Table 1.1

<table>
<thead>
<tr>
<th>SI Base Units and Supplementary Units 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Units</strong></td>
</tr>
<tr>
<td><strong>Unit</strong></td>
</tr>
<tr>
<td>metre</td>
</tr>
<tr>
<td>kilogram</td>
</tr>
<tr>
<td>second</td>
</tr>
<tr>
<td>ampere</td>
</tr>
<tr>
<td>kelvin</td>
</tr>
<tr>
<td>mole</td>
</tr>
<tr>
<td>candela</td>
</tr>
</tbody>
</table>

Using the units in Table 1.1 and the relationships between physical quantities, all other units which comprise the SI system can be derived. Other units can be obtained with the help of decimal prefixes (Table 1.2), e.g. mV (millivolt), but these are not part of the SI system per se.

Departure from the SI system is tolerated where it has sound justification, e.g. where use of non-SI units is so entrenched internationally that it will continue indefinitely (Øgrim and Vaughan 1977). Some non-SI units allowed for general use which are used extensively in forest measurement are listed in Table 1.3.

When using metric symbols, certain rules apply, namely.

(a) **Capitals, Prefixes and Symbols**

Do not use capitals for any SI units written out in full. Capitals are used for symbols only when the unit is derived from a proper name, e.g. newton N, hertz Hz. Capitals are not used for numerical prefixes or symbols other than the symbols T for tera (10^{12}), G for giga (10^9) and M for mega (10^6), e.g. kilopascal kPa, megapascal MPa, milligram mg, megagram Mg. Incorrect use of capitals could be confusing if not disastrous, e.g. substituting Mg (megagram) for mg (milligram).

---

1 Adapted from Øgrim and Vaughan (1977)
Table 1.2
Decimal Prefixes Denoting Multiples and Sub-Multiples

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Multiplication factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>exa</td>
<td>E</td>
<td>$10^{18} = 1,000,000,000,000,000,000,000,000$</td>
</tr>
<tr>
<td>peta</td>
<td>P</td>
<td>$10^{15} = 1,000,000,000,000,000,000$</td>
</tr>
<tr>
<td>tera</td>
<td>T</td>
<td>$10^{12} = 1,000,000,000,000$</td>
</tr>
<tr>
<td>giga</td>
<td>G</td>
<td>$10^{9} = 1,000,000,000$</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$10^{6} = 1,000,000$</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$10^{3} = 1,000$</td>
</tr>
<tr>
<td>hecto</td>
<td>h</td>
<td>$10^{2} = 100$</td>
</tr>
<tr>
<td>deca</td>
<td>da</td>
<td>$10^1 = 10$</td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>$10^{-1} = 0.1$</td>
</tr>
<tr>
<td>centi</td>
<td>d</td>
<td>$10^{-2} = 0.01$</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>$10^{-3} = 0.001$</td>
</tr>
<tr>
<td>micro</td>
<td>µ</td>
<td>$10^{-6} = 0.000,001$</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>$10^{-9} = 0.000,000,001$</td>
</tr>
<tr>
<td>pico</td>
<td>p</td>
<td>$10^{-12} = 0.000,000,000,000,001$</td>
</tr>
<tr>
<td>femto</td>
<td>f</td>
<td>$10^{-15} = 0.000,000,000,000,000,001$</td>
</tr>
<tr>
<td>atto</td>
<td>a</td>
<td>$10^{-18} = 0.000,000,000,000,000,000,001$</td>
</tr>
</tbody>
</table>

Table 1.3
Some Non-SI Units Used in Forest Measurement

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Quantity</th>
<th>Value in SI units</th>
</tr>
</thead>
<tbody>
<tr>
<td>degree</td>
<td>°</td>
<td>plane angle</td>
<td>$17.453,293 \times 10^{-3}$ rad</td>
</tr>
<tr>
<td>minute (part of degree)</td>
<td>'</td>
<td>plane angle</td>
<td>$290.888,21 \times 10^{-6}$ rad</td>
</tr>
<tr>
<td>second</td>
<td>''</td>
<td>plane angle</td>
<td>$4.848,136,8 \times 10^{-6}$ rad</td>
</tr>
<tr>
<td>centimetre</td>
<td>cm</td>
<td>tree diameter</td>
<td>$0.01$ m</td>
</tr>
<tr>
<td>hectare</td>
<td>ha</td>
<td>Area</td>
<td>$10^4$ m$^2$</td>
</tr>
<tr>
<td>day</td>
<td>d</td>
<td>time interval</td>
<td>$86.4 \times 10^3$ s</td>
</tr>
<tr>
<td>hour</td>
<td>h</td>
<td>time interval</td>
<td>$3.6 \times 10^3$ s</td>
</tr>
<tr>
<td>minute (part of hour)</td>
<td>min</td>
<td>time interval</td>
<td>$60$ s</td>
</tr>
<tr>
<td>tonne</td>
<td>t</td>
<td>Mass</td>
<td>$10^3$ kg</td>
</tr>
<tr>
<td>tonne per cubic metre</td>
<td>t/m$^3$</td>
<td>Density</td>
<td>$10^3$ kg m$^{-3}$</td>
</tr>
</tbody>
</table>

---

2 Table ex Everard (1971). The multiples and sub-multiples recommended for common usage are shown in bold type. These are prefixes representing 10 raised to the power of a multiple of ±3. The prefixes hecto, deca, deci and centi should be avoided unless this causes inconvenience. Such is the case with centimetre which is used widely in forestry in measurement of tree diameter (use of millimetres or metres would require unnecessary digits.

3 Adapted from Øgrim and Vaughan (1977).

As at 2007, reformatted 2012 but no textural changes
Rules governing the use of multiplying symbols and prefixes are as follows:

- Apply only one multiplying prefix at a time to a given unit, *e.g.* one-thousandth of a millimetre is referred to as 1 micrometre, not 1 milli millimetre.

- Use no space or hyphen between the prefix and the name of the unit which it qualifies (*e.g.* millimetre, kilogram) and no space between the symbol for the prefix and the unit (*e.g.* mm, kg), *i.e.* the prefix is regarded as part of the unit symbol. Thus, \( \text{mm}^2 \) means \( (\text{mm})^2 \), not \( \text{m}(\text{m})^2 \).

- Use Roman type face for unit symbols (m, kg, s, N, etc.), prefixes (G, M, p, µ, etc.), numerals (5, 12, 457, etc.), and mathematical operators (dx, Δx, ∂x, etc.).

- Use ordinary italic type face for quantities (\( m, v, V_m, β, ∂, \text{etc.} \)) and bold italic type face for vector and matrix quantities (\( \mathbf{F}, \mathbf{a}, \text{etc.} \)).

Standardised general symbols adopted by IUFRO in 1956 for reporting results in forest mensuration are listed in Table 1.4 (Van Soest *et al.* 1965).

<table>
<thead>
<tr>
<th>Name of quantity</th>
<th>Symbol(^{4})</th>
<th>Name of quantity</th>
<th>Symbol(^{4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>( t )</td>
<td>basal area</td>
<td>( g )</td>
</tr>
<tr>
<td>circumference or girth</td>
<td>( c )</td>
<td>diameter</td>
<td>( d )</td>
</tr>
<tr>
<td>form factor</td>
<td>( f )</td>
<td>form quotient</td>
<td>( k )</td>
</tr>
<tr>
<td>height</td>
<td>( h )</td>
<td>increment</td>
<td>( i )</td>
</tr>
<tr>
<td>number (of stems, years, etc.)</td>
<td>( n )</td>
<td>increment per cent (volume, value, etc.)</td>
<td>( p )</td>
</tr>
<tr>
<td>volume</td>
<td>( v )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The general symbols listed above can be expanded if necessary (*e.g.* using subscripts) for wider application (Table 1.5).

Other mathematical and statistical symbols commonly used in forest literature are listed in Table 1.6.

(b) Plurals

Use the plural, where appropriate, when writing the name of an SI unit in full. Values of one and less are considered singular.

Always write symbols for units in the singular, *e.g.* 30 kilometres, but 30 km; 1.72 grams, but 1.72 g; 0.2 gram.

(c) Punctuation

Do not use periods after symbols except at the end of a sentence, *e.g.* "the table measured 1.2 m by 1.0 m."

---

\(^{4}\) Capital letters (\( G, N, V \text{ etc.} \)) are reserved for denoting totals per unit area or population totals derived from sampling or inventory.

As at 2007, reformatted 2012 but no textural changes
### Table 1.5
Useful Expansions of the Standard Mensuration Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Expansion</th>
<th>Interpretation or comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(c)</td>
<td>As for (d)</td>
<td>Circumference or girth</td>
</tr>
<tr>
<td>(d)</td>
<td>(d_g)</td>
<td>Quadratic mean diameter, corresponds with mean basal area of stand.</td>
</tr>
<tr>
<td></td>
<td>(d)</td>
<td>Arithmetic mean diameter</td>
</tr>
<tr>
<td></td>
<td>(d_M)</td>
<td>Diameter of the median tree</td>
</tr>
<tr>
<td></td>
<td>(d_{gM})</td>
<td>Diameter corresponding to median basal area</td>
</tr>
<tr>
<td></td>
<td>(d_{0.1h})</td>
<td>Diameter at 0.1 of total tree height from the ground</td>
</tr>
<tr>
<td></td>
<td>(d_{0.5h})</td>
<td>Diameter at half tree height from the ground</td>
</tr>
<tr>
<td></td>
<td>(d_6)</td>
<td>Diameter at six metres from the ground</td>
</tr>
<tr>
<td>(g)</td>
<td>(g)</td>
<td>Arithmetic mean basal area</td>
</tr>
<tr>
<td></td>
<td>(g_M)</td>
<td>Basal area of the median tree</td>
</tr>
<tr>
<td></td>
<td>(g_{0.1h})</td>
<td>Basal area at 0.1 of total height from the ground</td>
</tr>
<tr>
<td></td>
<td>(g_{0.5h})</td>
<td>Basal area at half total height from the ground</td>
</tr>
<tr>
<td></td>
<td>(g_6)</td>
<td>Basal area at six metres from the ground</td>
</tr>
<tr>
<td>(h)</td>
<td>(h_L)</td>
<td>Mean height by Lorey’s formula</td>
</tr>
<tr>
<td></td>
<td>(h)</td>
<td>Arithmetic mean height</td>
</tr>
<tr>
<td></td>
<td>(h_d)</td>
<td>Height corresponding to mean diameter</td>
</tr>
<tr>
<td></td>
<td>(h_g)</td>
<td>Height corresponding to mean basal area</td>
</tr>
<tr>
<td></td>
<td>(h_{dM})</td>
<td>Height corresponding to median diameter</td>
</tr>
<tr>
<td></td>
<td>(h_{gM})</td>
<td>Height corresponding to median basal area</td>
</tr>
<tr>
<td></td>
<td>(h_{dom})</td>
<td>Average height of dominant trees. Give the exact definition in the text</td>
</tr>
<tr>
<td>(k)</td>
<td>(k_a)</td>
<td>Absolute form quotient = (d_{0.5(h+1.3)}/d)</td>
</tr>
<tr>
<td></td>
<td>(k_{d/1.3})</td>
<td>Artificial form quotient based on diameters at 6 m and 1.3 m above ground</td>
</tr>
<tr>
<td></td>
<td>(k_{0.5h/0.3h})</td>
<td>Natural form quotient based on diameters at 0.5 and 0.3 total height from ground</td>
</tr>
<tr>
<td>(v)</td>
<td>(\bar{v})</td>
<td>Arithmetic mean volume = (\Sigma v/n)</td>
</tr>
<tr>
<td></td>
<td>(v_7)</td>
<td>Volume to minimum top diameter of 7 cm</td>
</tr>
<tr>
<td></td>
<td>(\bar{v}_7)</td>
<td>Arithmetic mean volume to minimum top diameter of 7 cm = (\Sigma v\sqrt{g}/n)</td>
</tr>
<tr>
<td>(f)</td>
<td>(f_7)</td>
<td>Artificial stem form factor up to a minimum top diameter of 7 cm = (v\sqrt{g}/n)</td>
</tr>
</tbody>
</table>

\(^5\) Adapted from Van Soest et al. (1965).
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Expansion</th>
<th>Interpretation or comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i$</td>
<td>$\bar{i}$</td>
<td>Arithmetic mean increment of a number of trees in one year</td>
</tr>
<tr>
<td>$i_{21,30}$</td>
<td>Periodic annual increment of a tree between ages 21 and 30 years</td>
<td></td>
</tr>
<tr>
<td>$\Sigma i_{21,30}$</td>
<td>The total increment of a tree between ages 21 and 30 years</td>
<td></td>
</tr>
<tr>
<td>$i_g$</td>
<td>Basal area increment in one year</td>
<td></td>
</tr>
<tr>
<td>$i_v$</td>
<td>Volume increment in one year</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.6**

**Mathematical and Statistical Symbols Used in Forest Literature**

<table>
<thead>
<tr>
<th>Letter/symbol</th>
<th>General use</th>
<th>Specific use</th>
</tr>
</thead>
<tbody>
<tr>
<td>a, b, c</td>
<td>Algebraic constants</td>
<td>a, $b_0$ – also used as the intercept of a regression line on the ordinate.</td>
</tr>
<tr>
<td>$b_0$, $b_1$, $b_2$</td>
<td></td>
<td>$b$, $c$, $b_1$, $b_2$ – also used as the regression coefficients</td>
</tr>
<tr>
<td>e</td>
<td>Base of natural logarithms</td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>Frequency in statistical distributions</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Snedecor’s F, the variance ratio used in ANOVA tests of significance</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>Estimate of moments in statistical distributions</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>Number of items or values</td>
<td>Often sample size</td>
</tr>
<tr>
<td>N</td>
<td>Total number of values</td>
<td>$N = n_1 + n_2 + \ldots n_r = \Sigma n$</td>
</tr>
<tr>
<td>p</td>
<td>Probability or proportion of successes</td>
<td>Used in statistical distributions</td>
</tr>
<tr>
<td>q</td>
<td>Probability of failure (q=1-p)</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>Estimate of coefficient of correlation</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Coefficient of multiple correlation</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>Coefficient of determination</td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>Estimate of standard deviation, or standard error</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>Student’s t</td>
<td></td>
</tr>
</tbody>
</table>

(Cont.)

---

Adapted from Van Soest et al. (1965).

As at 2007, reformatted 2012 but no textural changes
### Table 1.6 (cont.)

