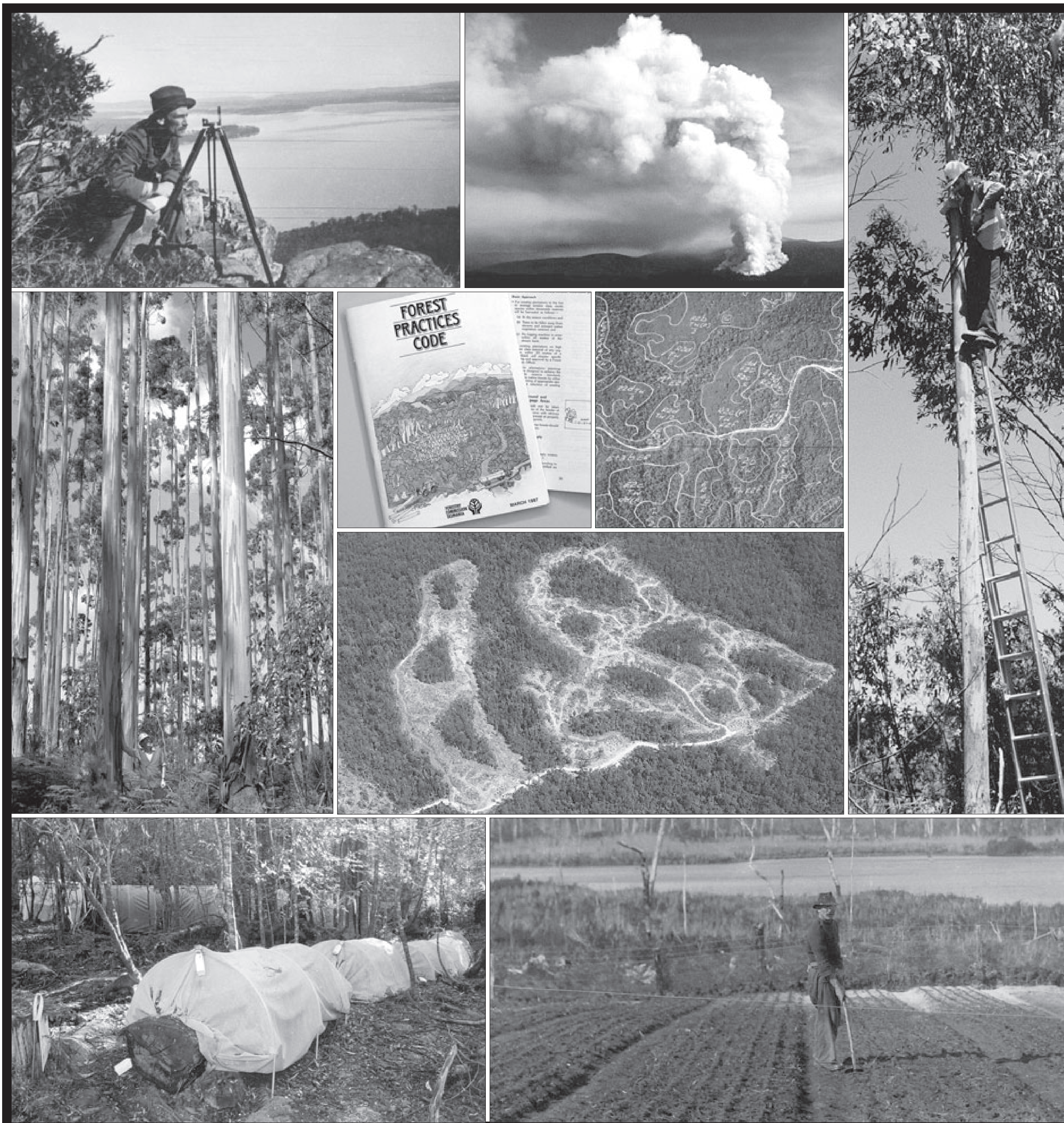

A History of Innovation

Eighty-five Years of Research and Development at Forestry Tasmania

Humphrey Elliott   Ken Felton   Jean Jarman   Martin Stone

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Forestry Tasmania

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Eighty-five Years of Research and Development at Forestry Tasmania

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ISBN 978-0-646-49207-0

Published by Forestry Tasmania 2008

Contents

Chapter 5 Plantation Forestry

Chapter 6 Maintaining Forest Health

Chapter 7 Forest Biology and Conservation

Acknowledgements

We are very grateful to the many people who kindly gave their time and knowledge to assist the preparation of this account.

The encouragement and assistance given by Evan Rolley to compile a history of research and development at Forestry Tasmania, and the support provided by Hans Drielsma throughout the work, are gratefully acknowledged. Andrew Wilson provided invaluable assistance in the library, sourcing references and other information.

Mick Brown, Steve Read and Andrew Wilson patiently read drafts of all chapters and their comments are much appreciated. Individual chapters were read by Dick Bashford, Peter Bennett, Tony Blanks, Dick Chuter, Leigh Edwards, Susan Elliott, John Hickey, Sue Jennings, Neil McCormick, Tony Mount, Bill Neilsen, Mark Neyland, John Quick, Peter Volker, Tim Wardlaw and Graham Wilkinson; their comments are similarly appreciated. Other helpful comments and/or information on various parts of the text during its preparation were provided by Bern Bradshaw, Steve Candy, Jane Elek, Adrian Goodwin, Steve Maxwell, Bob Mesibov, Peter Moore, Graham Sargison and Steve Whiteley.

We thank the many people who provided photographs or assisted with finding and/or interpreting them, including Paul Adams, Dick Bashford, Andrew Blakesley, Tony Blanks, Dick Chuter, Colin Crawford, Kim Creak, Leigh Edwards, Yvette Fuller, Tim Geard, Simon Grove, John Hickey, David Hinley, Peter Hopson, Sue Jennings, Emil Johnston, Bob Knox, David Mannes, Steve Maxwell, Mike McLarin, Neil McCormick, Dion McKenzie, Ben Merritt, Mark Neyland, Martin Piesse, Tony Rainbird, Karen Richards, Alen Slijepcevic, John Sulikowski, Andrew Walsh, Julie Walters, Tim Wardlaw, Dean Williams, Kristen Williams and Andrew Wilson. Assistance with maps was provided by Tony Rainbird, Peter Ladaniwskyj and Gerald Coombe. We also thank the Archives Office of Tasmania for allowing us to examine their collections and for providing digital images, the State Library of Tasmania for providing a digital image from an old newspaper, and the Tasmanian Herbarium for allowing us to photograph Type material, and use facilities and equipment there.

Figures and maps are acknowledged with their caption. Photo credits for each image are given at the end of the text (p. 361). The name of the photographer, if known, is included for unpublished photos and a reference is provided for photos sourced from publications.

Silvicultural research plots established in *Eucalyptus obliqua* forest by the Forestry Department at Lady Bay, near Southport, in 1936. These plots comprised thinned and control areas, and the trees were approximately 40 years old when this photo was taken in February 1950. Max Gilbert is in the foreground.

Introduction

This account covers the period 1921 to 2006. It has been written to record the development of scientific and technical information used in the management of State-owned forests by the Tasmanian Forestry Department and its successors, the Forestry Commission and Forestry Tasmania. The Forestry Department began operating on 1 January 1921 and that event marked the beginning of a systematic approach to conserving and developing the State's forest resources in accordance with the conditions of the *Forestry Act 1920*.

Section 7 of the Act sets down two objectives for Forestry Tasmania. The corporation is required:

> *As a manager of forest land with a commitment to multiple use ... to optimise:*
>
> - *The economic returns from its wood production activities; and*
> - *The benefits to the public and the State of the non-wood values of forests.*

Thus, the management of State forests must achieve a balance between wood production and other forest values. For more than three decades, there has been a vigorous debate in Tasmania over the allocation of forested land for particular purposes and the methods used to manage forests. The debate about land allocation is a political process and a matter of public policy, while the discussion of methods is part of the scientific process, taking place within the political debate and interacting with it. A clear distinction needs to be drawn between decisions on the values to be supplied by a forest, such as wilderness preservation or a mix of production and conservation, and the necessary scientific information on which to base the management decisions that will deliver these values. This account deals with the history of the research and development and operational experience that have provided the factual basis for management decisions on State forests.

It describes the development of methods for estimating forest resources (management research), the establishment, management and protection of forests (silvicultural research) and the conservation of natural values. It is arranged into chapters on the main areas of research such as eucalypt silviculture, fire management, and forest health; within each chapter, research is recorded in an approximate chronological sequence. A substantial reference list is provided for follow-up reading. We have concentrated on the main projects that delivered improved methods of forest management, using examples where there were large numbers of projects within particular subject areas, rather than exhaustively recording every experiment or trial.

The knowledge used on State forests is also useful for the management of the one-third of Tasmania's forests that are privately owned. Some of this knowledge was developed in private forests, for the tenure difference is much less important than the biological similarities.

The research and development work described here is an important part of the history of Forestry Tasmania. Useful references dealing with other aspects of this history and therefore providing further context for research and development activities include Steane (1935, 1947), Cunningham (1989), Cubit (1996) and Bennett *et al.* (2006). Since 1973–74, separate Annual Reports have been published by the research group at Forestry Tasmania and these, together with the organisation's Annual Reports, provide additional information. A list of important dates in the history of public forestry in Tasmania is provided on page 5.

In addition to documenting research work, this history is intended as a tribute to the operational, research and support staff who have worked over many decades to continuously improve our knowledge of Tasmanian forests. Their work has provided a firm basis for sustainable forest management on behalf of the Tasmanian community. Improved methods of forest management usually result from incremental advances and many of these occur as a result of operational experience which is often not formally documented. In particular, the work by staff in the Forest Districts has been the basis for improved management and/or more detailed investigations by research staff.

We have endeavoured to mention the main contributions that have come to our attention but are acutely aware that many improvements in operational practices are not recorded. This account relies heavily on published work by staff, especially books, papers in scientific journals, technical and research reports, and instruction/information leaflets. We have reported information from publications without comment on the experimental techniques or interpretations made by the authors. These publications usually do not focus on personnel but rather on the work being documented. If we have failed to give due acknowledgement to the efforts of anyone who has contributed to improving the management of Tasmania's forests through research, it has been unintentional, and we apologise in advance.

When reviewing the research work of Forestry Tasmania, we were cognisant of the large amount of collaboration that has occurred with researchers and forest managers outside the organisation, at local, national and international levels. We strongly acknowledge the significant contributions and co-operation of the forest industry, Co-operative Research Centres, universities, CSIRO, the Forest Practices Authority, the Tasmania Fire Service, and the Tasmanian Department of Primary Industries and Water (and their predecessors), other Government agencies, as well as forest management agencies in the other States. However, this book is about the work at Forestry Tasmania and therefore we have concentrated on that, mentioning the work of other institutions and their staff where appropriate.

A brief historical overview

The passing of the *State Forests Act 1885* marked the beginning of regular reporting of forest management activities in the State through the Lands and Surveys Department, which had responsibility for forestry until the Forestry Department began operating in 1921. Prior to that event, there had been many decades of experience gained by people who worked in the forests. Although little of their general knowledge and few of their observations were recorded, their experience would certainly have been transferred to those coming after them. Observation and experimentation have been blended over the years to produce improved methods of forest management. Much of this improvement, particularly in the early years of the Forestry Department, was achieved through keen observation of the ecology of forest species in Tasmania and the reaction of forests to natural phenomena and artificial manipulations. In more recent times, with employment of specialist research staff, detailed scientific investigations have enabled the organisation to manage a whole range of natural values more effectively for the many community stakeholders who rely on forests for their livelihood, enjoyment or both.

Following the formation of the Forestry Department, Llewellyn Irby, the Conservator of Forests at the time, began to gather knowledge on the different forest types, their distributions and commercial timber properties. In July 1921, District Foresters were appointed to each of the five Districts created by Irby: Southern, Central, North-East, North-West and Western. The Department's structure, shown in the Annual Report of 1922–23, included a 'sylvicultural' function comprising indigenous forests and afforestation. This work was the responsibility of the District Foresters. In addition, a Working Plans Officer was appointed that year to manage the 'working plans and topographical' function. These responsibilities remained the same for over twenty years.

Research activities in the 1920s were mainly directed at assessing and mapping the State's commercial timber resources. The early ground-based mapping was gradually replaced in the 1930s and 1940s by vastly more efficient aerial mapping. Later, estimating standing and future timber resources became much more sophisticated through the combination of improved photo-interpretation and the development of advanced modelling techniques to replace the early reliance on traditional volume and yield tables. The appointment of a librarian in 1944 improved the access to reference material for Forestry Department staff.

The Forestry Department was replaced by the Forestry Commission in 1947 and the research effort in all subject areas accelerated. In 1953, the Fire Protection Branch (formed in 1940) was broadened, becoming the Silviculture and Fire Protection Branch. The silviculture of wet eucalypt forests was a priority research area in the 1950s and 1960s. When broadscale pulpwood harvesting became possible with the advent of the woodchip export industry in the 1970s, silvicultural methods for a wide range of dry sclerophyll and high-altitude forest types were introduced. Fire protection was given enhanced recognition in 1974 when a separate Fire Management Branch was formed, silvicultural research activities being placed in the Silvicultural Research and Development Branch within the Division of Forest Management. This Branch became the Division of Silvicultural Research and Development in 1986, with three research units: Native Forests, Plantations, and Forest Biology (later Biology and Conservation). It was renamed Division of Forest Research and Development in 1996.

Management research has been undertaken since the Forestry Department began, but accelerated greatly in the 1960s and 1970s. From the 1970s, research into flora, fauna and other natural values expanded, particularly the science-based reservation of forest types. The first Forest Practices Code was introduced in 1987, and forest practices specialists were appointed in 1988–89, being placed within the Biology and Conservation Branch. Forestry Tasmania was created in 1994, becoming a corporation under the *Government Business Enterprises Act 1995.* Research and development activities continued to support the corporation's strengthened commercial focus.

In 2006, over 60 research projects were being managed by Forestry Tasmania staff, mostly in the fields of forest conservation, plantation establishment and management, native forest silviculture, management research, and protecting forests from fire, pests and diseases. There is strong co-operation with other forest growers and research providers such as the Co-operative Research Centres, the Forest Practices Authority, universities and CSIRO.

Documenting information

There has always been a strong belief in the value of reporting the work of the organisation; this has developed well beyond the mandatory requirements for a publicly funded body. It has continued right from the early years of the fledgeling Department, when Conservator Irby provided detailed information on Tasmania's forests and their management needs in the first Annual Report. In 1935, Conservator Sam Steane summarised valuable information in a booklet outlining the role of State forestry and the major management issues which needed addressing (Steane 1935). As the Department grew in size and additional staff were employed, papers reporting ecological observations and the results of trials began to appear in scientific journals (e.g. Gilbert 1958; Cremer and Mount 1965). With management activities becoming more complex, the demands for accurate, detailed information escalated across a wide range of forest-related subject areas. As the research broadened in scope, so the reporting became more sophisticated, the format tailored to the target audience: from simple educational leaflets to technical bulletins, instruction manuals, impact statements and scientific papers, the last directed at local, national and international audiences. A steady stream of books have been produced, providing in-depth treatments for poorly documented aspects of Tasmanian or Australian forests. Over the 85 years covered by the present historical account, there have been literally hundreds of technical and scientific publications produced by the organisation.

In 1989, the inaugral volume of the Commission's own scientific journal, *Tasforests*, appeared, aimed at making available the wealth of forest-related information 'mouldering away in filing cabinets'. This journal provides a means of communicating descriptive or technical information on a wide range of subjects relevent to those with an interest in Tasmanian forests. Subjects such as forest history, machinery developments, silvicultural research, nature conservation and forest ecology, generally with a Tasmanian bias, are typical of the content. All articles are refereed, mostly by external specialists, and maintaining high standards remains a priority, both in content and presentation. The journal is now heading towards its seventeenth volume.

The production of maps has been a core activity since the Department's inception, early hand-drawn sketch maps enabling a broad interpretation of timber resources in particular areas. The introduction of aerial photography and the production of forest type maps was a major step forward in improving the accuracy and extent of wood resource estimates. These days, computer technology and mapping skills have been combined to enable highly accurate and very sophisticated maps to be generated, providing an indispensible tool to aid the management of the forests.

Research facilities

Until the 1970s, most research work was field based, with some access to laboratory facilities being provided by forestry companies, CSIRO and the Department of Agriculture. Forestry Commission headquarters in Hobart were in the Public Service offices in Murray Street and the only facility for laboratory work was a small room in which a microscope and a weighing balance were located.

In 1975, recognising the need for better facilities for the expanding and more specialised research effort, the Forestry Commission explored opportunities for establishing the silvicultural research unit on the urban fringe of Hobart, together with a small amount of land suitable for a nursery and small research trials. Plans to move to places such as the Austins Ferry area or to what became a facility of the Tasmania Fire Service at Cambridge were overtaken by a decision to move the headquarters in Hobart from 10 Murray Street to Surrey House at 199 Macquarie Street. The move took place in May 1977, and laboratories were constructed in the basement for use by research staff. In August 1997, Forestry Tasmania moved to its current headquarters at 79 Melville Street, where new laboratories and other specialist research facilities were provided, and all the Hobart-based parts of the organisation were housed together for the first time. This move greatly improved the integration of research with forest management and operations functions.

Forest science needs these modern supporting facilities, but continuous improvement in forest management comes mainly from operational experience, observation and experimentation in the forests as described in the following chapters.