<table>
<thead>
<tr>
<th>Letter/symbol</th>
<th>General use</th>
<th>Specific use</th>
</tr>
</thead>
<tbody>
<tr>
<td>(w)</td>
<td>Range (of values) (i.e.) difference between maximum and minimum values in a sample</td>
<td></td>
</tr>
<tr>
<td>(x, y, z)</td>
<td>Algebraic variables</td>
<td>Used in regression for the independent and dependent variables respectively.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subscripts may be used to identify particular values ((x_1, x_2, \text{etc.}))</td>
</tr>
<tr>
<td>(\hat{y})</td>
<td>Best estimate of (y) obtained by regression</td>
<td></td>
</tr>
<tr>
<td>(\beta)</td>
<td>Population parameter of regression coefficients (of which (b) is an estimate)</td>
<td></td>
</tr>
<tr>
<td>(\eta)</td>
<td>Correlation ratio</td>
<td></td>
</tr>
<tr>
<td>(\upsilon)</td>
<td>Any angle measured from the horizontal</td>
<td></td>
</tr>
<tr>
<td>(\mu)</td>
<td>Theoretical mean of a statistical population</td>
<td></td>
</tr>
<tr>
<td>(\pi)</td>
<td>Constant</td>
<td>(3.141592654…)</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>Standard deviation of a population</td>
<td></td>
</tr>
<tr>
<td>(\chi^2)</td>
<td>Chi-square</td>
<td>Test of statistical “goodness of fit”.</td>
</tr>
</tbody>
</table>

#### (d) Decimal Marker

Use a period \((27.36)\) rather than a comma \((27,36)\) as the decimal marker although use of a comma is common practice in many metric countries. Start all values less than one with a zero \((0.2736)\).

#### (e) Thousand Marker

Use a space, never a comma, as a thousand marker, \(e.g.\) 4 632 137; 8 793.826 31. With four digit numbers, the space is optional, \(e.g.\) 1376 or 1 376. As stated above, the comma is used widely in many metric countries as a decimal marker. The comma was approved for use in Australia when the country adopted the metric system (see Øgrim and Vaughan 1977) but it found little support. By 1979, the decimal point was accepted as the standard decimal marker in Australia (ASA 1979). However, there is some justification for using the comma as a thousand marker in money transactions because a space provides an opportunity for fraudulent entry of an extra figure.

#### (f) Spacing

Leave a space between numbers and symbols, \(e.g.\) 17 kg not 17 kg, and between the parts of symbols for compound names, \(e.g.\) kW h. However, leave no space between a numerical prefix and symbol, \(e.g.\) kg, mm, not k g, m m.

#### (g) Per

Use the inversion symbol or the solidus (/), not the letter "p", thus kg \(m^{-3}\) or kg/m\(^3\), not kgpm\(^3\).
1.2 SIGNIFICANT DIGITS

All measurements are subject to error. This means that one is never able to quote an exact value for a measured physical quantity. If the height of a tree is estimated to lie somewhere between 38.5 and 39.5 m, then the result should be quoted as 39 m, i.e. 3.9 x 10. Such a measurement is said to have been made to two significant digits.

Avoid writing down a long string of numbers that have no significance - it is misleading! Meaningless digits are particularly liable to arise from a series of calculations. To avoid confusion, it is often preferable to write a result using an appropriate power of 10. For example, consider the following calculation:

\[
\frac{6.34 \text{ (m}^3 \text{ plot}^{-1}) \times 22 \text{,748.3 (total area)}}{0.15 \text{ (plot area)}} = 961 \text{,}494.8133 \text{ m}^3
\]

The result could be written 960 000 m\(^3\), but 9.6 x 10\(^5\) m\(^3\) is much better because it indicates clearly that only two digits are significant in the result. The rules to apply are as follows.

**Rule 1:** The significant digits in a number are those reading from left to right, beginning with the first non-zero digit and ending with the last digit written which may be zero, but if zero, it must not result from rounding-off, for example:

<table>
<thead>
<tr>
<th>2 sig. digits</th>
<th>3 sig. digits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0025</td>
<td>0.00257</td>
</tr>
<tr>
<td>0.25</td>
<td>2.57</td>
</tr>
<tr>
<td>2.5</td>
<td>25.7</td>
</tr>
<tr>
<td>2.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

It is incorrect to record more significant digits than are actually observed, e.g. length measurements of 8 metres taken to the nearest metre should not be written 8.0 m.

**Rule 2:** In multiplication and division, the factor with the least number of significant digits limits the number of significant digits in the product or quotient, for example:

\[
895.67 \times 35.9 = 32 \text{,}154.553 \quad \text{The result should be written 321. x } 10^2
\]

The rationale for this is that 895.67 represents a measurement between 895.665 and 895.675 and 35.9 represents a measurement between 35.85 and 35.95, and the products of these four limiting combinations differ in all except the first three digits. In other cases, the number of identical digits in all combinations of the product or quotient will be one less than that in the factor with the least number, for example:

\[
895.67 \times 1.5 = 1 \text{,}343.505
\]

The result should be written 13. x 10\(^2\) or 1.3 x 10\(^3\). Note, however, that the product of 27.146 and 50 (=1375.3) where 50 is an integer has five significant digits because the number of digits in an integral or whole number is infinite, i.e. the factor in the set with the least number of significant digits is 27.146 with five.

A good rule in a series of multiplications or divisions is to carry one more digit than the number of significant digits in the shorter factor of each set and round off to the proper number of significant digits at the end, for example:

**Set 1.**

\[
A \times B \times C = D
\]

[7] (3) (4) = (4)

**Set 2.**

\[
E \times F \times G = H
\]

[8] (2) (7) = (3)
Thus, round-off J to 2 significant digits.

Determining the number of significant digits in addition and subtraction requires that the numbers in the set be first aligned according to their decimal places. The number of significant digits in the result can never be greater than that of the largest of the numbers in the set and often is less. The rule to apply is:

**Rule 3:** In addition and subtraction, align the numbers according to their decimal places. Identify the largest number in the set and locate the right-most of its digits which aligns with at least the right-most digit of all the other numbers in the set. Count the number of digits to the left of and including that digit to determine the number of significant digits in the result.

Consider the following examples:

<table>
<thead>
<tr>
<th>Example 1</th>
<th>Example 2</th>
<th>Example 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>123.623</td>
<td>1786.413</td>
<td>1671.53</td>
</tr>
<tr>
<td>+ 1.1</td>
<td>- 6.2</td>
<td>+ 2000.34</td>
</tr>
<tr>
<td>4.72</td>
<td></td>
<td>8619.29</td>
</tr>
<tr>
<td>129.443</td>
<td>1780.213</td>
<td>13839.13</td>
</tr>
</tbody>
</table>

Round the results as 129.4, 1780.2 and 13 839.1 respectively.

**1.3 Rounding-off**

Normal practice is to round-off field records to the nearest smallest unit feasible from measurement or to a number which ignores the non-significant digits.

An accepted convention for rounding-off to a whole number which avoids bias is illustrated below for a two digit number, \( n.5 \), where \( n \) indicates the units digit.

- If the number is \(< n.5\), round off to \( n \).
- If the number is \( > n.5 \), increase the units digit by 1.
- If the number = \( n.5 \), then round-off to \( n \) if the units digit is even but increase \( n \) by 1 if the units digit is odd.

Thus, 7.3 rounds off to 7; 7.7 to 8; 7.5 to 8; and 8.5 also to 8.

In some situations, it may be desirable to round measurements to some other interval than a whole number, \( e.g. \), to the nearest 0.5. Sometimes convention dictates that measurements, \( e.g. \), of log length, be rounded down to the lower whole number.

**1.4 Bias, Accuracy and Precision**

These terms are often confused. Bias is a systematic distortion arising from such sources as a flaw in measurement or an incorrect method of sampling. Accuracy refers to the success of estimating the true value of a quantity, and precision refers to the clustering of sample values about their own average.
CHAPTER 2

MEASUREMENT OF INDIVIDUAL TREES AND LOGS

2.1 BOLE CHARACTERISTICS

The characteristics of tree boles most commonly measured by forest workers are diameter, height, bark thickness and volume, and less commonly, form and taper. Recommended field practices relevant to the measurement or estimation of these characteristics are summarised in sequence below. Common to all of these practices is the need for the recorder of the measure data (i) to call back clearly to the measurer the information that is being recorded (this simple procedure eliminates a common source of error in measurement), and (ii) to develop a competence in ocular estimation particularly of diameter and height. By quick ocular appraisal of a tree, a suspect measurement can often be identified and checked before the information is recorded.

2.1.1 DIAMETER

The most common and most important measurement made on forest trees is that of the diameter of the stem. The measurement is usually derived indirectly using a linear tape calibrated in \( \pi \) units to allow diameter to be read from a girth measurement. Diameter can also be read directly using a caliper as described later.

The universal convention is to measure the diameter of trees at a fixed height above ground called breast height (BH). This fixed height is 1.4 m in many countries of the world including New Zealand and 1.3 m in many other countries including Australia.

Recommended procedures for measuring diameter at \( BH \) under Australian conditions.

- Check that the instrument (diameter tape\(^7\), caliper) is in perfect working condition, viz.,
  - tape: not kinked (steel) and calibrations easy to read,
  - calipers: sliding arm firm (no play), straight tips on both arms, arms coplanar, and calibrations easy to read.
- Identify the zero mark (origin of measurement) on the girth tape.
- Displace loose mounds of soil and litter around the tree base and remove any vines, lichens, moss and loose bark at breast height (BH).
- Measure at 1.3 m above ground.
- On sloping ground, measure on the uphill side of the tree irrespective of its disposition, i.e. vertical or leaning.
- On level ground, measure leaning trees on the under side of the bole.
- Locate \( BH \) using a stick cut to length (assuming the point of measurement is not already marked on the tree, e.g. paint or scribe mark). In some applications, such as when measuring small sized material and recording the data in 2-3 cm classes, the point of measurement may be determined from a position on one's person known to be 1.3 m above ground.
- Measure in a plane perpendicular to the longitudinal axis of the bole irrespective of whether the tree is vertical or leaning. Minimise the diameter measurement at that point.
- Keep the tape comfortably taut at the moment of measurement.

---

\(^7\) As noted above, the 'diameter tape' used by foresters is really a girth tape calibrated to read diameter i.e. girth is measured and diameter is estimated!

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• Measure coppice stems at 1.3 m from ground level, not from the level of the stump or stool.

• Treat as double stems (B2), triple stems (B3) or multiple stems (Bn, where n indicates the number of forks) trees which breach or fork below BH, and record a diameter for each fork locating the BH points from ground level.

• Treat trees forking above BH as single stems. Code these as double leaders (D2), triple leader (D3) or multiple leaders (Dn).

• For trees forking at or just above BH, measure the diameter below the fork at the point of minimum bole diameter.

• Measure buttressed and fluted stems at a representative point above BH. Should the unrepresentative condition extend well up the bole, specify an arbitrary height for measurement, e.g. 3 m above ground.

• With calipers, record the diameter along two axes perpendicular to each other and average the result (arithmetic mean). Ensure that the caliper arms rest firmly against the tree or log surface and that its long axis lies perpendicular to the longitudinal axis of the object at the moment of measurement.

• If measurement of a single axis by caliper is acceptable (e.g. when the data are being grouped into, say, 5 cm diameter classes, or when measuring a large number of trees), take special care when measuring noticeably eccentric trees. In such cases, take the measurement on an axis approximately mid-way between the long and short axes.

• To derive under bark diameter from caliper measurements made on standing trees, record bark thickness at the points of contact of the caliper arms and the tree surface.

• If the BH point is unrepresentative (due to some malformation, e.g. branch whorl, fire scar, mechanical damage, etc.), take two measurements equidistant above and below the nominal point of measurement and average the two diameters. However, if the diameters differ appreciably in size, average their sectional areas and derive the diameter equivalent. Alternatively, choose for measurement a point on the bole judged by eye to be representative of the diameter at the nominal point of measurement had the malformation not been present.

• Should the BH point on a tree in a permanent sample plot or experimental plot be unrepresentative, follow the procedure outlined next above and then locate by trial and error a point of equivalent diameter on the stem. Mark this second point permanently on the bole (paint mark, soft nail, scribe mark, etc.) and confine subsequent remeasurements to it. Alternatively the height of measurement from the ground should be recorded (e.g. for smooth-barked trees).

• When measuring diameter at points along the bole other than BH, check that the point of measurement is representative. If unrepresentative, apply the same procedure as described above for an unrepresentative BH. If the point resides on or near a whorl at the upper extremity of the merchantable stem, measure the diameter at the position of smallest stem diameter below it (but record height to the unrepresentative point).

• In periodic (repeated) measurement, mark the BH point permanently on the stem with a scribe or paint mark.

---

8 Adjustment for unrepresentative points is essential if the purpose of measurement is to derive the volume of sawlogs but is less important if the trees are to be used solely for wood fibre or pulp.

9 There is a danger of bias with this approach but it is unlikely to be serious.
Trees of $dbhob$ less than a certain specified minimum diameter, e.g. 10.0 cm, may be ignored in some inventories or may be recorded only as number of stems.

2.1.2 HEIGHT

The height of a standing tree (total height, $h$) is defined as 'the vertical distance from ground level to its uppermost point' (Empire Forestry Association 1953). However, in situations where tree lean is common, it is prudent to adopt the definition, 'the length of the tree bole (=main axis) from base to tip' - otherwise, underestimation of standing volume will result. Record the height to either the nearest whole metre or nearest whole decimetre depending on the use of the data and the precision of the measuring instrument.

Total height differs from merchantable height ($h_m$) which is defined as 'the distance from ground level to which a tree is saleable' (Ford-Robertson 1971), i.e. to the highest point on the bole where the diameter is not less than some specified value, e.g. 10 cm, or where utilisation of the bole is limited by branching or defect. Merchantable height rather than total height is normally measured in mature hardwood stands: it is measured in the same way as total height.

Heights of trees in Australia are mostly measured either directly using height sticks of 1.5 m long sections or indirectly using hypsometers. Recommended procedures follow.

2.1.2.1 Height sticks

General

- If possible, use height sticks which are fitted with safety locking clips.
- Use for heights up to 20 m (fibre glass sticks) and 25-30 m (hollow duralumin sticks with a hollow steel ferrule). For taller trees, use a hypsometer.
- Do not use in strong winds.
- Wear safety helmets, field boots (preferably shod with a steel toe cap), and protective glasses to prevent pine needles and other dislodged debris from lodging in the eye.
- Avoid idle chatter and other distractions during measurement. Concentration is essential for crew safety.
- Do not permit inexperienced persons to use height sticks unless supervised. Sound training is essential to minimise measurement error and ensure crew safety.
- Count and record the number of sticks in the set before commencing measurement.
- A crew of two persons is usually appropriate when measuring trees less than 10 metres tall. For taller trees, a 3-person crew is essential, viz. a 'stick person' who erects the sticks, an assistant who stands nearby holding the unused sticks, and an observer who stands well away from the tree.
- Clean the ferrules of the sticks after each day's use and thoroughly check the set each season for straightness and "smooth action".

Duties of the 'stick person'

- Quickly observe the tree's branching habit and other features (lean, etc.) and position yourself at the tree base so that (i) the sun is either behind you or over your left or right shoulder and (ii) the passage for the sticks through the crown is reasonably clear.

---

10. The procedures listed apply particularly to hollow duralumin sticks fitted with a hollow steel ferrule and without safety clips. Preferably height sticks should be fitted with safety locking devices.

As at 2007, reformatted 2012 but no textural changes
• When erecting the sticks.
  - Erect them with ferrules pointing downwards.
  - Look upwards most of the time.
  - To prevent the sticks falling out of the tree, keep their centre of gravity between your person and the tree. Do this by always holding the basal two sticks vertical and leaning the upper sticks inwards to rest against the bole.
  - With leaning trees that have 'self-corrected', erect the sticks from a position directly below the point of correction. For trees that have not corrected, attempt to lay the sticks along the upper side of the leaning stem.

• When retrieving sticks.
  - Constantly look upwards, keep your feet well apart, hold the sticks directly in front of your person, and retrieve smoothly. Right-handed operators should hold the erected sticks in their right hand, which should be held high, and remove the bottom stick with the left hand. The converse applies to left-handed persons.
  - Either allow the sticks to slide through the upper hand, clamping and retrieving the sections one by one, or retrieve them hand over hand. Pass each stick to the assistant as it is detached, looking upwards continuously.
  - Do not jerk or suddenly pull the sticks downwards. If pressure is felt during retrieval, proceed very cautiously until release is felt. If the sticks suddenly feel light, they have probably parted. If this happens, don't panic. Move your assistant to a safe place away from the tree base while you attempt to reconnect the sticks. Should this cause the upper, parted section to dislodge, drop everything and move rapidly to the opposite side of the tree and away from it.
  - If upward movement of the sticks is impeded by a branch or cone, simultaneously shake the sticks laterally and push upwards to guide the tip onto a new path.
  - Whenever pressure is felt when erecting the sticks, stop, retrieve at least one stick, and seek a new path before proceeding further.
  - To correct sticks which begin to splay outwards on the side of the tree away from you, retrieve several sticks, move closer to the tree and re-erect the sticks.
  - To correct sticks which begin to splay behind you, retrieve several sticks, move back 0.3 m to 1 m from the tree base, hold the basal sticks vertical, and proceed to re-erect the sticks.
  - If the sticks splay to the point where they begin to fall out of the tree, do not 'fight' them. Rather, move around the sticks so that you face the direction in which they are falling and guide them down so that they fall flat in one continuous piece. Doing otherwise with duralumin sticks can ruin the full set.
  - Watch out for falling cones. Should you be aware that a cone has been dislodged, do not move and do not look upwards. Stand erect with shoulders hunched and head inclined slightly forward until the cone hits the ground.

Duties of the stick assistant
• Stand close beside the stick person and hand over (and retrieve) the sticks in a manner similar to that of a scalpel being passed between a nurse and surgeon.
• Count the sticks both as they are erected and retrieved and check that the counts are consistent with both the original count and the number of unused sticks (sticks have been
known to become wedged between branches or cones during retrieval and to have parted without the knowledge of the 'stick person', thus presenting an on-going hazard for anyone working beneath).

- Use a stick graduated in decimetres to measure the odd length at the base of the tree. Measure from ground level to the top of the ferrule of the lowest stick. Add this length to the product of the number of sticks erected and stick length to determine tree height. Check the calculations before recording the result.

Duties of the observer

- Be alert and active at all times. Stand well away from the tree at a position offering a clear view of the tree bole and sticks (angle of observation ≤ 45°). Follow the progress of the sticks both during their erection and retrieval and warn the stick person and assistant should the tip of the sticks begins to splay or a cone or other object be dislodged.

- Ensure that parallax error is eliminated by standing in a plane perpendicular to the vertical plane generated by the upper bole of the tree and the sticks. Define this plane by moving around the tree until its upper axis is obscured by the sticks or vice versa. Then move away from the tree perpendicular to that plane and locate a point on the ground convenient for sighting. Guide the 'stick person' in the up-and-down movement of the sticks until the tops of the tree and the sticks are aligned. At this point, record the height.

- Be fully aware that parallax error is the most common and most serious error encountered when using height sticks!

2.1.2.2 Hypsometers

- Use a hand-held instrument based on trigonometric rather than geometric principles (e.g. Suunto clinometer, Forester Vertex, Haga, Blume Leiss, Relaskop, Abney level, etc.).

- To reduce computation and speed-up the measurement process, use direct reading scales in preference to angular and percentage scales.

- Visually check the tree for lean before measurement begins. This is essential to minimise serious error in the height estimate (much of the 'noise' in data bases of tree height arises due to failure by measurers to recognise and account for tree lean!) To illustrate this point, consider a tree with a slight lean of 3°. Measuring such a tree as if it is vertical will incur an error ranging from +5.4% to -5.1% depending on the direction from which the tree is observed. For a tree with a lean of 6°, the corresponding errors range from +11.1% to -10.0% (Table 2.1). These errors are serious!
Table 2.1

Maximum Errors Incurred in Measuring the Height of Leaning Trees as if they were Vertical

<table>
<thead>
<tr>
<th>Angle of lean (°)</th>
<th>Percent error&lt;sup&gt;11&lt;/sup&gt;</th>
<th>Angle of lean (°)</th>
<th>Percent error&lt;sup&gt;11&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>leaning towards</td>
<td>leaning away</td>
<td>leaning towards</td>
</tr>
<tr>
<td>1</td>
<td>+1.8</td>
<td>-1.7</td>
<td>+11.1</td>
</tr>
<tr>
<td>2</td>
<td>+3.6</td>
<td>-3.4</td>
<td>+13.0</td>
</tr>
<tr>
<td>3</td>
<td>+5.4</td>
<td>-5.1</td>
<td>+15.0</td>
</tr>
<tr>
<td>4</td>
<td>+7.2</td>
<td>-6.7</td>
<td>+17.1</td>
</tr>
<tr>
<td>5</td>
<td>+9.1</td>
<td>-8.4</td>
<td>+19.2</td>
</tr>
</tbody>
</table>

- For vertical trees, carefully set off the horizontal distance in the direction most likely to give a clear view of both the tree tip and base. This distance should be equal to or greater than the height of the tree, i.e. angle of observation to the tree tip should be 45° or less<sup>12</sup>. Measure the distance from the tree centre (offset) to the observer. Failure to set out a horizontal line incurs positive bias.

- For instruments with multiple scales (e.g. Haga, Blume Leiss, Relaskop) take care that the correct scale is read.

- If the tip and base (or plumb point) of a tree are not visible from the appropriate fixed distances incorporated in the instrument in use, proceed as follows.
  - Move to a position from which both the tip and base (or plumb point) are visible, mark the spot on the ground, and measure the horizontal distance to the tree (or plumb point) (s).
  - Sight to the tree tip and base (or plumb point) using any scale x on the instrument (e.g. 30 m) and record the readings (h<sub>t</sub>, h<sub>b</sub>).
  - Determine total height (h) as follows:
    \[ h = (h_t + h_b) \times (S/X) \] plus correction for lean if appropriate (1)

  Note: If the reading to the tree base (or plumb point) is an elevation, h<sub>b</sub> in Formula 1 is negative.

- From the viewing point, take 2-3 readings and average. The precision of these readings should be better than ± 2.5%, i.e. ± 0.5 m in 20 m. If it is not, repeat the measurement.

- Use a range-finder only if it is unavoidable<sup>13</sup>, e.g. assessor working alone. Range-finder attachments to conventional hypsometers do not allow for slope; their targets are mostly designed to be fixed to the fronts of trees (rather than at the sides); additional support is required to set them up at plumb points; and they require a subjective decision to be made. All of these features serve to decrease the accuracy and precision of the height estimate. With 2-person teams, it is more satisfactory, and just as quick, to set out the horizontal distance manually.

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<sup>11</sup> Leaning towards and leaning away indicates the tree leaning towards and away from the observer respectively.

<sup>12</sup> Confine the sighting angle to the range of 30-45°, i.e. stand away from the tree a distance between one and one and a half times the tree height. For sighting angles greater than 45°, the probability of incurring error increases greatly due to both reduced visibility of the tip and reduction in the scale interval (tangents increase rapidly above 45°).

<sup>13</sup> This advice may change with advances in technology.

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• Add the estimates (readings to the tree tip and base) if they are of opposite sign (elevation to tip (+) and depression to base(−)) and subtract them if they are of similar sign, i.e. both elevations (eye of operator below the level of the tree base).

• For precise and accurate measurement, assess height from two positions on the ground establishing sighting lines to the tree which are roughly 90° apart. The two readings should agree within ± 2.5%. If they don’t, error in measurement is indicated: repeat the measurement.

• If an appropriate position on the ground cannot be found from which both the tree tip and base are visible, select a position from which the tip is visible and sight both to it and to a visible datum on the lower bole. To derive total height, add the height of the datum above ground to the derived length between the datum and tip.

• In very dense stands, e.g. young, unthinned, unpruned plantations where it is often difficult to locate the tip of a particular tree, have an assistant kick the butt about 60 cm above ground. Movement of the tip will be readily observed.

• For trees with a slight lean (≤ 5°), set off the horizontal distance from the geometric centre of the tree bole in a direction perpendicular to the plane of lean. This confines the error to < 1% (Table 2.2).

<table>
<thead>
<tr>
<th>Angle of Observation = 45°</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Angle of Lean (°)</th>
<th>Error (%)</th>
<th>Angle of Lean (°)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−0.0</td>
<td>11</td>
<td>−3.6</td>
</tr>
<tr>
<td>2</td>
<td>−0.1</td>
<td>12</td>
<td>−4.2</td>
</tr>
<tr>
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<td>−0.3</td>
<td>13</td>
<td>−4.9</td>
</tr>
<tr>
<td>4</td>
<td>−0.5</td>
<td>14</td>
<td>−5.7</td>
</tr>
<tr>
<td>5</td>
<td>−0.8</td>
<td>15</td>
<td>−6.5</td>
</tr>
<tr>
<td>6</td>
<td>−1.1</td>
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</tr>
<tr>
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<td>19</td>
<td>−10.1</td>
</tr>
<tr>
<td>10</td>
<td>−3.0</td>
<td>20</td>
<td>−11.1</td>
</tr>
</tbody>
</table>

• For leans > 5°, plumb the tip to ground as described later, set off the horizontal distance from the plumb point, sight to the tree tip and the plumb point and, if one line of sight is an elevation and the other a depression, sum the resultant heights to give the height of the vertical component, otherwise subtract them. If necessary, correct the estimated height for displacement as described next below.

• To determine whether or not a correction for lean should be made to the height of the vertical component, apply the formula:

\[ s_{\text{max}} = k H_{vm} \]  

(2)

where \( k = 0.1425 \) and \( s_{\text{max}} \) is the maximum horizontal displacement allowable without correction to restrict to 1% the error incurred by assuming that the height of the vertical component (\( H_{vm} \)) equals the true height. Both \( H_{vm} \) and \( k \) are independent of the unit of measurement.
When estimating the total height of trees of deliquescent habit (rounded, spreading crowns), sight through the crown to the point in space judged by eye to be coincident with the crown's upper surface and plumb above the top of the main trunk or bole of the tree, i.e. the point where the crown begins (called 'crown break'). Plumb the latter to ground to identify the point from which the horizontal distance is measured.

On sloping ground, preferably set off the horizontal distance on the contour, otherwise upslope. The former is preferable because it is not uncommon for trees on slopes to lean slightly downhill. If setting out the horizontal distance is impractical or impossible, follow the procedure described below (Formula 5).

When estimating total tree height using the degree scale of an Abney level or other clinometer, apply the formula:

\[ h = s \left[ \tan(\beta) + \tan(\delta) \right] \]  
(3)

where \( h \) = total height  
\( s \) = horizontal distance  
and \( \beta, \delta \) = angles to tree tip and base respectively.

Note in this case that:

(a) the tangents of the angles, not the angles per se, are added

(b) \( \delta \) is mostly a depression. If it is an elevation, e.g. the observer is down slope and below the level of the tree base, Formula 3 becomes:

\[ h = s \left[ \tan(\beta) - \tan(\delta) \right] \]  
(4)

In situations where it is impossible to set off a horizontal distance, measure and record the slope distance (\( s \)) and slope angles \( \beta \) (from the observer to the tree tip) and \( \phi \) (from the observer to the tree base or to a datum on the lower bole), and apply the formula:

\[ h = s \left[ \sin(\beta \pm \phi) / \cos(\beta) \right] + d \]  
(5)

where ± is + for eye level above tree base and – for eye level below tree base. Confine the angles \( \beta \) and \( \phi \) to the range +50° to -10° and -30° to +10° respectively.

When using instruments for which the scales are not visible while sighting (e.g. Haga, Blume Leiss), allow several seconds for the oscillating pointer to come to rest before depressing the clamp or break button.

Don't measure in high winds because, apart from the safety hazard, it is difficult to avoid serious error in the height estimate.

In permanent sample plots and experimental plots, it is desirable to retain the same viewing position for each measured tree if possible (i.e. from year to year) to improve the precision of estimate of height increment.

Recorded height data derived from hypsometers do not warrant a decimal point, i.e. if a decimal point is shown, figures after it invariably are not significant.¹⁴

2.1.2.3 Plumbing a tree tip to ground

If the tip of a leaning tree is visible from a point on the ground approximately beneath it, locating its projected position on the ground is done most easily using an instrument which projects a vertical line of sight (e.g. Weir 1959; Khan 1971; Tihonov 1971; Jackson and Petty

¹⁴ For most hypsometers based on trigonometrical principles, the instrument error is ±2.5%. This means that trees of actual heights 10, 20, 30, 40 and 50 m should have their heights rounded to the nearest ¼, ½, ¾, 1 and 1¼ m respectively. Obviously this poses problems when entering data into a computer data base. The solution is accept one figure after the decimal point when entering data into the data base and round-off appropriately any processed output.
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For most trees however, the tip is obscured by foliage and the projection has to be done indirectly. The procedure with two and three people respectively is as follows.

(a) **Two people:** Stand roughly in the plane of lean with the tree tip pointing towards you (operator A) and, using a plumb-bob, define the plane by moving until the vertical line defined by the suspended plumb-bob appears to pass through both the tree tip and base. Now have your assistant (operator B) move into the plane beyond the expected position of the projected tip and turn and face the tree base. Then move out (*i.e.* A) from the tree base roughly perpendicular to the previously defined plane and define a second plane passing this time through the tip only. Ask your assistant (B) to move towards the tree base until he or she intersects the new plane. Mark this point of intersection, the plumb point, on the ground.

(b) **Three people:** The procedure is greatly simplified. Two people (A and B) with plumb-bobs stand at positions on the ground from which the respective lines-of-sight to the tree are roughly perpendicular to each other. Each operator defines the vertical plane through the tree tip and then operator C moves to a position on the ground which intersects both planes, and marks the spot.

### 2.1.2.4 Ocular estimation of height

An ability to estimate tree height by eye with reasonable accuracy and precision can be developed with practice. Ocular estimation is used in South Australia in strip-line assessment of site quality in *Pinus radiata* plantations aged 9-10 years (heights up to about 18 m) (Lewis *et al.* 1976, p. 31) and is an important component of the second-stage sampling process in point-3P (P3P) and point-model based (PMB) sampling (Wood and Schreuder 1986).

Recommendations relevant to ocular estimation follow.

- Train the assessors well and ensure that they 'calibrate their eyes' regularly by checking their estimates against known standards (tree heights measured by instrument).
- When practical, place a 'calibration pole' of known length (preferably 3 m) at the base of each tree being assessed, *e.g.* in P3P and PMB sampling.

### 2.1.3 BARK THICKNESS

The thickness of bark on trees varies with species, genotype, age, rate of growth and position along the bole. On standing trees, it is measured indirectly by an instrument such as a bark gauge, bark probe, or hammer, nail and graduated scale. Examples of specialised instruments are the Swedish bark gauge and the "handy bark gauge" described by Lewis (1953). The operation is probably the most error-prone of all the operations in forest measurement because it relies heavily on feel. Considerable experience, skill and care are required to obtain reliable results.