Box 1

Some significant dates in the history of public forestry administration in Tasmania.

1885	*State Forests Act 1885* passed. This Act included a provision for the appointment of a Conservator of Forests. Management of public forests was the responsibility of the Lands and Surveys Department.
1886	George Perrin appointed first Conservator of Forests. He resigned in 1888 to take up the position of Conservator of Forests in Victoria.
1889–1892	William Brown, Conservator of Forests.
1892–1919	Position of Conservator remained vacant.
1899–1921	John Compton Penny, Chief Forest Officer within the Lands and Surveys Department.
1919–1928	Lewellyn Irby, Conservator of Forests.
1920 (December)	*Forestry Act 1920* passed.
1921 (January 1)	Forestry Department began operating.
1928–1930	Thomas Stubbs, Acting Conservator of Forests.
1930–1947	Samuel Steane, Conservator of Forests.
1947 (April 15)	Forestry Commission, Tasmania, created.
1947–1971	Alec Crane, Chief Commissioner.
1971–1981	Paul Unwin, Chief Commissioner.
1978	Private Forestry Division formed.
1985	*Forest Practices Act 1985* passed.
1981–1986	John Quick, Chief Commissioner.
1987	Forest Practices Code introduced.
1987–1990	Andris (Andy) Skuja, Chief Commissioner.
1988	Helsham Inquiry report released.
1990–1994	Evan Rolley, Chief Commissioner.
1990	Forests and Forest Industry Strategy released.
1990–1996	Intensive Forest Management Program.
1994 (July 1)	Forestry Tasmania established.
1994–2006	Evan Rolley, Managing Director.
1994	Private Forests Tasmania and Forest Practices Board created.
1995	*Government Business Enterprises Act 1995* passed.
1997	Regional Forest Agreement (RFA) between Tasmanian and Commonwealth Governments.
1997–2005	RFA intensive forest management program.
2005	Tasmanian Community Forest Agreement.


Wielangta forest, south-eastern Tasmania.

Chapter 1

Wood Resources and Sustainable Yield

Introduction

The formation of the Forestry Department in 1921 was a turning point for forestry in Tasmania as it can be truly said to have marked the beginning of a continuing journey towards sustainable development of the State's public forests. Since European settlement (1803), economic development had been a high priority of successive Governments in efforts to reach self-sufficiency. As a result, by 1921, there had been over 100 years of alienation of public land, forest clearance and exploitation of the main commercial timber trees. This is not to say that forest clearance was completely unfettered. Indeed, in the first week of settlement at Sullivans Cove in February 1804, Lieutenant-Governor Collins issued a general order that prohibited the cutting of '… any timber, whether young or old, near the encampment' (HRA 1921, p. 220). However, the land grant system with 'requirements to clear and cultivate' (Felmingham 2005) was an effective device to encourage investment and facilitate development.

The general progress of land alienation is described by Scott (1965), who noted that in the 1850s the colony liberalised its land laws in an effort to attract immigrants following the loss of people to the Victorian goldfields. An important event around this period was the passage of the first *Waste Lands Act* in 1858. It did not mention forestry or timber growing but encouraged the settlement of the wet sclerophyll forests (Jetson 2005). Earlier settlement had been concentrated in the drier, open forests, where use of fire by Aborigines and browsing by marsupials had created ideal conditions for the introduction of domestic stock by pastoralists. The dense forests in higher rainfall areas occupied more fertile sites that were potentially more productive but needed hard work to clear, and so tended to be left untouched. In an early example of seeking a balance between production and preservation, the 1858 Act also provided for limited licensing of timber getting. However, powers to set aside Crown Land for timber production did not arrive until the *Waste Lands Act 1881*. Section 5 of this Act stated:

> *The Governor in Council may, by proclamation, except from sale and reserve to her Majesty such land as he sees fit for the preservation and growth of Timber, and may from time to time, after Sixty days' notice shall be given in the Gazette, alter and revoke any such Proclamation.* [Steane 1947, p. 3]

These powers lead to a century of efforts by foresters to protect forests from clearing, secure a dedicated forest estate, and replace exploitation by management.

A *State Forests Act* was passed in 1885, with a provision for appointing a Conservator of Forests, a prerequisite for the start of scientific management of the State's forests. George Perrin (after whom *Eucalyptus perriniana* is named) was appointed to this post in March 1886. Perrin proposed silvicultural measures and plans for managing the forests, including the first recommendations for Tasmanian forests of a system of sustainable harvesting practice, as described in Steane (1947, p. 3):

> *His recommendations regarding forest management are very interesting. They amount to the sub-division of each State Forest into Periodic Blocks and cutting out these blocks in rotation. Each block on being cut out, would then be closed against further exploitation for a long period – say, 40 years – during which period no cutting would be allowed except silvicultural thinnings.*

After Perrin's resignation in 1888, the position of Conservator was rarely filled until Llewellyn Irby was appointed in 1919 (Carron 1985). He fathered the *Forestry Act 1920*, which included a provision for the establishment of a Forestry Department that began operating in 1921. Irby had a clear vision about what was needed to place forestry in Tasmania on a sustainable basis. The first very important step was the power given in the Act for the Department to have exclusive control over State forest and timber reserves, silvicultural operations, harvesting permits and licences, collection of royalties and other revenues, and registration of sawmills. Thus, the basis was laid for effective controls over the day-to-day use and development of the timber resource and a mechanism by which revenue from timber sales could be used to fund forest management.

Strategic development was not neglected, for Section 17 of the Act required the Department to have dedicated as State forest at least 1.5 million acres (600 000 ha) of land within seven years of the commencement of the *Forestry Act*. An important initiation of formal planning processes was contained in Section 22 of the Act. This required the Conservator to prepare Working Plans for each State forest, which aimed to regulate the management of those forest areas.

In the first Annual Report of the Department, Irby referred to the years of over-exploitation of Tasmania's forests in the following terms:

> *In the process of settlement of a young country, the work of deforestation invariably continues for a considerable period, virtually unchecked.* [Forestry Department 1921, p. 3]

Llewellyn Irby, the Department's first Conservator (right) and Thomas Stubbs, Acting Conservator 1928–30, in the Florentine Valley in 1922.

However, in the following year he pledged:

> *… henceforth the cutting on all State Forests will conform with the provisions of the Working Plans, which will ultimately ensure a sustained annual yield.* [Forestry Department 1922, p. 5]

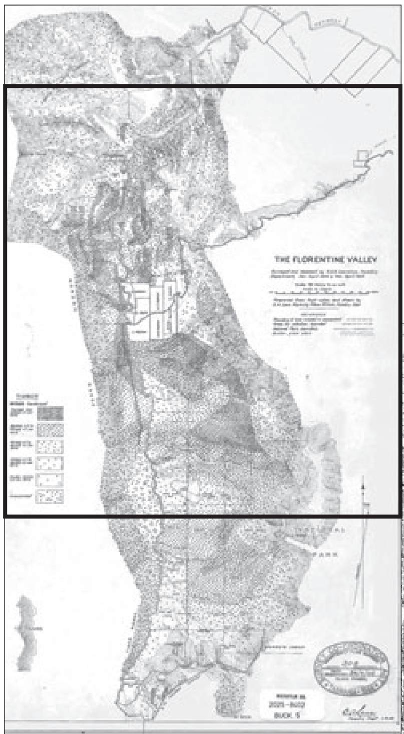
This chapter traces the progress of mapping the locations and assessing the quantity of wood resources, and developing the technical methods required to calculate reliable estimates of sustainable yield, thus delivering Llewellyn Irby's pledge, the keystone of sustainable management.