Procedures helpful for minimising error in estimating bark thickness on standing trees include the following.

- Thoroughly train field crews on a wide range of tree sizes (and tree species if relevant).
- Use palm and shoulder/forearm pressure only when forcing entry through the bark. Do not twist the gauge at any time or hammer it in. Gauges such as the Swedish bark gauge are easily broken and they are costly to replace.
- Push the gauge straight in until resistance of the wood is felt, then push the flange firmly against the bark surface and read the scale while the instrument is still embedded. Pull the gauge straight out, firmly and without twisting.
• Take four measurements at roughly equidistant points around the bole and average to derive the thickness at a given height. Two measurements may be adequate on small diameters.

• Measurement instructions should indicate whether bark thickness should be measured on the ridges or in the fissures of trees which have furrowed barks.

• Use a safety belt when working above the ground.

• On particularly thick and tough barks, use a hammer, nail (10-20 cm long) and a thin metal scale rule and rely on sound and feel to determine when the nail begins to penetrate the wood. On thicker barks, an option is to replace the hammer and nail with a brace and bit.

• If calipers were used to measure the diameter, measure bark thickness at the points of contact of the caliper arms with the surface of the stem.

On felled trees, bark thickness can be measured indirectly as described above or by measuring the diameter at the specified point on the bole before and after removing the bark. Alternatively, it can be measured directly using a scale ruler either on a cut face perpendicular to the long axis of the stem (e.g. ‘v’ shaped axe cut) or at the log ends.

2.1.4 VOLUME

Procedures for estimating the volume of individual tree stems vary depending on whether the tree is standing or felled and whether direct or indirect measurement is used. Procedures to follow during measurement include those already listed in Sections 2.1.1 (diameter), 2.1.2 (height) and 2.1.3 (bark thickness). Additional procedures necessary in various situations for deriving reliable estimates of volume and ensuring a safe work environment are listed below.

2.1.4.1 Standing Sample Trees: Direct Measurement

The following procedures apply specifically to conifers and may need adaptation for hardwoods.

Procedures related to measurement

• Before measurement commences, clearly mark the breast high position (1.3 m) on the bole and use this mark as the datum for later height measurement (superimpose the 1.3 m marks on the linear tape and tree and read heights above ground directly). Sometimes a marked point at some other height may be more convenient.

• If possible, take measurements over the full length of bole distributing them roughly proportional to volume (or value), i.e. concentrate at least one-half of the measurements in the lower third of the bole, e.g. for a tree of dbhob 60 cm, total height 30 m, and 10 points of measurement, an appropriate distribution would be: 0.3 m, 0.7 m, 1.3 m, 2.5 m, 5 m, 8 m, 11.5 m, 15.5 m, 20 m, and 25 m. In some circumstances, e.g. for repeat measurements, fixed length sections may be preferred.

• Should a sharp reduction in diameter occur at any point along the bole, measure both immediately below and above the point of sudden change in taper.

• If one's exclusive interest is in the sawn product, confine the points of measurement above breast height to mid-internodes; otherwise, measure at any convenient point along

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15 Thus, no allowance is made for the stump. This is unimportant because allowance for stump is best made later when the use of the data is known.
16 The nominated points of measurement are not fixed, i.e. they could be moved either up or down to avoid nodes, stem abnormalities, etc.
17 i.e. at a height above ground equal to one-half of the diameter over bark at breast height. This is a reasonable approximation of stump height.

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the internode but avoid points with abnormal cross-section due to local swelling, damage, etc.

- When measuring bark thickness, use the safety belt and branches to move around the tree bole to obtain the most suitable position for using the gauge properly at each of the four selected positions. Do not attempt to measure all four from a single position on the bole.

**Procedures related to crew safety**

- Exclude from climbing persons with a genuine fear of heights or who have an impediment which restricts their climbing ability. Normally this will be considered in crew selection and training.

- Avoid taking any kind of risk when climbing. Do not skylark.

- Don't sit or stand under a tree being climbed except when the climber requires a measurement of height above ground; and avoid taking measurements on the lower bole of a tree when another person is aloft.

- Always wear a safety helmet when on the ground and a safety belt when aloft.

- Before climbing a tree, thoroughly check the condition of the belt and test it with your full weight on the lower bole. Ensure the buckle is engaged, the belt tongue is secure in its keeper, and the belt itself is not so tight that movement is restricted. Do not climb until you have full confidence in the belt.

- Ensure that equipment carried aloft (e.g. girth tape, bark gauge) is firmly secured to your person. Should a piece of equipment be dropped or a pine cone or branch be dislodged, shout a warning immediately to those below.

- Do not deliberately drop equipment from aloft.

**Procedures related to the use of ladders**

- Use them only on the lower bole up to the base of the green crown - unless higher branches are too small to carry a person's weight or the internodes are too long.

- Don't overdo pruning of the lower branches. These help stabilise the ladders and offer useful footholds when moving around the bole to measure bark thickness. Prune only those lower branches which impede either erection of the ladders or climbing.

- Climb with caution. Wear light footwear preferably with a non-slip sole.

- Climb a vertical ladder unsecured at the top by holding the tree bole with the hands.

- Secure each ladder section firmly to the tree before ascending further.

- When attaching a new section to an already secured ladder, stand on the second or third rung from the top, secure your safety belt to the tree, and thread the new section of ladder between your person and the tree into the female coupling. If the tree is sinuous, it may be necessary to loosen the chain securing the upper section of ladder before the new section can be engaged.

- The load limit for an extended set of climbing ladders is one person. Except in exceptional circumstances, do not ascend a tree when another person is aloft. In the exceptional case, ensure that the person aloft is firmly secured to the tree by safety belt and remains motionless while the second person climbs.

- Climb in the green crown making full use of branch crutches as holds for hands and feet. Test each branch before giving it your full weight. Be extremely wary of dead branches.

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18 A Guide to Safe Tree Climbing issued by the Department of Primary Industries in South Australia is appended to this document. [ACFA note: It was not actually appended. ForestrySA has replaced PISA Forestry.]
Handbook to accompany “An Australian Standard for Valuing Commercial Forests”

RWG#2 Code of Practice Annex 20

- Disengage a set of ladders one section at a time by releasing the chain of the upper section and retreating to the section next below. Then secure the safety belt, gain a firm purchase on the lower rung(s) of the section to be removed and with a gentle sideways ‘to and fro’ motion, disengage the ladder. Release the safety belt, thread one arm through the gap between the two upper rungs, and lower the ladder to ground.

2.1.4.2 Standing Sample Trees: Indirect Measurement

Volumes of standing trees are measured indirectly using either tree volume functions or dendrometry. With tree volume functions, the one or more independent variables appropriate to the function are measured, using procedures described elsewhere in this chapter, and volume is estimated from the function. When using dendrometry, some additional precautions need to be followed as listed below.

- Tree stems are seldom truly circular.
- Dendrometry involves estimating diameter along the bole generally in the one plane only.
- A reliable bark function or correction factor is required to derive under bark estimates. Thus, volumes derived from dendrometry cannot be expected to be as accurate or as precise as volumes derived from direct measurement.
- An appropriate size of crew for forest inventory based on dendrometry is commonly three persons.
- Check the tree for lean. If leaning, set-up the dendrometer on the ground in a plane perpendicular to the plane of lean (this is vitally important for dendrometers using the optical fork principle to determine diameter, e.g. Relaskop, Telerelaskop). If appropriate, measure and record the lean so that later height (section length) measurements can be adjusted.
- If log grade is part of the estimation process, ensure that at least one crew member is thoroughly familiar with the grading specifications.
- Position the dendrometer on the ground such that the sighting angle to the tree tip is 45° or less; the full width of the bole at breast height can be seen through the eyepiece; and a good view is possible of the majority of the bole including the tip. Time spent selecting the best position for viewing is well worthwhile.
- Measure diameters at breast height and below by girth tape. If under bark volume is required, measure and record bark thickness at breast height.
- Stand upright to one side of the base of the tree a datum pole 2.5 to 3 m long and brightly painted at the tip. Take the first dendrometer readings of diameter \( d_p \) and height to the top of the pole. Check that \( d_p \) is either less than the breast high diameter \( i.e. d_p < d \) or if not, that the anomaly is explainable \( e.g. \) local swelling.
- Before taking any reading, ensure that the section of bole under observation is sighted in a plane perpendicular to the longitudinal axis of the section.
- Check that each subsequent reading of diameter and height along the bole is consistent with the reading recorded previously and immediately check any anomalous result. If the reading is found to be correct, seek an explanation for the anomaly and make an appropriate noting on file: this is essential for verifying that the recorded measurements are sound should they subsequently be rejected during processing. A schema of the tree showing the points of measurement, and highlighting any features likely to have influenced measurement, is particularly useful in this process and should be made mandatory.
Distribute points of measurement along the full bole roughly proportional to volume (or value) as described in Section 2.1.4.1. Preferably select them well away from the branch nodes on a representative section of the bole.

If an estimate of merchantable volume only is sought, dendrometer readings will be required up to the merchantable limit. However, for trees of excurrent habit, this limit is often determined by some specified minimum top diameter. In this case, preferably take the final (upper) reading beyond the expected limit (judged by eye) and subsequently derive the merchantable limit later by linear interpolation during processing. For trees of deliquescent habit (most mature hardwoods), the merchantable limit is often set by crown break. In this case, take the final height reading to the base of the break but record diameter at a representative point below, i.e. at the level of least diameter.

In advance of measurement, prepare either an appropriate form (hard copy) or format on a portable data recorder/field computer for recording the data.

2.1.4.3 Felled Sample Trees: Direct Measurement

Measurements commonly required on felled trees include length, diameter and bark thickness. Instruments mostly used comprise the girth tape and caliper for diameter, logger's (linear) tape for length, and bark gauge for bark thickness. The procedures recommended for measuring standing trees (Section 2.1.4.1) mostly apply to felled trees as well, but owing to the different situation (tree on the ground), some additional procedures need to be followed.

Prior to felling the tree, circumscribe the bole with a clear mark at breast height (or at some other datum on the lower bole at a known height above ground) to enable heights above ground after felling to be read directly.

Fell the tree on top of small logs placed at intervals along the expected line of fall and perpendicular to it. This improves access to the underside of the tree for measuring diameter by girth tape and bark thickness by bark gauge.

Lay out unused equipment at the stump (e.g. on a small tarpaulin or kit-bag, etc.).

Add one or more cant hooks to the equipment list for rolling the tree when required.

Trim the branches by axe or chainsaw and move the smaller branches away from the tree so that a clear line of access is established along both sides of the bole.

Immediately after trimming the bole, measure and record total and merchantable height and any other heights of interest ensuring that the tape is kept straight and taut during the measurement.

Mark the intended points of measurement along the bole with lumber crayon. If bark is to be removed after measuring the over bark diameters so that under bark diameters can be measured directly, make saw cuts into the surface of the wood just below each point of measurement to facilitate later relocation.

If under bark volume is needed and time and costs permit, debark the tree either completely or in bands approximately 10-15 cm wide at the selected points of measurement. Ensure that the sections of bole to be measured are clear of all bark before measurement.

If a caliper is specified for measuring diameter and the underside of the bole is not accessible, measure along two axes lying perpendicular to each other and roughly at 45° to the vertical plane. If the tree is not barked and under bark volume is required, measure bark thickness by gauge at the four points of contact of the caliper arms with the bole.

If height to the base of the green crown needs recording, take the measurement before the relevant branches are removed.

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On occasions, the tree bole may be partly embedded in the ground. If a girth tape is specified for measuring diameter, use a small, light crow bar to dislodge the earth beneath the bole and a thin flexible steel probe with a hook at the distal end for 'threading' the tape under the bole. Measure bark thickness at four readily accessible points distributed at roughly 90° intervals around the perimeter of the bole.

For measuring diameter at unrepresentative points, follow the procedures described in Section 2.1.1.

2.1.5 STEM FORM AND TAPER

The terms form and taper as applied to tree stems are not synonymous. In forest mensuration, stem form (synonymous with stem shape), is determined by the way the stem tapers, i.e. by the way its diameter decreases from base to tip.

The taper of a solid body of regular outline is governed by the values of 'k' and 'b' in the equation:

\[ y^2 = k x^b \]  

where \( y \) is the radius of cross section at a point \( x \) vertically below the apex, 
\( b \) determines the way the body tapers (i.e. its form or shape), and, 
\( k \) determines the rate of taper within that form.

Thus, measurements of the form and taper of tree stems involve measuring diameter at specified positions (heights above ground) along their length. Although these positions will vary depending on the particular situation, the basic procedures for measurement outlined in Sections 2.1.1 and 2.1.2 apply.

Change in the way a tree tapers occurs naturally but it can be induced artificially by silvicultural or other treatment, e.g. fertilising, pruning, thinning. Any treatment which affects in some way the crown of a tree is likely to have an effect on the taper and form of its stem! As these effects are (i) manifest over a period of years rather than of months, (ii) tend to be concentrated over the portion of the bole immediately below the green crown, and (iii) have implications for the methods and formulas used to estimate stem volume, it is imperative that points selected for measurement to detect or monitor a change in stem taper or form following treatment, be chosen with care. To ensure that the chosen points are representative and that the measurements have been made without error, plot the diameters or sectional areas against height above ground: a smooth curve or straight line should be evident.

2.2 LOG CHARACTERISTICS

Although measurement by weight is being used increasingly for log sales, a majority of sawlogs in Australia is still sold on a volume basis.

It is a common misconception that it is a simple matter to estimate the volume of a log accurately. People overlook the fact that:

- logs are often irregular in cross-section and profile,
- many logs are flared at one end (butt logs), and,
- in deriving the volume estimate, an assumption must be made about log shape.

These factors create opportunities for error. Thus, set procedures as outlined below (sub-sections 2.2.1 - 2.2.3) need to be established and followed during measurement. As a general principle, measure long logs (>15 m) in at least two sections of approximately equal length - it is essential that this be done with logs exceeding 20 m in length.
2.2.1 DIAMETER

- Measure in whole centimetres (commonly rounded down) unless a higher precision of measurement is expressly required (e.g. research).
- When using a scale ruler (at the log ends) or calipers, measure diameter along two axes aligned perpendicular to each other, and average. Measurement along one axis only may be appropriate where highly accurate volumes of individual logs is not required.
- Differentiate between butt logs and other (middle and upper) logs. The basal flare in butt logs can cause serious bias in the volume estimate unless allowance is made for it.
- If a specified point of measurement on a log is unrepresentative, choose a representative point to replace it (except when using Bruce’s formula - refer Table 2.4 (b)).
- If measuring by diameter tape, choose a steel tape. Wind the tape firmly around the circumference of the log in a plane at right angles to the long axis and ensure that it is not twisted.

2.2.2 LENGTH

- Use a linear tape (preferably steel) held straight and taut along the length of the log.
- Measure in metres and decimetres (rounded down) unless a higher precision of measurement is expressly required (e.g. research). Rounding down is often recommended to allow for loss of volume due to end-squaring of timber cut from logs.
- Logs may be measured to nominal lengths, i.e. the product length may differ from the actual length. Measurers need to be aware of such local rules.

2.2.3 VOLUME

Logs differ in type and situation (long log or short log\textsuperscript{20}, butt log or upper log, barked or unbarked, single or stacked, representative point at butt end accessible or inaccessible, etc.) and these differences bear directly on the measurement procedures applied to derive their volume. A key factor underpinning the accuracy of the volume estimate of an individual log is awareness by the measurer of the error incurred by measuring at unrepresentative points. Log measurers should quickly appraise each log for aberrations in taper before measurement commences and adjust their measurement technique accordingly. For ease of reference, the various methods available for measuring logs are presented in Table 2.3 The legend for this table and the various formulas referred to within it are presented in Table 2.4.

The volume of individual pine logs (\textit{Pinus} sp.) can be derived from log length ($L$) and diameter measured inside bark at both the small end ($d$) and large end ($D$) by applying the formula of Ellis (1982) derived for exotic pines in New Zealand, \textit{viz.}:

$$V (\text{m}^3) = \exp[1.944 157 \ln(L) + 0.029 931 (d) + 0.884 711 \ln \{(D–d)/L\} – 0.038 675] \times 10^3$$
\[+\ 0.000 078 54 \ (d^2 \times L) \quad (12)\]

This formula should apply reasonably well in Australia for two reasons: it requires input of inside bark measurements and the taper and solid shape of the central boles of New Zealand and Australian grown exotic pines are similar (the frusta approximate 2nd-degree paraboloids).

\textsuperscript{20} As indicated earlier, it is prudent to measure long logs (> 15 m) in at least two sections to minimise error arising from possible violation of the shape assumptions in the estimation formula.

\textit{As at 2007, reformatted 2012 but no textural changes}
Table 2.3 Procedures appropriate for Deriving the Volume of Logs on the Ground
(refer to Table 2.4 for the legend and formulae)

LOGS ON THE GROUND

STACKED

BUTT LOG

Unbarked

Barked

Representative point accessible at the butt end

A

Representative point not accessible at the butt end

B

OTHER THAN BUTT LOG

C

D

D

UNSTACKED (Single logs)

BUTT LOG

Unbarked

Barked

C or H

Research use

Routine use

Research use

Routine use

OTHER THAN BUTT LOG

Barked

Unbarked

Barked

Unbarked

H

Research use

Routine use
Table 2.4

(a) Legend

A Measure diameter by tape or caliper at a representative point in from the butt end and by scale rule at the small end, and apply Smalian’s formula.
B Measure diameter by caliper or scale rule at the two log ends and apply Bruce’s formula.
C Measure inside bark diameter at both log ends by caliper or scale rule and apply Bruce’s formula.
D Measure diameter at both log ends by caliper or scale rule and apply Smalian’s formula.
E Measure diameter at both log ends by tape, caliper or scale rule, derive and locate the position of the centroid, measure diameter at that point (or nearby representative point), and apply centroid formula.
F Measure the diameter at both ends (at a representative point at the larger end of butt logs) and at mid log length, and apply Newton’s formula.
G Measure the diameter at mid-length (or nearby representative point) by tape or caliper and apply Huber’s formula.
H Either remove the ring of bark at the mid-length (or representative point) position, measure the inside bark diameter by tape and apply Huber’s formula, or measure diameter by caliper along two axes perpendicular to each other at the mid-length (or representative point) position, measure bark thickness at the points of contact of the caliper arms with the bole, derive average diameter inside bark, and apply Huber’s formula.

(b) Log Volume Formulae

Bruce’s formula:

\[ V = (0.25B + 0.75S)L \]  \hspace{1cm} (7)

where \( V \) is volume (m\(^3\)); \( B \) and \( S \) are the cross sectional areas (m\(^2\)) at the large and small ends respectively; and \( L \) is the log length (m).

Smalian’s formula:

\[ V = \left(\frac{B+S}{2}\right)L \]  \hspace{1cm} (8)

Huber’s formula:

\[ V = ML \]  \hspace{1cm} (9)

where \( M \) is the cross sectional area (m\(^2\)) at log mid-length.

Centroid formula:

\[ V = \frac{SL + bL^2/2 + cL^3/3}{L} \]  \hspace{1cm} (10)

where \( b = \frac{(B - S - cL^2)}{L} \),
\[ c = \frac{(B - C(L/e) - S(1 - L/e))}{(L^2 - Le)} \]

and \( C \) = cross sectional area (m\(^2\)) at the mid-volume (centroid) of the log measured at a distance \( q \) from the large end
\[ e = \frac{L - q}{L} \],
\[ q = L - ((\sqrt{(D/d)^4 + 1}) - \sqrt{2})/\sqrt{2} (D/d^2 - 1) \L), \]
\( D, d \) = diameter (cm) at the large end and small end respectively,
\( B, S, L \) are as defined in formula 7.

Newton’s formula:

\[ V = \frac{(B + 4M + S)}{6}L \]  \hspace{1cm} (11)

where \( V, B, M, S \) and \( L \) are as defined above.
2.2.4 WEIGHT

Measurement of timber quantity by weight (weight scaling) has many attractive advantages when large quantities of material are involved for which it is fast, easy and objective. For smaller operations, or if weight scaling is not feasible, log dimensions must be measured and log volume tables applied to derive the volume.

Weight scaling is the most efficient method of assessing 'log volume' provided access to a weighbridge is practicable. Log volume is then derived from green (wet) weight using a conversion factor (CF) established by continuous sampling:

\[ V = W \times CF \]  

where \( V \) is volume (m\(^3\)) and \( W \) is green weight (tonnes). The conversion factor will vary not only with region, species, tree age/size and the amount of bark on the logs, but also with the season and the time elapsed between felling and weighing.

Timber weight is recorded to the number of significant figures required, usually two or three. On trucks, it is usually measured by subtracting the empty weight (tare) of the truck from the loaded or gross weight. Because the tare is a constant and includes the weight of fuel, oil, water, and ancillary equipment (chains, bolsters, etc.), these must be the same at each weighing. The problem of a variable tare can be avoided if a weighbridge is available at the mill site. Then, each truck is weighed loaded and immediately after unloading, a practice now commonly applied in modern mills. Alternatively, the timber can be weighed as it is loaded in the forest using an electronic device such as a 'Loadrite' mounted on a front-end loader. The 'Loadrite' is a small transducer which uses the hydraulic pressure in the loader arms to weigh a bundle of logs. It can assess loads in the bush and accumulate the results over a series of lifts. Its capacity is 40 tonnes/lift and data can be accumulated to 2000 tonnes. It avoids the need for tare weights.

2.2.5 ALLOWANCE FOR DEFECT

Traditionally, log defect refers to those imperfections which result in the complete loss of some of the volume of a log when it is sawn. It poses a problem when log quantity is estimated. Overcoming it requires that log grading rules be applied which specify the allowance (scale deduction) to be made for each type of defect, viz. rots, insect flight passages, ring shakes, checks, splits and crooks. Note that features such as size and frequency of sound knots, spiral grain, sap-stains, resin pockets, bark inclusions, etc. are not considered to be defects because they do not affect the quantity of the sawn produce - although they degrade its quality. Allowance for the impact of these 'degraders' on the value of the sawn timber is made in the mill during the routine grading of the sawn produce.

One of the most serious defects in sawlogs of Australian tree species is pipe which is the rotted, central longitudinal core found in many mature eucalypts and rain forest tree species. Allowance for pipe is usually computed assuming that the cross section of the pipe is a square of side equal to the pipe diameter. Commonly, allowance is made by measuring the diameter of the defect at each end of the log (to the nearest whole centimetre above) and averaging the two. Volume of defect is then this measurement squared times the log length.

Making deductions for log defect requires that one determine the type and extent of the defect and then compute the loss. Grosenbaugh (1952) provided a consistent set of rules for doing this, some of which have universal application.

(a) Defect affecting entire cross-section

\[ D_p = \frac{d}{l} \]
Defect affecting a wedge shaped cross-section

\[ D_p = \left( \frac{l_d}{l} \right) \left( \frac{a}{360} \right) \]

(c) Crook

\[ D_p = \left( \frac{l_c}{l} \right) \left( \frac{c}{d} \right) \]

where

- \( D_p \) = proportion of gross volume lost due to defect
- \( d \) = top diameter inside bark (cm)
- \( l \) = length of log (m)
- \( l_d \) = length of defect (m)
- \( a \) = central angle of the wedge shaped defect (degrees)
- \( l_c \) = length of crook (m)
- \( c \) = maximum deflection (cm).

2.3 CROWN CHARACTERISTICS

The primary functions of the tree crown are to display its actively photosynthesising leaves to radiant energy and to provide for leaf renewal. Because crown size has a marked effect on the overall growth of a tree, accurate measurement of its dimensions is important. The dimensions most commonly measured are width, depth, surface area, volume, and weight.

2.3.1 WIDTH

The width of a tree crown is measured either by projecting its edges vertically to ground or by scalar expansion of the width of its image measured on an aerial photograph.

When defining a tree crown and projecting its edges vertically to ground, ignore very small individual branches and minor crown irregularities. Use either a plumb bob, 'crown-meter' or 'crownometer' (see Weir 1959, Khan 1971, Tihonov 1971, Jackson and Petty 1973), or a similar instrument incorporating two right-angle prisms (penta prisms) which avoids inverting or reversing the image and eliminates any effect of slight movement on the angle of reflection. Once projection is complete, measure by linear tape the horizontal distance between two or more sets of diametrically opposite edges, and average. Record the results to the nearest decimetre (0.1 m).

The accuracy of estimates of crown width derived from aerial photographs depends on the photographic scale, film resolution, ability of the assessor, and the nature and density of the forest canopy. Often, crown widths estimated from aerial photographs are less than those measured on the ground because, with photo measurements, only those parts of a crown visible from above are measured, i.e. parts obscured by the branches of other trees are not seen. Because of the strong correlation existing between crown width and tree dbhob (\( d \)), tree volume tables based on crown width (rather than \( d \)) can be compiled for use with aerial photographs. The ratio of crown width to \( d \) is called the crown ratio. This ratio is of silvicultural interest and is used in photogrammetry to deduce \( d \) from measurements of crown width.

If the crown is regular in outline, calculate its sectional area from the average of the measured widths. If irregular, plumb the edges to ground, measure the horizontal distance along several axes, plot the data and determine the area by planimeter.

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22 This negative bias is considered to be unimportant because the photo measurement is probably a better measure of the functional growing space of the tree and is better correlated with tree and stand volume (Husch, Miller and Beers, 1982).

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2.3.2 DEPTH

Determine crown depth or length using one of the direct or indirect measuring height instruments discussed in Section 2.1.2. Crown depth is sometimes expressed as green crown percent (= 100 \(L/h\)) or crown length ratio (= \(L/h\)), where \(L\) is the length of the living crown (m) and \(h\) is total height of the tree (m). Measure \(L\) either to the lowest live branch-whorl (upper crown length) or to the lowest live branch excluding epicormics (lower crown length). The crown length ratio is not to be confused with crown ratio defined above.

2.3.3 SURFACE AREA

The most active photosynthetic region in a tree crown comprises the young leaves at or near the crown surface. Thus, the surface area of the crown should be a useful predictor of the growth of a tree particularly prior to over-maturity. Surface area is estimated from crown width and depth assuming an appropriate solid shape for the crown space. Usually, this space is modelled as a conoid (particularly apt for conifers and young hardwoods) but for some species and under certain circumstances, a paraboloidal or hemispheric model may be more appropriate. Thus, the formulae appropriate for deriving the surface area of tree crowns, ignoring the crown base, are:

- **Conoid**
  \[
  C_A = \frac{\pi D_b}{2} \sqrt{L^2 + \left(\frac{D_b}{2}\right)^2}
  \]

- **Paraboloid**
  \[
  C_A = \frac{\pi D_b}{12L^2} \left(\frac{D_b^2}{4} + 4L^2\right)^{1.5} \cdot \frac{D_b^3}{8}
  \]

- **Hemisphere**
  \[
  C_A = \frac{\pi D_b^2}{2}
  \]

where \(C_A\) is the crown surface area (m\(^2\)), \(D_b\) is the diameter at the base of the crown (m), and \(L\) is the crown depth (m).

2.3.4 VOLUME

The volume of a tree crown is also a useful predictor of tree growth and, like crown surface area, it is derived from crown diameter and length assuming a solid shape appropriate to the crown in question, *e.g.* conoidal, paraboloidal or hemispheric. The appropriate estimation formula for each of these shapes is:

- **Conoid**
  \[
  C_V = \frac{\pi D_b^2 L}{12}
  \]

- **Paraboloid**
  \[
  C_V = \frac{\pi D_b^2 L}{8}
  \]

- **Hemisphere**
  \[
  C_V = \frac{\pi D_b^3}{12}
  \]

where \(C_V\) is the crown volume (m\(^3\)), \(D_b\) is the diameter at the base of the crown (m), and \(L\) is the crown depth (m).

2.3.5 BIOMASS

The traditional approach to estimating crown biomass or weight has been to fell selected sample trees, sever the branches (or a sample of them), strip the leaves, weigh both components fresh, dry a sub-sample and reweigh, determine the individual tree component dry weights, and then derive prediction equations relating these weights to diameter breast...
height, $d$, and total height, $h$. Once developed, the equations are applied to the population at large to estimate the crown biomass of any tree. Procedures for doing this are well documented in the forestry literature but they are not necessarily unbiased (Cunia 1979, De Gier and Kaboré 1993, Gregoire et al. 1994).

A new, unbiased and more efficient technique for estimating biomass (also volume, mineral content, number of cones, and many other characteristics) of the above-ground components of sample trees was published by Valentine et al. (1984). It comprises two steps, randomised branch sampling (Jessen 1955, Valentine and Hilton 1977) and importance sampling (Gregoire et al. 1986), both of which invoke variable probability sampling. The technique is quick to apply particularly to trees and shrubs with multiple stems (mallee type habit) because measurement of weight is confined to a single disc cut from the tree. The procedure has been applied successfully to estimate woody fuel biomass in natural woodlands and shrublands (De Gier 1989, De Gier and Kaboré, 1993) and biomass in loblolly pine (Williams 1989; Valentine et al. 1994). Readers interested in the technique should refer to these papers and the excellent review paper of Gregoire et al. (1994).

### 2.4 STEM ANALYSIS

Stem analysis enables the history of growth of a tree stem which exhibits truly annual rings to be reconstructed either partially or completely. Whereas partial stem analysis is applied to one position on the stem and provides information on growth in diameter only at that position, complete stem analysis involves sampling at a number of positions and enables the complete history of growth of the stem in diameter, height, surface area, volume or value to be determined.

The procedure used in sampling a stem for stem analysis differs somewhat depending on whether the tree is standing or felled. Stem cores obtained using an increment borer (bark to pith core) or increment hammer (core of recent growth only) are the basis of analysis in standing trees. For felled trees, the analysis is based on excised stem cross-sections (discs or ‘biscuits’) 2-5 cm thick. For small projects, the data are mostly collected and processed manually as described in Jerram (1939). For large projects, collection and processing of the data are mostly done using sophisticated measuring equipment, data recorders and computers.

**Field Procedure for Complete Stem Analysis**

The steps in procedure in sequential order are as follows.