Early Assessments of the Forests

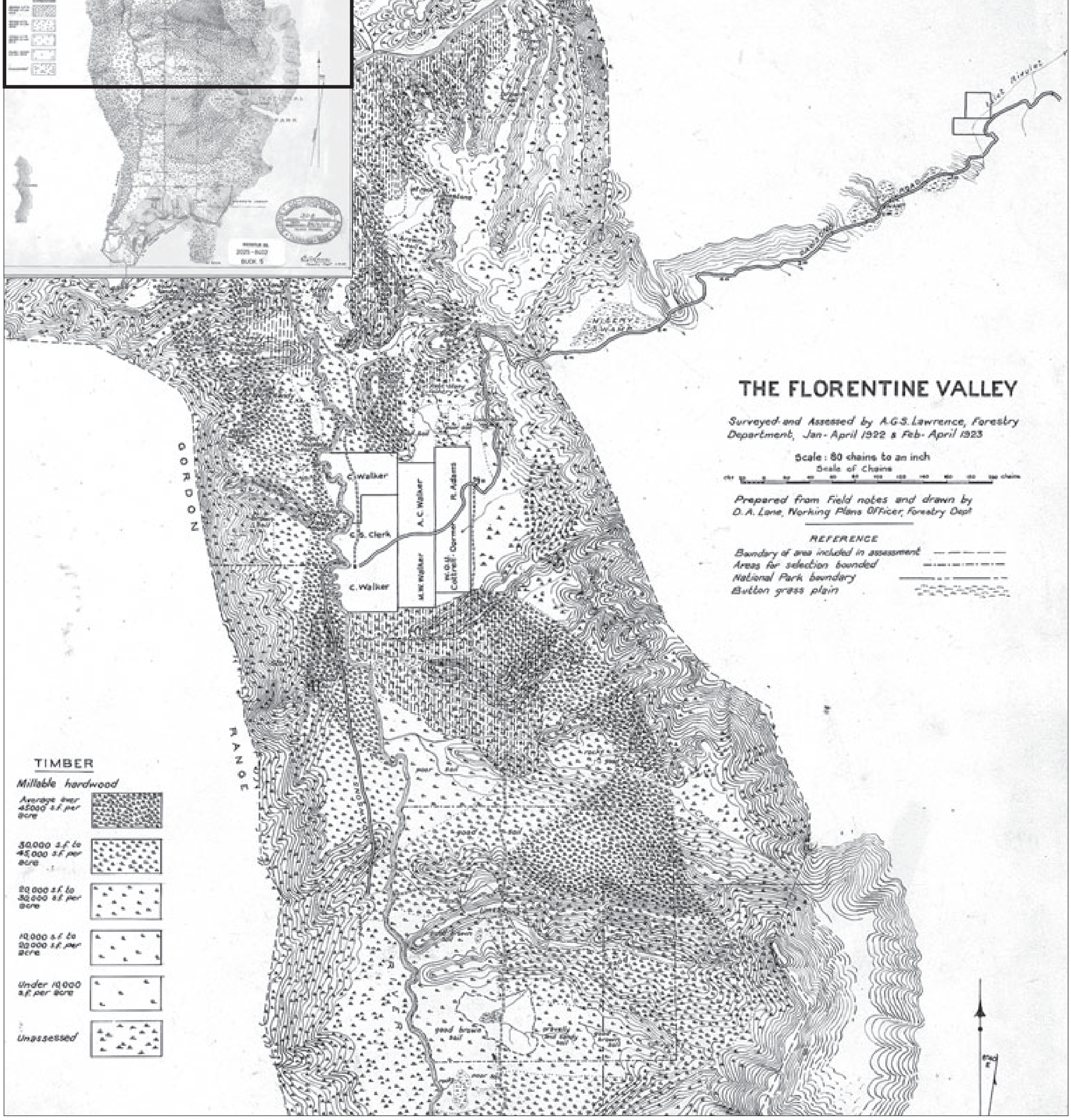
Formal assessments of the State's timber resources began soon after the new Department was established. By 1922, Mr A.G. Lawrence, under instructions from the Conservator of Forests, had commenced an assessment of the southern half of the Florentine Valley. His assessments produced figures on the volume per acre of the main commercial species, *Eucalyptus obliqua*, *E. regnans* and *E. delegatensis*. Other examples of exploratory assessments are given in *Recollections from the Forest* (Cubit 1996),

Lieutenant-Colonel Denis Lane, Working Plans Officer, taking bearings from Mount Franklin, with Lake Sorell in the background, c.1925.

Arthur Warren (left), District Forestry Officer, Western District, and Llewellyn Irby on the Pieman River during a forest survey on the West Coast, 1923.



A map of the timber resources in the Florentine Valley prepared by Lieutenant-Colonel Denis Lane from the survey and assessment work of A.G. Lawrence in 1923. Note the area of the private blocks still known as The Settlement. (From the Mapping Branch Collection, Forestry Tasmania.)




A survey party at the hut at the Gordon Bend, Florentine Valley, in 1922. Lieutenant-Colonel Denis Lane is third from left; the other members of the party are not identified.

enlivened by personal reminiscences of members of the teams. The explorations resulted in a surprisingly advanced state of mapping of the Statewide distribution of commercial timber species at this time (early 1920s), although its limitations were recognised:

> *A map showing the distribution of the various species of timber throughout Tasmania has been compiled from information collected by J. Compton Penny, Esq. (late of the Forestry Department), and partly from information obtained through inspections and explorations made by forestry officers.*
>
> *This map, at best, gives but a general idea of the distribution of indigenous timbers, and can only be considered as a general guide. An accurate map cannot be prepared till reconnaissances have been effected of the whole State.* [Forestry Department 1923, p. 15]

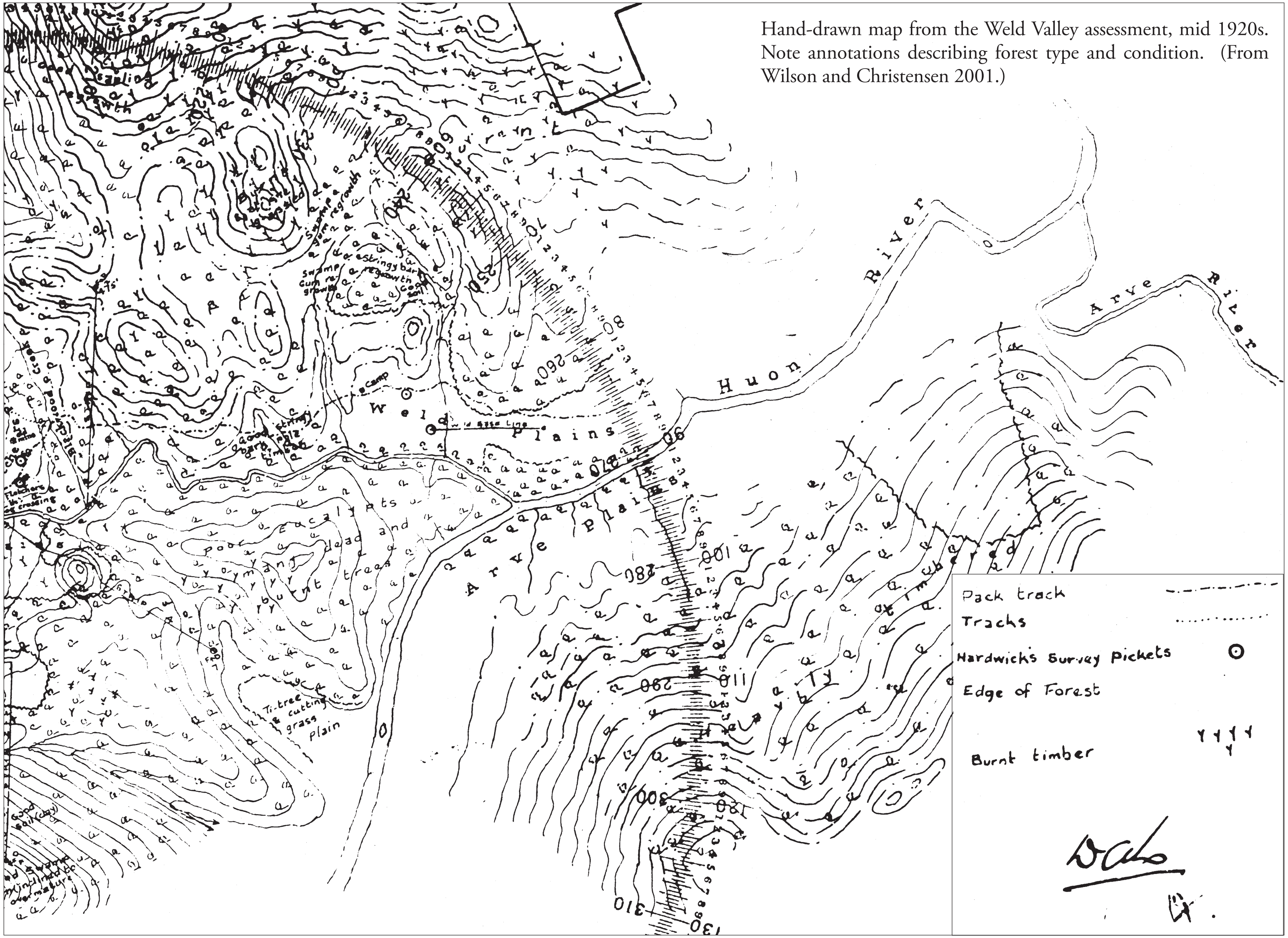
Unfortunately, a copy of this very early map has not been located.

The development of Working Plans as required by Section 22 of the *Forestry Act* was accelerated by the appointment in March 1922 of a Working Plans Officer. The importance of this work was emphasised by the Conservator in his Annual Report for that year.

> *As there are no existing statistics available upon which to base rates of growth, annual increment, rotation etc. of the various species of indigenous trees, it is necessary to adopt measures for the compilation of such data. Research in this respect is being effected, and it is intended to establish sample plots in various parts of the State from which data will be available for use in the compilation of Working Plans of the future. On the completeness and stability of the Working Plans depends the whole question of the sustained yield, and the importance of preparing such plans for all State forests is paramount.* [Forestry Department 1922, p. 11]

Thus, a program for the establishment of inventory and yield plots in State forests was initiated, and this occupied the Department's officers as a high priority for many decades. Later inventory systems (see Continuous Forest Inventory, p. 36) provided a crucial database underpinning the management of State forests.

An over-riding problem for early assessors was the lack of proper base maps, Tasmania being



Hand-drawn map from the Weld Valley assessment, mid 1920s. Note annotations describing forest type and condition. (From Wilson and Christensen 2001.)

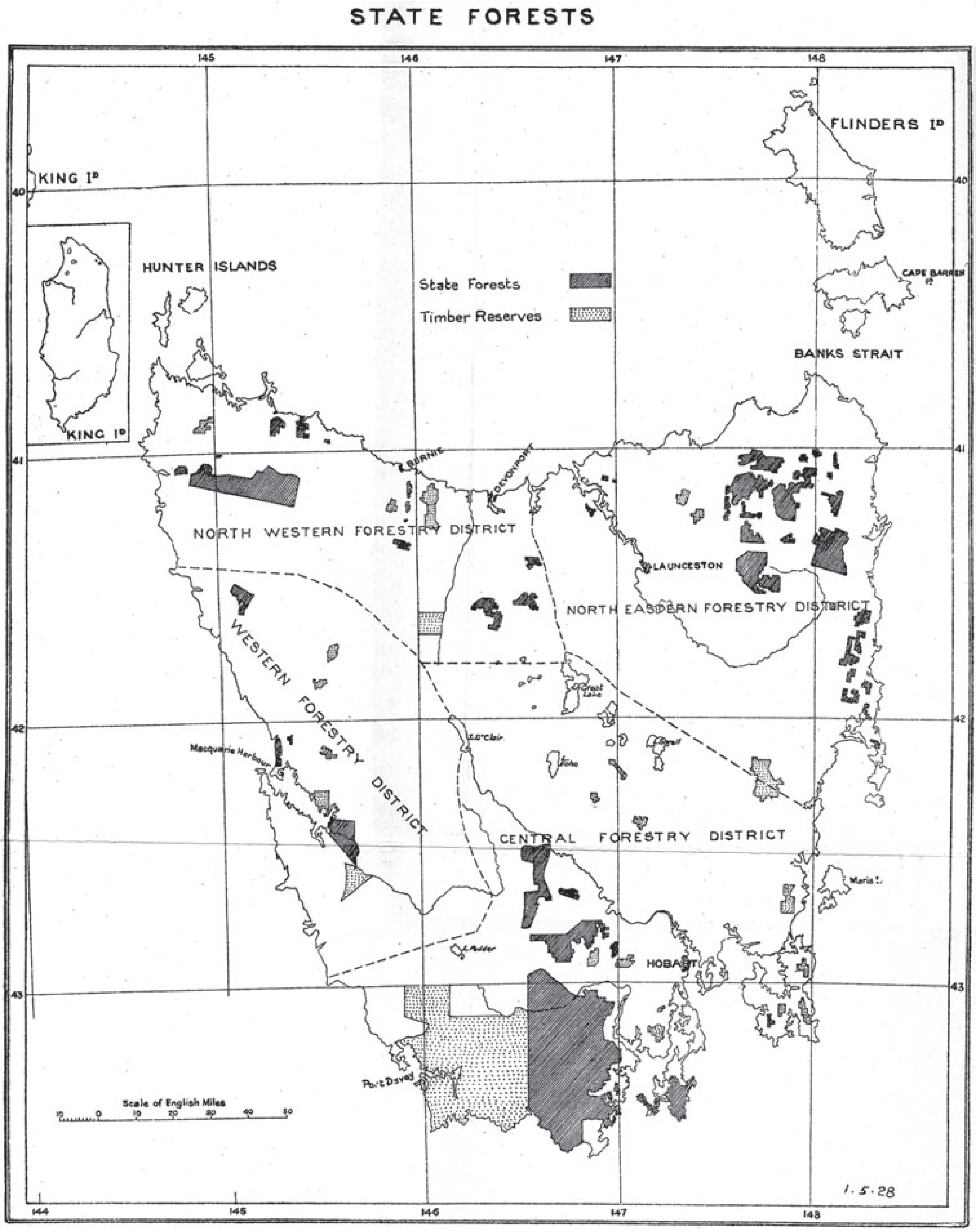
Members of the Forestry Department team involved in assessing the Weld Valley in the mid 1920s. From left, Lieutenant-Colonel Denis Lane (Working Plans Officer and leader of the team), A.J. (Jack) Lovett and Norman Lane.

covered at the time by only rudimentary, very small-scale maps, with county charts of settled areas (Stephens 1996) showing private property boundaries and little else. The assessors had to produce their own sketch maps showing creeks and rivers, hills and mountains and other features at the same time as they assessed the forest. A fascinating example is the assessment of the Weld Valley by a Forestry Department team led by the Working Plans Officer, Lieutenant-Colonel Denis Lane, in 1925 (Wilson and Christensen 2001). The main outcome of this survey was a hand-drawn map which showed contours, watercourses and other topographical features and notations on the main forest types and their locations. These notations were typically brief such as 'good stringy bark' or 'good swamp gum inclined to be overmature', but nonetheless they were an informative guide to the commercial potential of the forests.

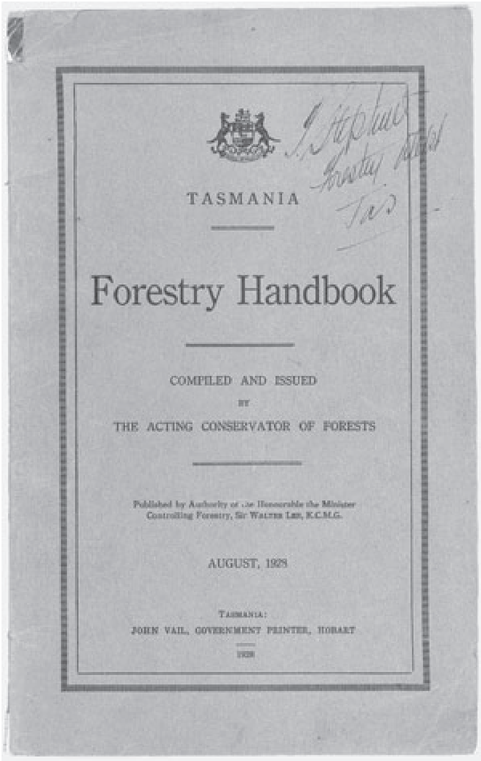
Reconnaissance work, sketch-mapping and opportunistic data-gathering on growth and annual increments of commercial species in some localities continued through the 1920s. In some cases, more formal research was conducted through establishment of sample plots to measure growth rates and the response to thinning of blackwood (*Acacia melanoxylon*), stringybark (*E. obliqua*) and white gum (*E. viminalis*).

By 1927, six years after the formation of the Forestry Department, only 327 929 acres (131 172 ha) of the 1 500 000 acre (600 000 ha) target set by the Forestry Act 1920 had been dedicated as State forest, but by the end of 1928, this had increased to 1 252 543 acres (501 017 ha). However, much of this area was later reported to be unfit for commercial forestry, and large areas of good forest were omitted (Forestry Department 1930).

A forestry handbook was published in August 1928, compiled by the Acting Conservator of Forests (Thomas Stubbs), mainly to provide information for delegates attending the Empire Forestry Conference of 1928. This Handbook contained a map, dated 1 May 1928, showing the location of State forests and Timber Reserves at that time. A system of proclaiming Timber Reserves was in place prior to the passing of the *Forestry Act 1920*, its main purpose being to withhold forest areas from selection until the timber was removed. Most of the Reserves were incorporated in State forests in the 1920s.



An early map of State forests contained in the *Forestry Handbook*, published in 1928.