1. Select the tree for analysis in an unbiased manner. If possible the tree should be sound, straight and round (unless this makes it unrepresentative of its class). Record the date, species, location, and history of the tree if known - otherwise, record notes on the general conditions of growth in the area and whether the tree is predominant, dominant, intermediate or suppressed. Take notes on any observable damage to the tree, malformations, etc.

2. Locate the breast-high point (1.3 m) on the tree while it is still standing and mark it using lumber crayon, extending the mark around the full circumference of the bole.

3. Fell the tree as near to ground level as possible. Immediately after felling, reconstruct the tip (excurent trees) or establish the position on the ground of the upper extremity of the crown in a line of continuation with the main stem axis (deliquescent trees).

4. On multinodal tree species, locate all the spring whorls\(^\text{23}\) and mark them with lumber crayon at the stem junctions. Record the heights above ground of each of these whorls by measuring the distance from the breast-high mark and adding 1.3 m. These heights

\(^{23}\)For lower intensities of sampling, mark every second or third whorl.
are accepted as being the heights of the sample discs marked in (5) and cut in (8). In effect, the discs are assumed to be representative of the stem at the spring whorls.

5. Also mark the stem with crayon at the point of minimum diameter below each spring whorl. Usually with plantation conifers, this point occurs from 10-20 cm below the whorl. If the lower bole is branch free, make marks at regular intervals at representative points (e.g. every 2 m) depending on the intensity of sampling desired.

6. Lop the branches to the tip (excurrent trees) or to crown break (deliquescent trees) to facilitate access to the bole.

7. Measure and record the following.
   i. Total height of tree (measure by tape the length to the tip from the breast-high mark and add on the breast height of 1.3 m).
   ii. In deliquescent trees, the height to crown break (as well as to the whorls - see (4)). As before, measure from the breast-high mark and add 1.3 m.
   iii. Diameter over and under bark at all the points marked in (5). Before removing the bark for the under-bark measurements, define the points of measurement by using a hand saw to make thin cuts in the wood surface immediately below the points of over-bark measurement.

8. Cut a disc 5-10 cm thick from either the top of the stump or from the extremity of the butt of the felled bole and decide which of the two surfaces of the disc is to be used in the analysis. Record the height of this surface above ground (by measuring from ground level if cut from the stump or back from the breast-high mark if cut from the felled bole). On the opposite face of the disc, write identifying information, e.g. 15/1 might signify disc #1, tree #15. If the age of the tree is not known, estimate how long the tree would have taken as a seedling to grow to stump (disc) height and record the estimate.

9. Cut discs 5-10 cm thick at breast height and at all points of diameter measurement marked on the bole. As in (8), define which of the two surfaces of each disc is to be used in the analysis. Record the height of this surface above ground (measure from the breast-high mark and add on 1.3 m) and identify the disc appropriately on the opposite face.

10. Transfer the discs to the laboratory for analysis. If it is expected that there may be some delay before the analysis can proceed, it may be desirable to protect the discs against splitting from drying out by soaking them in a vat of polyethylene glycol (e.g. see Grimmett (1981)).

**Preparation of the Discs for Stem Analysis**

Procedure is as follows.

1. On each disc, plane the surface on which the rings are to be counted.

2. Taking each disk in turn, draw axes across its face for measuring diameters. The way to do this depends on the shape of the stem cross-section and the position of the pith.
   i. **Shape of cross-section approximately circular and pith approximately central.** Draw two axes passing through the pith and at right angles to each other.
   ii. **Shape of cross-section approximately circular but pith clearly offset from centre.** Confine measurements to the single diameter passing through the pith.
   iii. **Shape of cross-section approximately elliptical and pith approximately central.** Measure on the long and short axes.
   iv. **Shape of cross-section approximately elliptical but pith clearly offset from centre.** Measure the length of the long and short axes of the section and average.
Then, by trial and error, locate and draw the two axes of average length passing through the pith.

v. **Shape of cross-section irregular and pith approximately central** (not uncommon with stumps of large trees). Measure the average length of four axes passing through the pith (axes oriented 45° to each other). Then, by trial and error, locate and draw two axes of this average length passing through the pith.

vi. **Shape of cross-section irregular and pith clearly offset from centre** (not uncommon with stumps of large trees). Measure the average length of a minimum of four axes passing through the *approximate geometric centre* of the cross-section (the relative orientation of the axes is: four axes - 45°; six axes - 30°). Then, by trial and error, locate and draw through the pith at least one axis (but preferably two axes) of this average length.

Procedures for counting the annual rings and compiling growth information on the tree are detailed in standard texts, *e.g.* Graves (1906), Jerram (1939), Husch, Miller and Beers (1982), *etc.*
CHAPTER 3

MEASUREMENT OF GROUPS OF TREES (STANDS)

3.1 NUMBER OF TREES

Estimates of the number of trees in a forest stand or per unit area are needed for various purposes, e.g. to assess the success of a regeneration or revegetation programme, to determine the volume of timber in an area using a volume tariff, etc. Most often, the estimates are derived using equal probability sampling methods based on fixed-area plots, quadrats or points. Fixed-area plots are probably the safest to use as problems can arise with the latter two methods when the pattern of occurrence of the trees is clustered or there are gaps in the regeneration mosaic (Greig-Smith, 1964) 24. An approach to overcome some of these problems was published by Ward (1991). It involves triangular tessellation, uses randomly or systematically located points, and is easy to implement in the field, viz. the sides of a triangle formed by three trees around a sample point are measured for horizontal length and fed into a hand-held computer containing a simple program (listed on p. 289-290 of Ward’s paper) which outputs an estimate of stems per hectare. Sampling stops when the cumulative estimate stabilises.

If for some reason an angle-count sample (point sample) forms the basis of the estimate of stocking density (trees per hectare) at a sample point in the forest (e.g. the assessment is just one part of a much broader, multi-stage inventory), the estimation formula is:

\[
\text{Stocking (trees/ha)} = BAF \sum_{i=1}^{n} \frac{1}{g_i}
\]

where \( BAF \) is the basal area factor (m\(^2\)/ha) of the angle-count instrument used,
\( n \) is the number of trees counted 'in' in the sweep, and,
\( g_i \) is the basal area of the \( i \)-th tree counted.

3.2 DIAMETER

The mean diameter of a group or stand of trees can be expressed by either the arithmetic or quadratic mean. The latter is the more useful and more widely applied measure because it is directly related to volume. It is the diameter of the tree of mean basal area, i.e. the quadratic mean diameter (\( d_g \)) of all the trees in the stand, \( d_g \), is preferable to the arithmetic mean, \( \bar{d} \), as a size parameter of trees in a stand because of the additional weight it gives to the larger diameters. The mean diameter calculations usually exclude any dead trees, but if these are included it should be stated clearly. In larger stands, derivation of the mean diameter may be based on a representative sample of trees drawn from the population.

3.3 BASAL AREA

The basal area of a stand, international symbol \( G \) (m\(^2\) or m\(^2\)/ha), is the sum of the basal areas, usually over bark, of all the trees. Mostly \( G \) relates to all the living trees or to those of interest to the observer, e.g. the living trees larger than a specified minimum diameter. \( G \) values in both coniferous and hardwood forests commonly range from 10 to 60 m\(^2\)/ha. In rare cases, \( G \)s as large as 150 m\(^2\)/ha may be reached on exceptionally good sites.

In small stands, \( G \) is derived by reference to tables or by summation by calculator:

\[
G \text{ (m}^2\text{)} = 0.000 \, 078 \, 539 \, 8 \, \sum d_i^2
\]  

(14)

24 Bounded (fixed-area) plots are well known to be more efficient for estimating stocking density (trees ha\(^{-1}\)) (see Palley and O’Reagan 1961, Kulow 1966, Whyte and Tennant 1975).

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where \( d_i \) is the dbhob in cm of the \( i \)-th tree and the constant 0.000 078 539 8 is approximately \( \pi / 40 \times 10^4 \).

\( G \) is an important reference variable for a forest stand and is particularly useful in quantitative description. Also useful is the stand mean basal area, \( \overline{g} \). \( \overline{g} = G/N \), where \( N \) is the number of trees in the stand. The diameter equivalent to \( \overline{g} \) is called the quadratic mean dbh, the international symbol for which is \( d_{\overline{g}} \). \( \overline{g} \) should not be confused with \( \overline{G} \), the mean stand basal area of a forest comprising many stands. \( \overline{G} \) is estimated by sampling the forest using either fixed-area plots (= bounded plots) or angle count sampling (ACS - also known as variable radius plot-sampling or point-sampling).

### 3.3.1 DERIVING \( \overline{G} \) USING FIXED-AREA PLOTS

Measure \( d \) of each tree in each sampling unit (circular, rectangular or square plots) and derive \( \overline{G} \) from the formula:

\[
\overline{G} = \frac{\sum_{i=1}^{n} \left( \sum_{j=1}^{m} g_{ij} / a_i \right)}{n}
\]

where

- \( n \) = number of plots
- \( m \) = number of trees in the \( j \)-th plot,
- \( g_{ij} \) = basal area (m\(^2\)) of the \( j \)-th tree in plot \( i \) (=\( \pi d^2 / 40 \times 10^4 \))
- and \( a_i \) = area (ha) of the \( i \)-th plot.

Sampling for \( \overline{G} \) using fixed-area plots is not as precise or efficient as sampling using ACS (see Palley and O'Reagan, 1961; Kulow, 1966; Whyte and Tennent, 1975) because when a population mean depends more on the size of large compared with small units, it is more efficient to select the larger units with greater probability. This is done using a technique called PPS Sampling, i.e. sampling with a Probability Proportional to Size. ACS is one form of PPS sampling.

### 3.3.2 DERIVING \( \overline{G} \) - USING ANGLE COUNT SAMPLING

The principle of PPS sampling has been applied to various forest sampling problems but most notably to estimating \( \overline{G} \) by angle counting where inclusion of a tree in the count depends on the basal area of the tree and its proximity to the sample point. The procedure is simple, quick and cheap to apply, but applying it properly requires considerable skill and a thorough understanding of the many sources of error likely to affect the estimate.

Collectively, the instruments used in ACS are termed angle gauges, the best known and most widely applied of which are the Spiegel Relaskop and wedge prism. Because of its exceptional versatility and other features, the Relaskop is particularly appropriate for forest inventory, whereas the low cost of the wedge prism makes it ideal for controlling silvicultural operations, e.g. monitoring the basal area that is both removed in thinning and left after it.

Apart from cost, the wedge prism has two advantages over the Relaskop. Firstly, only two lines need to be aligned to decide whether a tree is ‘in’ or ‘out’ and, secondly, slight movement of the tree or instrument does not interfere with the alignment - the tree and its image remain in the same relative position. Thus, the wedge prism is sometimes claimed to be faster and more accurate than the Spiegel Relaskop. In dense stands however, a problem may be experienced with the prism in matching the images to the trees from which they derive! This
problem is easily overcome by rotating the prism through 90°; in the vertical plane which
causes each image to 'return' to 'its' tree.25

Controlling the many sources of error likely to affect estimates derived from ACS requires
careful attention to the procedures described in Section 3.3.2.1.

3.3.2.1. Controlling Error in Angle Count Sampling

The procedures for controlling error in angle count sampling are grouped below into three
categories related to (a) general matters, (b) the wedge prism, and (c) the Spiegel Relaskop.26

(a) General

- Train the user to recognise when a tree is 'borderline' (applies to any angle gauge). This is
  best done by measuring the diameters of a number of trees, calculating the limiting
distance for each using the appropriate formula (wedge prism - Formulas 19 or 20;
standard metric Relaskop - Formula 22), and then viewing each tree from the appropriate
limiting distance.

- Use a team of two persons comprising an assessor and an assistant. Have the assistant
carry a 'T'27 piece around the periphery of the area being swept to define the DBH point on
any doubtful tree, to help check any tree still doubtful after using the T-piece (see later),
and to ensure that trees are not missed in the sweep. The assistant should also tally the
count: this may include recording the species, crown classification, and bole quality, etc.
of each counted tree.

- Select a distinctive tree or other fixed object, e.g. boulder, to define the start and finish of
each sweep.

- If a tree is obviously unrepresentative at breast height, select a representative point and
  sight to it. Record this diameter as the dbh and record the height above ground at which it
  was taken.

- On all trees whether vertical or leaning, sight to breast height in a plane at right angles to
  the long (central) axis of the bole. Judge the breast-high level by eye unless the tree is
doubtful (see next below).

- Check all doubtful trees by direct measurement and derive the limiting distance
determining whether a tree is 'in' or 'out' (the formulas are presented later). Remember that
ACS is frequently used in resource inventory where the intensity of sampling is often
much less than 0.1%, i.e. one tree in a sweep actually represents at least 1000 trees in the
population. If that one tree is a 'doubtful' tree and if it is worth, say, $30 on the stump,
than $30 000 hinges on the decision whether the tree is 'in' or 'out'. Obviously, such a
decision should be made with care!

- On average, the number of 'doubtful' trees in a sweep should not exceed 10% of the total
  count. A higher percentage than this suggests that the operator either has eyesight or other
health problems, is inexperienced, or is unwilling to make a decision. Further training or a
medical check may be required. Assessors inexperienced in using a Relaskop might try

---

25 Skilled operators find no difference between the Relaskop and wedge prism in speed of use or accuracy because they check all doubtful
cases by direct measurement anyhow, and the self-correcting-for-slope facility of the Relaskop compensates for the effects of slight hand or
tree movement.

26 Adhering to these procedures is vital for sound forest resource inventory. It is much less important if the angle gauge is being used as a
means of controlling thinning removals.

27 Make the 'T' piece out of lightweight material and paint the cross-arm white or bright orange. The cross-arm should be approximately
10 cm wide, as long as the diameter of the largest tree expected in the forest, and placed perpendicular to the vertical stud with its centre
exactly 1.3m above the base of the stud.

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mounting the instrument on a tripod or other support for a day or two. Prolonged use of a tripod is undesirable as it is time consuming.

- To avoid missing trees when sweeping in dense stands of plantation grown trees, proceed with the sweep row by row.

- Trees wrongly counted in a sweep lead to an error in estimating $G$ equal to the basal area factor (BAF) in m2/ha. Thus, one must compromise when selecting the BAF to use. Using a small factor gauge in a dense stand results in a large count and a greater likelihood of making a wrong count (missing a tree, etc.) but a relatively small error if a miscount is made. Conversely, a large factor gauge results in a small count and less likelihood of making a wrong count but a large error if a miscount is made. A satisfactory compromise is a count of 7-12 trees per sample point. Considering that in Australian forests, the basal area per hectare of fully stocked stands frequently lies between 20-50 m2/ha, BAFs of 2 to 5 should be appropriate in most situations. However, in heavily thinned stands and young poorly stocked forests, basal areas of 10-20 m2/ha are common. Thus, BAFs of 1 to 2 would be more appropriate.

- If a full 360° sweep is not possible at a sample point near the forest boundary, determine $G$ at the point by applying the practical and unbiased methods of either Grosenbaugh (1958) or Schmid-Haas (1982)28. Grosenbaugh's method involves using a 180° sweep if near a side boundary and a 90° sweep if in a corner, and then weighting the estimate accordingly (x2 or x4).