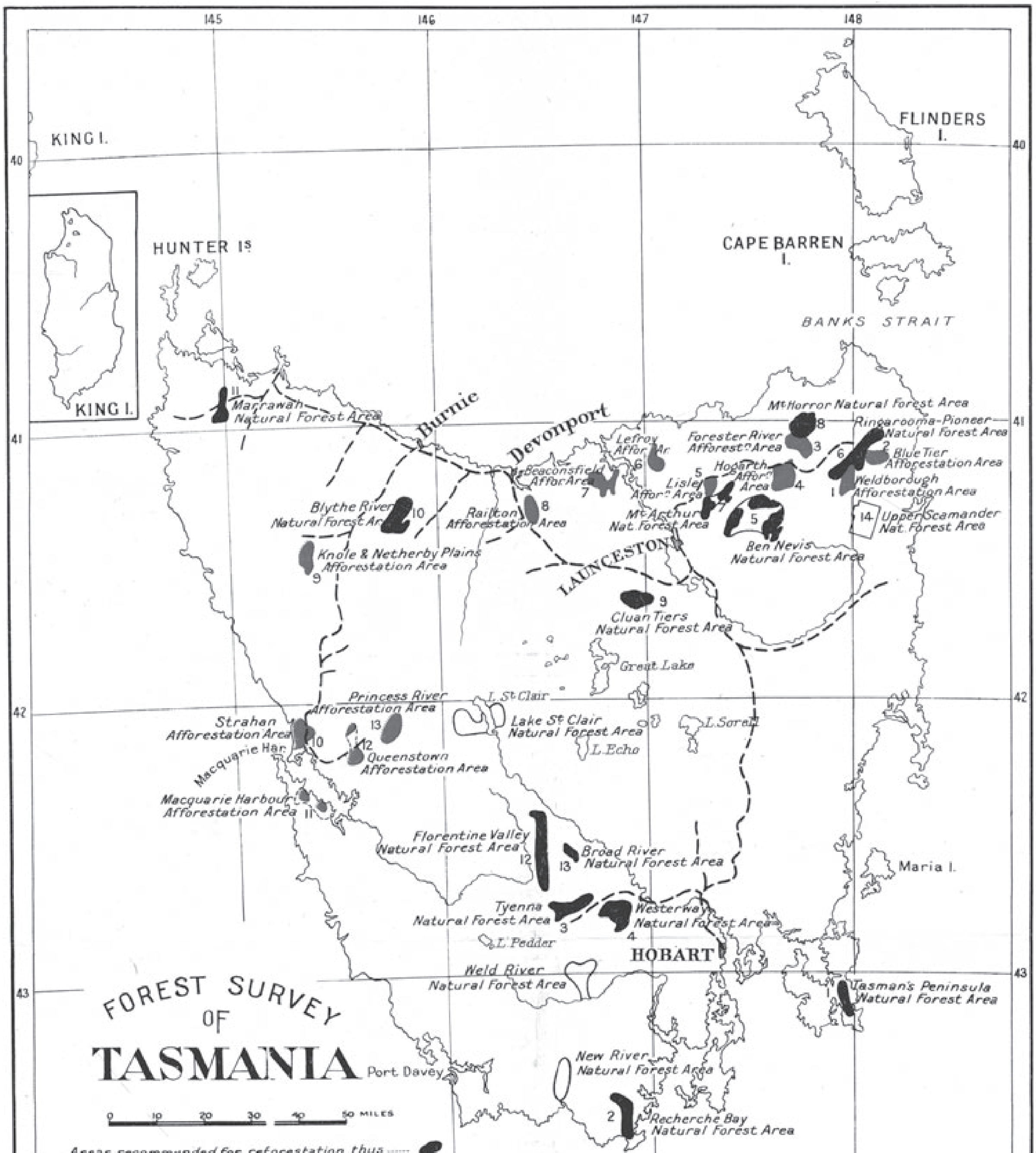


Forestry Handbook, 1928, prepared by the Acting Conservator, Thomas Stubbs, for the Empire Forestry Conference.

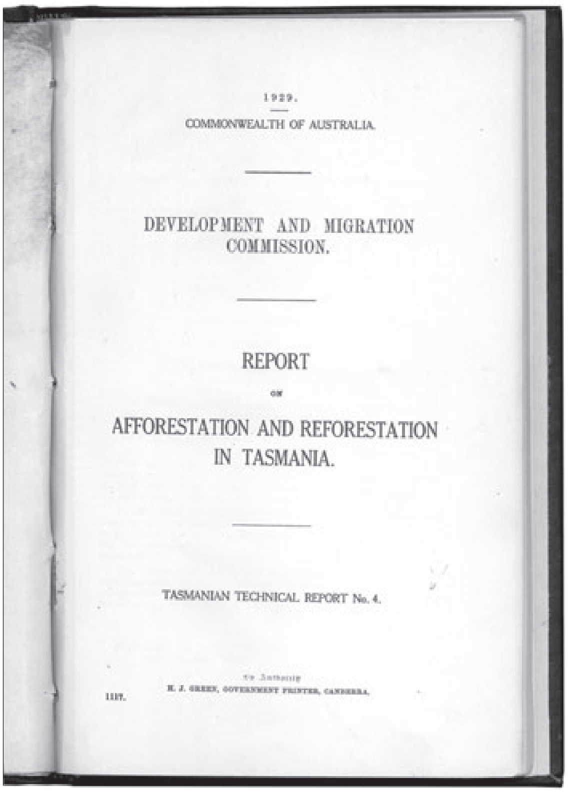
The 1928 Survey of Tasmania's Forest Resources

In 1927, the Development and Migration Commission of the Commonwealth of Australia asked the Commonwealth Forestry Bureau to report on afforestation and reforestation in Tasmania as part of a comprehensive survey of the economic position of the State of Tasmania. The survey had its origins in Llewellyn Irby's proposition for a 'Forest Plantation Homes' scheme (see Chapter 5) for which Commonwealth endorsement was required. Mr G.J. Rodger, the Chief Forester of the Federal Capital Territory, conducted the 'economic survey of the forest resources and possibilities of Tasmania' under instructions from the Inspector-General of Forests of the Commonwealth Forestry Bureau, Mr C.E. Lane-Poole. One of the terms of reference for this task was to examine and report on the 'Measures necessary to assess the hardwood resources of Tasmania and the possibility of silvicultural regeneration' (Development and Migration Commission 1929).

Charles Lane-Poole (seated), Inspector-General of Forests of the Commonwealth Forestry Bureau, with Forestry Department personnel, as the party approached rapids on the Franklin River, West Coast, February 1926.



A map showing areas recommended for reforestation and afforestation prepared by G.J. Rodger during his 1928 survey of Tasmania's forest resources. (From Development and Migration Commission 1929.)


1929.

COMMONWEALTH OF AUSTRALIA.

DEVELOPMENT AND MIGRATION COMMISSION.

REPORT

ON

AFFORESTATION AND REFORESTATION IN TASMANIA.

TASMANIAN TECHNICAL REPORT No. 4.

By Authority
H. J. GREEN, GOVERNMENT PRINTER, CANBERRA.

1117.

The report from the 1928 survey of Tasmania's forest resources by G.J. Rodger, Chief Forester, Federal Capital Territory. It includes an introduction by Charles Lane-Poole of the Commonwealth Forestry Bureau.

In the introduction to Rodger's report, Lane-Poole comments on the history of Tasmanian forestry up to this point (1929):

> *Up to the present, Tasmania's forests have not been worked according to the basic principle of forestry summed up in the term* sustained yield. *The idea of a continuous production of timber to meet the requirements of the community for all time has not been recognised. Instead, the forests have been regarded as mines, that is to say, national wealth which is exhaustible but not replenishable. As a consequence, sawmillers have been encouraged to develop the utilisation side and no serious thought has been given to the replenishment by scientific sylviculture of the timber asset of the people.* [Development and Migration Commission 1929, p. 6]

Considering the short time over which Rodger's survey was conducted (September 1927 to May 1928), his report is extraordinarily comprehensive. He lists natural forests 'capable of being profitably treated silviculturally' as totalling over 334 000 acres (135 000 ha), defining such forests by criteria including a rotation length of 80 years and a minimum yield of 15 000 super feet per acre (88 m^3/ha). For each of the recommended forests, he provides details of its area, species, standing volume per acre, proposed initial operations (mainly topographical surveys and timber assessments), the costs of these works, and the stumpage price necessary to cover this expenditure and payment of an equivalent amount to Consolidated Revenue. He also submitted preliminary Working Plans for each of these areas.

An overall sustainable yield of 6.25 million super feet per year (147 405 m^3) was recommended for the eucalypt forests. Importantly, he emphasised the urgent need for topographical survey and timber assessments to determine:

- Location, quantity and quality of natural timber;
- Qualities of sites as they affect forest growth;
- Location of natural features, thus permitting the definition of milling areas, lines and costs of extraction, and suitable lines for fire control.