- Be wary of the bias which can arise with eccentric and leaning stems. The former is the more serious but nothing can be done about it. One hopes that in a full sweep the errors will compensate. With a leaning stem, align the 'measuring' edge of the gauge at right angles to the longitudinal axis of the stem. Be particularly careful with trees which lean towards or away from the observer, especially if they are near 'borderline'. In this case, measure the slope distance from the sample point to the centre of the tree at ground level.

- When one tree is obscured by another, move sideways on the radius keeping the horizontal distance from the subject tree constant until the tree is clearly in view. Then make the reading and return to the sample point.

- Be alert for dead trees which normally are excluded from assessment.

- In mixed species forests, record the species of each tree counted to enable separate estimates of $G$ to be made for each species as well as overall.

- If an estimate of the average basal area ($\bar{G}$) of a forest stand (or compartment, etc.) is required, locate within the stand a number of sample points chosen either at random or systematically (e.g. superimpose a grid of an appropriate scale on a map of the area and sample at the grid intersections). If the structure of the forest is heterogeneous, stratify the forest prior to assessment and select an angle gauge of appropriate strength for each stratum (see next below). Use the same strength gauge throughout a stratum: doing otherwise causes problems later when analysing the data.

- To select an appropriate gauge for a forest tract, undertake a quick reconnaissance survey of $G$ within the tract using 5-7 subjectively chosen but well dispersed sampling points. Select any gauge, preferably one with a BAF between 2 and 4 m2/ha, and undertake a sweep at each point. From the 5-7 estimates of $G$ derive $G$ and then apply the formula:

\[
F = \frac{G}{10}
\]  

(16)

28 The less practical but unbiased tree-concentric method is recommended for intensive inventories repeated over time (see Schreuder, Gregoire and Wood 1993, p. 271 and p. 300)
where $F \, (m^2/ha)$ is the BAF required. Select for the main survey an angle gauge whose BAF most closely approximates $F^{29}$. Adopting this procedure should give an average count of approximately 10 trees per sample point.

- Beware of operator bias when locating sample points in the field. Pacing the distance between successive points may be permissible provided one does not veer away from the specified bearing or alter one’s pace to prevent the sample point falling, say, on a rocky knoll, in a creek bed, or within a large clump of nettle. To avoid such bias, pace out the major part of the distance but measure the last 30 metres or so by tape, keeping to the desired bearing throughout.

- Statistically speaking, each point within a forest qualifies as an independent sample point for ACS, i.e. two points only a metre apart could provide two independent estimates of basal area for a given stand even though the trees included in both samples may be identical or differ by only one or two trees. In practice, however, it is prudent to prevent such overlap. This is done by specifying in advance of the survey that the distance between plot centres must be more than double the limiting distance of the largest trees likely to be encountered in the stand (refer Formulas 19, 20 or 22).

- If information on the variability of $G$ within a tract of forest is unknown, a rough guide to the number of sample points required in ACS to give a precise estimate of $G$ in reasonably uniform forest (most plantation stands) is:

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>No. of sample points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-2.0</td>
<td>8</td>
</tr>
<tr>
<td>2.0-10.0</td>
<td>12</td>
</tr>
<tr>
<td>over 10.0</td>
<td>16</td>
</tr>
</tbody>
</table>

- For more variable stands or if a highly precise estimate of $G$ is required, the number of sample points should be increased.

- For most efficient sampling, a quick reconnaissance survey of the forest is necessary as described above to give a rough estimate of the coefficient of variation ($CV$) of $G$. The actual number of sample points required can then be derived from the formula:

$$N = \left( \frac{CV \times t}{E} \right)^2 \quad (17)$$

where $N$ = estimated number of samples

$CV$ = coefficient of variation ($\%$) of $G$ derived from the reconnaissance survey

$t$ = Student's-$t$ value appropriate for the number of df's attached to the pilot sample and the desired confidence level

$E$ = the specified error limits (desired standard error of the estimate) ($\%$).

- Thus, a quick pilot survey based on 7 sample points well distributed over an area to be assessed may indicate a $G$ of 32.4 m$^2$/ha with a standard deviation of 5.21 m$^2$/ha. Thus, $CV = 100 \times (5.21/32.4) = 16.1\%$. Assuming that the error limit ($E$) is specified as $\pm10\%$ at the 95% level of confidence, the number of sample points ($N$) required in the main survey is:

$$N = \left( \frac{16.1 \times 2.447}{E} \right)^2 = 16 \quad (t \text{ for } 6 \text{ df's } = 2.447)$$

---

29 With the Relaskop, this may be one of the single bands or one of the combination of bands.

30 This applies equally well when locating sample plots of fixed area.
**Wedge prism**

- To avoid error when sighting through the prism, hold it vertical at any convenient distance from the eye and perpendicular to the line of sight to the tree, and view the tree through its centre. Fixing the prism in a sighting tube of approximate diameter 45 mm and length 300 mm eliminates these likely sources of error. It also protects the prism from scratching, minimises smudging of the lens surface, confines the field-of-view to the tree under observation, and makes the prism easier to handle (and find).

- When making a judgement using a prism, keep it (not the observer's eye) vertically above the sample point or angle count spot as it is often called (note that the reference angle is generated at the surface of the prism whereas, with the Relaskop, it is generated at the eye)\(^{31}\).

- Check any 'doubtful' tree by measuring \(d\), the diameter of the tree over bark at breast height, and \(D\), the measured slope distance from the sample point to the centre of the tree, and calculating for the BAF of the prism the maximum or limiting distance (\(LD\)) from the sample point within which a tree of that \(d\) is counted. Then compare this calculated limiting distance with the measured distance (\(D\)).

\[
BAF = 2500 \left( \frac{d}{LD} \right)^2 \quad (d \text{ and } LD \text{ in metres})
\]

thus \(LD = \frac{50d}{\sqrt{BAF}}\) \(\text{(18)}\)

If \(d\) is measured in cm and \(LD\) in metres, Formula 19 becomes:

\[
LD = \frac{d}{2\sqrt{BAF}}
\]

One compares the calculated limiting distance (\(LD\)) with the measured slope distance (\(D\)) from the centre of the tree to the sample point:

- If \(D > LD\), the tree is 'out',
- If \(D = LD\), the tree is a true borderline tree (which is rare!),
- If \(D < LD\), the tree is 'in'.

Prepared 'borderline tables' or a scientific calculator are essential for conducting this check efficiently.

On completing a sweep on sloping ground, correct the basal area estimate to horizontal by multiplying it by the secant of the maximum angle of slope (\(\theta\)) recorded through the sample point spot, \(viz.\):

\[
G = N \times BAF \times \text{Sec}(\theta)
\]

Correction for slope can be done in other ways (Barrett and Nevers, 1967) but all have the same result. The method outlined above is the one that is generally recommended. Note that correction can be ignored for slopes of 5° or less as the error is less than 0.5% (Table 3.1).

---

\(^{31}\) Adhering to this requirement is not essential in situations where the tree is well ‘in’ or well ‘out’. It becomes essential when the decision is ‘doubtful’, i.e. when the tree is ‘near borderline’.

\(^{32}\) Recording the maximum angle of slope is best done using an assistant who stands on the fringe of the area being swept on the side of the sampling point opposite to that of the observer. Then, from a series of positions around the perimeter of the area swept, the observer sights to the assistant through the sampling point and records the maximum reading.
Table 3.1

Errors resulting in ACS from failure to correct for slope

<table>
<thead>
<tr>
<th>Slope Angle (°)</th>
<th>Secant</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.000</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>1.000</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>1.001</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>1.002</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>1.004</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>1.005</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>1.008</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>1.010</td>
<td>1.0</td>
</tr>
<tr>
<td>9</td>
<td>1.102</td>
<td>1.2</td>
</tr>
<tr>
<td>10</td>
<td>1.015</td>
<td>1.5</td>
</tr>
<tr>
<td>15</td>
<td>1.035</td>
<td>3.5</td>
</tr>
<tr>
<td>20</td>
<td>1.064</td>
<td>6.4</td>
</tr>
<tr>
<td>25</td>
<td>1.103</td>
<td>10.3</td>
</tr>
<tr>
<td>30</td>
<td>1.155</td>
<td>15.5</td>
</tr>
</tbody>
</table>

(c) **Spiegel Relaskop**

The following comments relate specifically to the standard metric Relaskop.

- When making a judgement using a Relaskop (also thumb, stick, etc.) for which the reference angle is generated at the observer's eye, keep the eye vertically above the sample point spot.

- When checking borderline trees by Relaskop (which self-corrects for slope), measure the slope angle (°) from the observer's eye to the centre of the tree at breast height, the breast high diameter d (cm) and the slope distance D (m). Then apply Formula 22 to determine the limiting distance (LD (m)):

  \[ LD = d \times k \times \sec(\theta) \] (22)

Values of k for the various bands and band combinations of a Relaskop are listed in Table 3.2.

Table 3.2

* k values for Determining Limiting Distances when Angle Count Sampling Using a Standard Metric Spiegel Relaskop with Brake Feed *

<table>
<thead>
<tr>
<th>Band</th>
<th>BAF</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 narrow band (NB)</td>
<td>0.0625</td>
<td>2</td>
</tr>
<tr>
<td>2 NB</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>3 NB</td>
<td>0.5625</td>
<td>0.66</td>
</tr>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1 + 1 NB</td>
<td>1.5625</td>
<td>0.4</td>
</tr>
<tr>
<td>1 + 2 NB</td>
<td>2.25</td>
<td>0.33</td>
</tr>
<tr>
<td>1 + 3 NB</td>
<td>3.0625</td>
<td>0.2857</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>0.3536</td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
<td>0.25</td>
</tr>
</tbody>
</table>

(Ex G.B. Wood 1982)

33 Adhering to this requirement is not essential in situations where the tree is well ‘in’ or ‘out’. It becomes essential when the decision is ‘doubtful’, i.e. when the tree is ‘near borderline’.

As at 2007, reformatted 2012 but no textural changes
3.3.2.2. Calibrating an Angle Gauge

Generally speaking, it is unnecessary to calibrate or check the calibration of either manufactured wedge prisms, which today are made from lenses of 'eyeglass' quality, or of the bands and band combinations of a Relaskop. However, if the prisms are cut locally, e.g. in a scientific workshop on a university campus, the user will need to calibrate each instrument. Calibration is best done in the laboratory. Recommended procedure is as follows.

- Preferably sight to a flat target stood vertically (e.g. two clear, parallel lines a known distance apart drawn on a flat board) or, less preferably, to a target of circular cross section (e.g. drum or section of pipe of known diameter stood on end, etc.), and move backwards or forwards until the target is perfectly covered by the gauge (Relaskop, thumb, stick) or the image is perfectly displaced (wedge prism).
- Measure the width of the target \(d\) and the slope distance \(D\) from the eye to the target (for Relaskop with brake button depressed, thumb, or stick) or from the instrument to the target (for wedge prism).
- With the Relaskop, also measure the slope angle from the instrument to the target and correct the measured slope distance to its horizontal equivalent.
- Apply the appropriate calibration formula, namely:

**Flat Target**

(a) Relaskop, plastic or wooden gauges

\[
\text{Basal Area Factor (BAF)} = \frac{10000}{1 + 4 \left( \frac{D}{d} \right)}
\]  

(23)

where \(d\) (width of the target) and \(D\) (slope distance) are both in metres.

(b) Wedge prism

\[
\text{Basal Area Factor (BAF)} = 10000 \left( \sqrt{1 + \left( \frac{d}{D} \right)^2} - 1 \right)
\]  

(24)

where \(d\) (width of the target) and \(D\) (slope distance) are both in metres.

**Circular Target**

For all angle count instruments:

\[
\text{Basal Area Factor (BAF)} = 2500 \left( \frac{d}{D} \right)^2
\]  

(25)

where \(d\) (width of the target) and \(D\) (slope distance) are both in metres.

---

A quick check of the calibration of an angle gauge can be made in the forest at any time using a measured diameter near breast height on any standing, smooth barked tree of regular cross section and known distance away (apply Formula 25).
3.3.3 ADVANTAGES AND DISADVANTAGES OF ANGLE COUNT SAMPLING

Advantages

• Relative ease and speed of estimating $G$. Theoretically, the estimates are exact.
• For periodic assessment, only the sample points (angle count spots) need be marked in the field. However, for ease of location, more identifiers may be required, e.g. blazed or banded trees.

Disadvantages

• The method estimates $G$ from a sample so the estimate is subject to sampling error. In a series of estimates, the precision of estimate of $G$ depends on:
  (a) the size of sampling unit, i.e. BAF of the angle gauge,
  (b) variation of $G$ in the area under study,
  (c) the experience of the operator.

• The stocking density ($N$ - number of trees per hectare (or per size class)) is not given directly. However, this information can be derived by having an assistant measure the diameter at breast height of each tree counted in the sweep. The stocking density is then given by:

$$N = F \sum_{i=1}^{n} \left( \frac{1}{g_i} \right)$$  \hspace{1cm} (26)

where $F$ = basal area factor ($\text{m}^2/\text{ha}$) of the angle count instrument used,
$n$ = number of trees counted 'in',
and $g_i$ = basal area ($\text{m}^2$) of the $i$-th tree counted.

An alternative is to lay out a temporary circular plot with its centre at the sample point and count the trees within the plot boundary\(^{35}\).

• It is sometimes difficult to obtain a clear unimpeded view of particular trees in unpruned stands or in stands with heavy undergrowth. Using an instrument of higher BAF\(^{36}\) and moving sideways from the sample point while keeping constant the radial distance to the tree under observation can overcome many of these sighting problems.

3.4 HEIGHT

The height of forest crops in Australia is described in terms of mean height or of predominant height, top height, or dominant height.

3.4.1 MEAN HEIGHT

Mean height is meaningless as a stand characteristic in uneven-aged stands but it is of considerable value in even-aged stands. It is defined as the arithmetic mean height of all the trees, $N$, in a stand (international symbol, $\bar{h}$).

$$\bar{h} = \frac{\sum_{i=1}^{n} (h_i)}{N}$$  \hspace{1cm} (27)

where $h_i$ = height of tree $i$.

---

\(^{35}\) Remember that in sampling for stocking density (number of trees per unit area) as opposed to basal area, probability is no longer proportional to size but to frequency of occurrence. In this case, bounded plots are more efficient and appropriate.

\(^{36}\) This is not appropriate if an estimate of the precision of basal area is required (the BAF must be kept constant within a stratum).
With the exception of experimental plots and small but valuable stands, this measure of stand height is rarely used in Australia owing to the cost of measuring all trees. More usually, an approximation is used, viz. \( \bar{h} \) is accepted as being the average height of a defined number, \( n \), of trees (e.g. 60/ha) having a dbhob most closely approximating the arithmetic mean basal area (= quadratic mean \( d \) (international symbol \( d_q \)) of the stand. Defined this way, stand mean height can be derived either directly by enumerating the stand for \( d \) and measuring, and averaging, the heights of the \( n \) trees most closely approximating \( d_q \), or indirectly by compiling a stand height curve (\( d \) vs. \( h \)) and reading off the curve the height equivalent to \( d_q \). Alternatively, \( \bar{h} \) can be estimated by sampling, e.g. by measuring the height of, say, 10 trees per hectare selected systematically from the whole of the main crop, and averaging the result. Whatever method is used, it should be applied consistently over time.