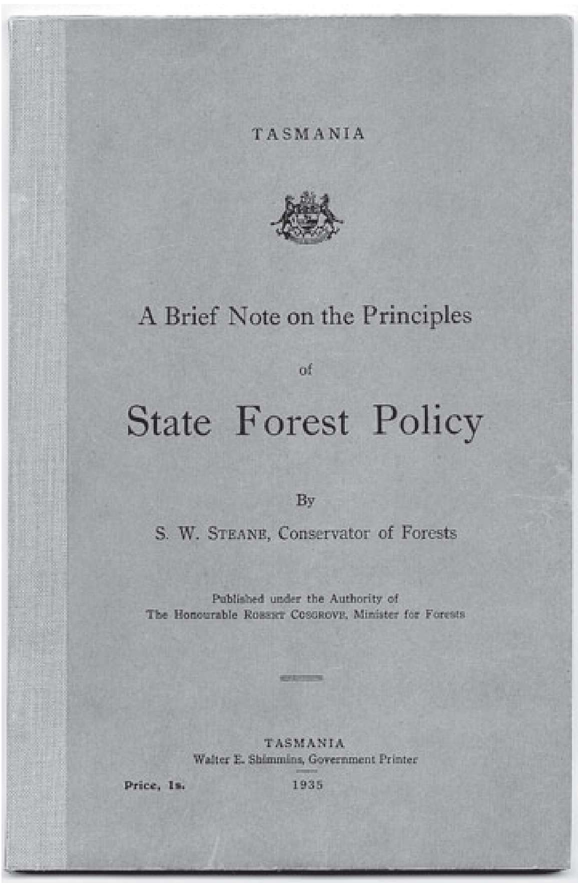
Eleven areas comprising some 103 000 acres (41 200 ha) were recommended for afforestation with softwoods (see Chapter 5), and Working Plans were submitted covering species, methods, operations necessary, costs, and estimated value of the final crop.

Rodger also documented his frustration at the lack of information on timber volumes and growth:

> *As no assessments, even in the way of estimates by inspection, are available for any forest area in Tasmania, except the two already mentioned* [Florentine and Welcome Swamp], *it has been difficult to obtain the relative value of the different stands of natural timber.*

Growth plots and rate of growth figures supplied by the Forestry Department are based on unsound assumptions and little information of any value can be obtained from them. There is also a decided inclination to base statements concerning rates of growth upon the most successful results, and upon those achieved with isolated trees. Such results are astounding, and the less successful areas are overlooked. [Development and Migration Commission 1929, p. 3]

Some of these comments may have been a little harsh considering the genuine, although somewhat disjointed, efforts of forestry officers over the previous six to seven years to undertake the enormous task of mapping and assessing the State's forest resources. However, the 1928 survey was a very important event in the history of the Forestry Department as it clearly set out factual information on some significant areas and their timber resources, as well as prescriptions for developing the overall potential of the State's forests.



The booklet on the principles of State Forest Policy prepared by the Conservator, Sam Steane, in 1935.

There is a gap of many years in records of work to survey timber resources. Perhaps there were none, for Sam Steane, appointed as Conservator of Forests in 1930, deplores that no surveys were done in 1931, 1932 and 1933 as forest revenue was so low in these depression years that only the barest administration costs could be met (Steane 1947).

Steane wrote a booklet on forest policy (Steane 1935) which contains an introduction by the Minister for Forests, Robert Cosgrove (later, Premier from 1939–58), stressing the need for increased employment, with forestry being a possible source. Steane deals in some length with the major problems of State forestry, discussing:

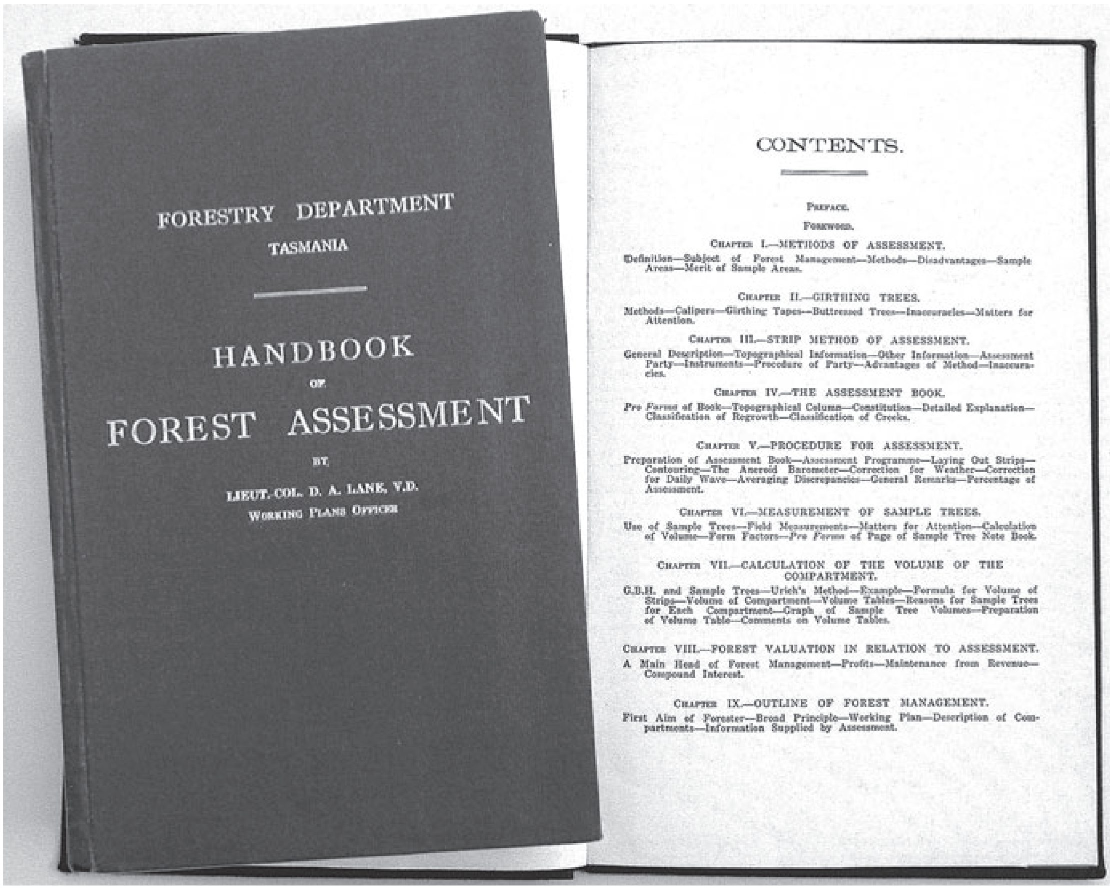
- The fire problem;
- Surveys and maps;
- Forest dedication;
- Silviculture;
- Exploitation;
- Forest grazing;
- Softwood plantations;
- The financial problem.

He advocated an active forest policy in order to provide continuity of timber supplies on a scale sufficient to meet the increasing requirements of timber-using industries, concluding, among other points, that there had to be:

A survey of resources and regulation of the cut of the present stand of commercial timber to spread it over the period required to bring the regrowth to maturity. [Steane 1935, p. 54]

These were similar sentiments to those expressed in 1921 by Llewellyn Irby, showing that little had changed in 15 years in terms of getting a complete picture of the total forest resource. The foresters of the day knew what needed to be done to get that picture; their ability to achieve

Forest survey/assessment party north of the Pieman River, West Coast, 1929–30. Sam Steane, Conservator from 1930–47, is second from the right. Other members of the party are, from left, G. Beckett, unidentified, C. Yann, J. Chipman and, to the right of Sam Steane, Denis Lane.



Early handbook on forest assessment prepared in 1937 by Lieutenant-Colonel Denis Lane, the Forestry Department's Working Plans Officer.

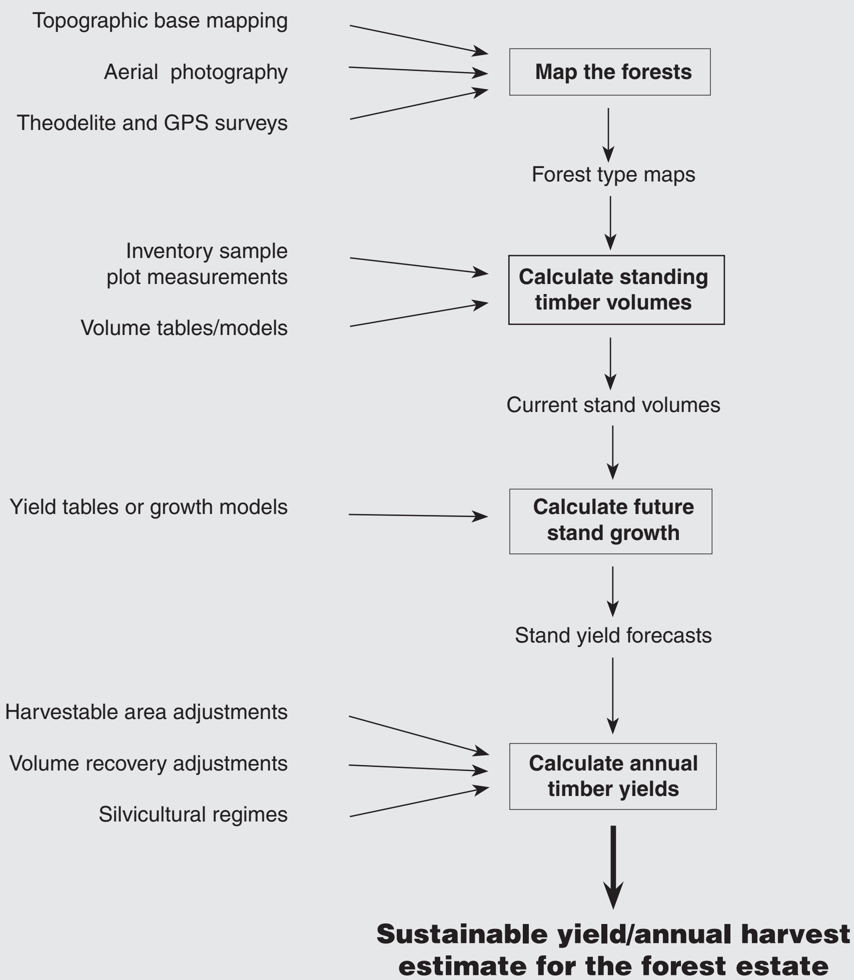
this was hampered by deficiencies in finance, technology, information and science. Thereafter, there was a slow but systematic assembly of the tools and information required to estimate and continually monitor the 'sustained annual yield' (summarised in Box 2) as required by the *Forestry Act 1920*.