3.4.2 PREDOMINANT HEIGHT, TOP HEIGHT, DOMINANT HEIGHT

Because thinning can affect mean height (\( \bar{h} \)) foresters were prompted to seek a crop parameter which was relatively unaffected by thinning. The parameters they chose were predominant height, top height and dominant height. These are derived as the average total height of respectively, a specified number of the tallest (predominant height), or largest diameter (top height) trees in the stand\(^{37}\) (whether the tallest or thickest trees are used depends on whether or not the tallest trees are easily identified from the ground), or of all or some of the dominants with or without the codominants (dominant height). The international symbol is \( h_{dom} \).

In Australia, predominant height (incorrectly called top height in some areas) is defined as the arithmetic mean height of the tallest trees in the stand generally at the rate of 40-75 /ha (viz. NSW and ACT, 40 /ha; Qld., 50 /ha; South Australia, 75 /ha)\(^{38}\). Assuming that a rate of 50 trees /ha is specified, proceed with assessment of predominant height as follows (the procedure for top height assessment is similar):

(i) **Experimental plots of defined area (< 0.1 ha)**\(^{39}\)

- Determine the number of trees required for measurement in a given plot by multiplying its area in hectares by 50 and rounding off to the nearest whole number (\( n_1 \)).
- Divide the plot into two or four sections of equivalent area and shape with at least one internal boundary line aligned perpendicular to the fertility gradient if it is apparent, e.g.

\[^{37}\text{Predominant height and top height are \emph{not} synonymous terms as their use in some parts of Australia may tend to suggest.}\]
\[^{38}\text{It is most unfortunate that a fixed rate is not applied throughout Australia! In New Zealand, predominant height (called predominant mean height there) is defined as the average of the heights of the tallest tree, free from malformation, in each 0.01 ha plot within the stand. Top height (called mean top height) is defined as the height predicted from a stand height curve (Pettersen curve) equivalent to the dbh corresponding to the quadratic mean dbhob of the 100 largest diameter trees/ha in a stand (Goulding 1986). In the United Kingdom top height is based on the 100 trees/ha of largest \( d \) from which 10 are selected systematically and their heights determined. From these, a \( h/d \) regression is calculated (\( h=a+bd+cd^2 \)) and the height corresponding to the mean diameter of the 1000 largest trees is determined.}\]
\[^{39}\text{Modify the procedure accordingly for plots of larger area.}\]
Allocate selection of the \( n_1 \) trees as evenly as possible to the two or four defined sections, \textit{e.g.} if \( n_1 = 5 \) and there are four sections, allocate one selection to each of the four sections and the fifth to the section which has the tallest tree not yet selected (see next below).

Because tree height is difficult to judge by eye, measure the height of twice the number of trees required in each section, unless the tallest tree(s) in a section is (are) obvious, and identify the tallest tree(s) in each required to make up the \( n_1 \) trees.

Average the height of the \( n_1 \) trees so identified.

(ii) Inventory

- Decide the size and shape of the plots to be used in the assessment. Conventionally, given a selection rate of 50 trees /ha, circular plots of 0.02 or 0.04 ha would be used, requiring the choice of 1 or 2 trees per plot.

- Select and measure for height what is judged by eye to be the 2 or 4 tallest trees per plot and accept for the assessment of predominant height the 1 or 2 tallest of these.

- Record in detail the definition of height used and how this was implemented.

3.4.3 STAND HEIGHT CURVE

A stand height curve (SHC) is the curve of best fit to a series of points generated by plotting \( h \) against \( d \) (or \( g \)) for some or all trees in a stand. In even-aged stands, the trend of the curve is usually apparent but not well defined because, within any diameter class, the height of individual trees may vary considerably due to genetic differences and differences in point density (affects \( d \) but has little effect on \( h \)). The trend is better defined by plotting class means of \( d \) and \( h \) against each other. The relationship invariably is curvilinear and concave to the abscissa (Figure 3.1).

![Figure 3.1: Example of a Stand Height Curve](image)

The curve is steep for young crops on good sites and near flat and linear for old crops and crops on poor sites (height growth arrested but diameter growth still active). With time, the relationship moves upwards and to the right, the movement being governed by the relative growth rates of \( d \) and \( h \) over time.

The SHC partly describes stand structure and is important to the silviculturist. It is useful in one method of deriving stand mean height (see Section 3.4.1) and in extension work for estimating stand volume in conjunction with a reliable 2-way volume function.

3.4.3.1 Sampling for the Stand Height Curve

The size of sample (number of trees) required to establish a reliable SHC depends on the size and variability of the population. Normally, 50-100 trees suffice for a compartment of up to 20 ha of even-aged plantation forest, and 10-20 trees for sample plots of area 0.1 - 0.2 ha.

As at 2007, reformatted 2012 but no textural changes
The sampling designs used to provide data for establishing the stand height curve include simple random, stratified random, systematic with a random start, and subjective sampling.

1. **Simple random sampling**

This design is not often favoured owing to poor precision but satisfactory results have been reported in some applications, *e.g.* see Arabatzis and Burkhart 1992.

2. **Stratified random sampling**

Generally, this design is the most efficient. The $d$ classes derived from a stand enumeration (partial or complete) are used as the strata, and distribution of the sample is weighted proportional to relative class frequency, *e.g.* consider Table 3.3, for an example of stratification by stem diameter.

### Table 3.3

**Selecting a Sample of (say) 15 trees from a Sample Plot for Establishing a Stand Height Curve**

<table>
<thead>
<tr>
<th>Diameter Class</th>
<th>Number of Trees</th>
<th>Relative Weighting</th>
<th>Samples Required from Class</th>
<th>Actual Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-15</td>
<td>1</td>
<td>0.012 (=1/85)</td>
<td>0.18 (=15x0.012)</td>
<td>1</td>
</tr>
<tr>
<td>16-17</td>
<td>3</td>
<td>0.035</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>18-19</td>
<td>6</td>
<td>0.071</td>
<td>1.06</td>
<td>1</td>
</tr>
<tr>
<td>20-21</td>
<td>7</td>
<td>0.082</td>
<td>1.24</td>
<td>1</td>
</tr>
<tr>
<td>22-23</td>
<td>6</td>
<td>0.071</td>
<td>1.06</td>
<td>1</td>
</tr>
<tr>
<td>24-25</td>
<td>9</td>
<td>0.106</td>
<td>1.59</td>
<td>2</td>
</tr>
<tr>
<td>26-27</td>
<td>11</td>
<td>0.129 (=11/85)</td>
<td>1.94 (=15x0.129)</td>
<td>2</td>
</tr>
<tr>
<td>28-29</td>
<td>16</td>
<td>0.188</td>
<td>2.82</td>
<td>3</td>
</tr>
<tr>
<td>30-32</td>
<td>8</td>
<td>0.094</td>
<td>1.41</td>
<td>1</td>
</tr>
<tr>
<td>32-34</td>
<td>7</td>
<td>0.082</td>
<td>1.24</td>
<td>1</td>
</tr>
<tr>
<td>34-35</td>
<td>5</td>
<td>0.059</td>
<td>0.88</td>
<td>1</td>
</tr>
<tr>
<td>36-37</td>
<td>4</td>
<td>0.047</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>38-39</td>
<td>2</td>
<td>0.024</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>85</strong></td>
<td><strong>1.000</strong></td>
<td><strong>15.01</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

*a* The class interval used here is 2 cm, although the width of interval is not fixed, it is preferable to choose one which results in 10-20 classes.

*b* Note in this example that one tree is to be selected at random from both the two smallest classes combined (14-15 and 16-17 cm) and the two largest classes combined (36-37 and 38-39 cm).

3. **Systematic sampling with a random start**

This design is simple to apply and is appropriate particularly when time and money are limiting. Take, for example, the sample plot represented by Table 3.3. Here we have 85 trees from which 15 trees, *i.e.* 1 tree in every 5.7 trees, are to be selected for establishing the stand height curve. An appropriate procedure is as follows.

- Select a random number from the range 1 to 6 (6 is the absolute value of 5.7). Suppose that the number is 4.
- From the plot starting point, locate the 4th tree and measure it for height (and for diameter if not done already).
Also measure for height (and diameter if not done already) the 10\textsuperscript{th} (4+5.7), 15\textsuperscript{th} (4+5.7x2), 21\textsuperscript{st}, ..., 78\textsuperscript{th}, and 84\textsuperscript{th} (4+5.7x14) trees.

Establish the stand height curve by fitting a curve mathematically to the data (see Section 3.4.3.2 below) or by hand plotting ($h$ vs $d$).

4. Subjective sampling

Subjectively choosing the trees to be sampled may be justified if the forest plot is small and the assessor is experienced and knows the species well. It is sometimes useful in extension work, e.g. when a forest owner requires a quick, low cost appraisal of a stand, but the danger of bias is always present.

3.4.3.2 Fitting the Stand Height Curve

Fitting stand height curves free-hand was common practice until the advent of hand-held field computers made it possible to fit reproducible curves quickly and accurately in the field. An excellent fit is often achieved with models of the form

\begin{align*}
(i) \quad \log(h) &= a + b \log(d) + \varepsilon \\
(ii) \quad \log(h) &= a + b (1/d) + \varepsilon \\
(iii) \quad h &= a + b \log(d) + \varepsilon \\
(iv) \quad Y &= a + b/d + \varepsilon \\
& \quad \text{where} \quad Y = (1/(h-K))^{0.4} \\
& \quad K = \text{height of } d \text{ above ground, i.e. 1.3 m,} \\
(v) \quad h &= a + b(1/d) + \varepsilon \\
(vi) \quad h &= a d^b + \varepsilon \\
(vii) \quad h &= a e^{bd} + \varepsilon \\
(viii) \quad h &= a + bd + cd^2 + \varepsilon
\end{align*}

where $a$, $b$, $c$ are regression constants, $e$ is the base of Naperian logs, and $\varepsilon$ is the error term.

It is important that one test to see which function is the most suitable for a particular application (see, e.g. Arabatzis and Burkhart 1992) because the relationship of $h$ and $d$ changes over time in a given stand and, at a given time, may vary between stands.

It is difficult to establish a satisfactory relationship between total height, $h$, and $d$ in uneven-aged (native) forests in Australia, but in some situations one between merchantable height, $h_m$, and $d$ may be possible and useful. If such a relationship can be established and be shown to be reliable and constant over time (mature stands), $h_m$ need be measured the first time only in periodic management inventory. This has the advantage of reducing errors in the estimate of volume increment because errors in the measurement of $h_m$ will be held constant and differences of opinion between assessors on the merchantable limits of trees will be eliminated.

3.5 VOLUME

Stand volume cannot practically be measured directly. Rather, it is estimated in a variety of ways, the method chosen depending on the purpose of measurement, the location, size and value of the stand, stand characteristics, and the time, funds and labour available. Invariably, the estimation procedure involves measurement of some or all of the characteristics of either individual sample trees (e.g. $d$, $h$, $v$, bark thickness, taper - Section 2.1) or stands (e.g. number of trees, $d_g$, $G$, $\bar{h}$, $h_{dom}$ - Sections 3.1-3.4). Thus, the precautions discussed earlier for
minimising error when measuring any of these characteristics need to be applied rigorously when estimating stand volume.

3.6 CROWN CLOSURE

Crown or canopy closure is a concept applied to even-aged stands or to the upper canopy level (dominant/codominant stratum) of uneven-aged stands. It is expressed as a proportion or percent of the ground area covered by the vertical projection of the tree crowns. Because it is an approximate indicator of stand density, crown closure is an important variable in the estimation of stand volume from aerial photographs and in evaluating silvicultural operations and ecological conditions. It also has a significant influence on snow pack accumulation and snow melt.

Instruments used to estimate crown closure include the 'crown-meter' or 'crownometer' (see Weir 1959, Khan 1971, Tihonov 1971, Jackson and Petty 1973), spherical densiometer (Lemmon 1957), and moose horn (Robinson 1947, Garrison 1949). Establishing a reliable estimate of the crown closure of a forest stand requires a valid sampling frame and due consideration of the variability of the crown cover.

3.7 CROWN BIOMASS

The weight of tree crowns is important in biomass studies and in assessing the weight of slash left after logging operations. Crown weight can be related to dbh, site and stand density but only limited information of this type is available for Australian forest stands. Hopefully, the recent development of more efficient methods of estimating the biomass of various tree components (branches, leaves, etc.) using a combination of randomised branch sampling and importance sampling will help redress this deficiency (see Section 2.3.5).

3.8 GROWTH AND INCREMENT

*Growth* is increase in size over time, and *increment* is the increase in size which occurs in a specified time interval due to growth. To ensure the reliability and utility of growth and increment data for forest stands, it is imperative that the measurement, estimation and sampling procedures used to derive the information be standardised both within and between organisations and over time.

The two conventional expressions of increment are *current annual increment* (CAI) and *mean annual increment* (MAI).

Current annual increment is the increment over a period of one year at any stage in the history of the tree or stand. The period to which the CAI refers and the age and/or size of trees at that time must be defined (*e.g.* CAI 1969/70, age 25-26 years). The CAI varies from year to year being affected by seasonal conditions and treatment. For this reason, it is common practice to express the increment as a mean over a period of years, termed the *periodic mean annual increment* (PMAI or PAI). It is important to maintain the distinction between CAI and PAI. The PAI is a more realistic indicator of the capacity of a tree or stand of a certain age or size to grow.

Mean Annual Increment is the mean annual increment over the whole period from origin to a specific age. The specific age must be given when quoting MAI figures. The interrelationships of the CAI and MAI curves of a tree (more particularly of a stand), their relative shape, and the position of their point of intersection, are of particular interest to management. Conventionally, CAI and PAI data are plotted against the middle of the period to which they refer whereas MAI data are plotted against the specific year.
REFERENCES


Appendix 1 Checklist: Equipment and Materials

A. Plot Location, Establishment, Area Determination and Maintenance

- Relevant map(s) and locational data (bearings, distances, etc.)
- Recording materials and clipboard
- Scientific calculator or field computer/portable data recorder
- Compass
- Clinometer
- Survey arrows
- Survey chain or hip-chain distance measurer
- Centre pegs 1.5 m x 50 mm x 50 mm ground durable
- Corner pegs 1.5 m x 75 mm x 50 mm ground durable
- Axe and slasher
- Chainsaw, fuel, oil and tools
- Staple gun and staples
- Rolls of plastic tape
- Haversacks and kitbags
- Paint and brushes or aerosol cans
- Plastic tags and marker pens
- First aid kit and other safety equipment (helmets, etc.)

B. Plot Measurement

- Maps, plot layout diagrams, plot sheets, folders
- Clipboard and writing materials
- Scientific calculator (programmable)
- Algorithms or tables for calculating height, borderline distances (point sampling), etc.
- Field computer (if available, some of the items listed above will not be needed)
- 30 m and 50 m linear fibreglass tapes
- Height poles or a hypsometer (Haga, Blume Leiss, Relaskop or Suunto)
- Plumb bobs or heavy sinkers (for checking and establishing tree lean)
- Compass
- Survey arrows
- Girth tapes (steel and fibreglass)
- Bark gauge
- Breast height stick (temporary plots, or if breast height mark not present)
- Dendrometer
- Relaskop or wedge prisms
- Lumber crayon
- Water canteens
- First aid kit and other safety equipment (helmets, etc.)