A research and development program steadily improved the scientific understanding which was transformed into operational systems. Basic tree data gathered from field assessments were calculated and summarised using manual methods and mechanical computing machines. In this way, large sets of data began to be accumulated. With the arrival of electronic computers, more complex calculations could be made at ever faster rates but, importantly, they were the essential tool needed to synthesise the huge forest datasets into realistic models of the forest.

But there was a major development in the 1930s which greatly accelerated the task of describing the forest resource—the introduction of aerial photography.

Box 2

Basic steps to determine sustainable yield/annual timber harvest.



Mapping the Forests

Aerial photography and photo interpretation

Ground survey and mapping of forest types and detailed stripline assessments of timber volumes were slow, expensive and labour-intensive methods of building an inventory of the State's forest resources. In retrospect, it is highly unlikely that sufficient resources would ever have been available to produce comprehensive and accurate data. The report on the 1928 Survey captures the problem:

> *Natural conditions in Tasmania vary so rapidly and extensively within short distances that it is extremely difficult to form any reliable opinion of the real value of any large tract of country without spending considerable time in an exhaustive examination. The dense nature of the vegetation and the general inaccessibility are also a serious handicap in this necessarily exhaustive examination.* [Development and Migration Commission 1929, p. 20]

Flying over the forests and taking photographs to record a bird's eye view was an excellent way of outflanking these limitations. It had great potential to enable large areas to be quickly and efficiently classified into forest types. After the forest types had been identified, less extensive but carefully targeted ground sampling would provide estimates of timber volumes which could be applied across large areas of each type. This is exactly what happened in practice, the development and use of aerial photography being an outstanding example of innovative research in the Forestry Department. Aspects of this research are summarised below, and a more detailed account is provided by Stone (1998).

The first use of aerial photography for forest surveys in Australia was in 1930 in north-western Tasmania, where an area of 900 km^2 was photographed by the Federal Air Board (Carron 1985). The results were reported as satisfactory, and several reconnaissanc flights were also made in flying boats and in the Wapiti land planes used in the survey. The survey marked the beginning of an era of rapid progress in the mapping and assessment of forest resources in the State, which clearly established the Forestry Department as a national leader in this aspect of forest management.

The dense understorey in much of Tasmania's commercial forest made ground surveys slow and costly, estimated in the 1930s at £50 per square mile (39 c/ha). Aerial survey was seen as the only hope of obtaining maps at a reasonable cost (Steane 1935). In 1933, the Commonwealth Government offered to conduct an aerial survey of forests in Tasmania at a rate of £10 per square mile (8 c/ha), including the production of topographic and forest maps. The Conservator, Sam Steane, took the unusual step of making a public plea to the State Government to accept the offer:

> *If the public could only appreciate the extent to which the development of the country's assets is handicapped by the present lack of maps there would, surely, be a very insistent demand for the survey.* [Forestry Department 1934, p. 10]

But the Commonwealth Government's offer was not taken up.

Further photography was undertaken in the north-east in 1936, supplemented by ground surveys along a stripline through the forest. The changes in forest types along a strip were used to check the boundaries of forest types identified on the photos, but the results were not very satisfactory (Hemmings 1949). In 1937–38, during the visit of No. 204 Flying Boat Squadron RAF, arrangements were made for reconnaissance flights over several forest areas and, in the following year, 1100 square miles (284 900 ha) were surveyed, prompting an enthusiastic comment from Sam Steane:

> *Aerial survey is likely to revolutionise assessment methods and the lost ground under this heading will probably be made up within the next two years.* [Forestry Department 1939, p. 3]

However, aerial surveys in the State were abandoned in 1939 with the start of World War II because the Defence Department requisitioned planes, pilots were called up for service, and three of the Forestry Department's draftsmen enlisted with the AIF. After the war, in 1946, the Forestry Department formed a small Photo-interpretation Section, headed by Dudley Hemmings and made up of ex-members of the RAAF and WAAAF who were specialists in this type of work. The objectives of the Section's work were to provide type maps (maps showing the types of forest) which would allow forest resources to be determined, and topographic maps suitable for road location and forest management purposes. The Section made rapid progress in recognising species from aerial photographs and measuring tree heights. Lieutenant-Colonel Denis Lane was in charge of the early air-survey work and he carried out experiments in relation to identification of species and mapping (Hemmings 1949). Forest type maps were prepared using either ground surveys, ground surveys combined with aerial photographs, or aerial photo-interpretation techniques by themselves. Experience soon showed that ground survey for the production of type maps was unnecessary. Quality and quantity of the forest resource continued to be determined with the aid of ground survey parties, but the amount of ground sampling progressively decreased. The impact of aerial photography on the work of foresters was nicely summarised by Dudley Hemmings at the time:

> *The forester today is finding an increasing use for air photographs and maps prepared therefrom. Indeed, it may be said that air photographs and a stereoscope should become as much a part of his equipment as the compass chain and level.* [Hemmings 1949, p. 265]

After the Forestry Commission was established in 1947, its policy in relation to increased efficiencies to be gained from aerial photography was clearly stated:

> *The objective of the Commission is not only to obtain a satisfactory type and topographic map of forest areas but also directly to derive timber volumes and site quality classification from photo interpretation with minor field sampling only. Intensive research in conjunction with field estimation is proceeding to establish the minimum field sampling necessary.* [Forestry Commission 1948, p. 7]

But by the late 1940s there were still significant basic technical problems facing the photo-interpreters:

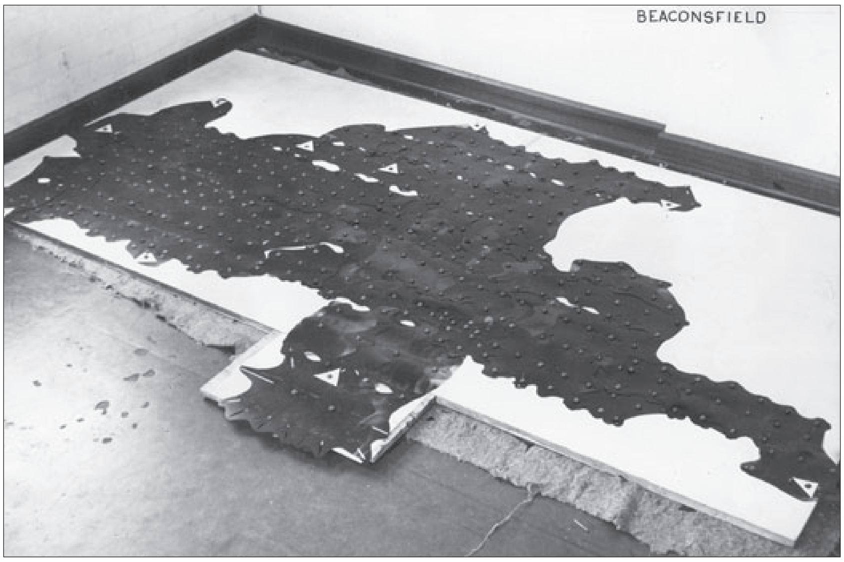
- Unavailability of accurate base maps;
- The lack of reference points of known location, identifiable on the photographs, which could be used to derive horizontal distances on the maps;
- The need for a rapid and accurate method of plotting data from photographs onto base maps.

The Forestry Commission initially had to produce its own base maps, but this work was taken over by the Lands and Surveys Department when it began to produce accurate maps in the 1950s.

In the late 1940s and early 1950s (and until maps were made by the Lands and Surveys Department), the Forestry Commission put considerable effort into establishing ground reference points in the areas being surveyed so that the interpreters could overcome the problem of not having clear points on the photographs for more precise measurement of distance. A Bristol Sycamore helicopter was used by the Commission in 1955–56 for the first time in the course of this work to fly in a survey party to establish a trig station on Mount Bertha, north-west of Waratah.

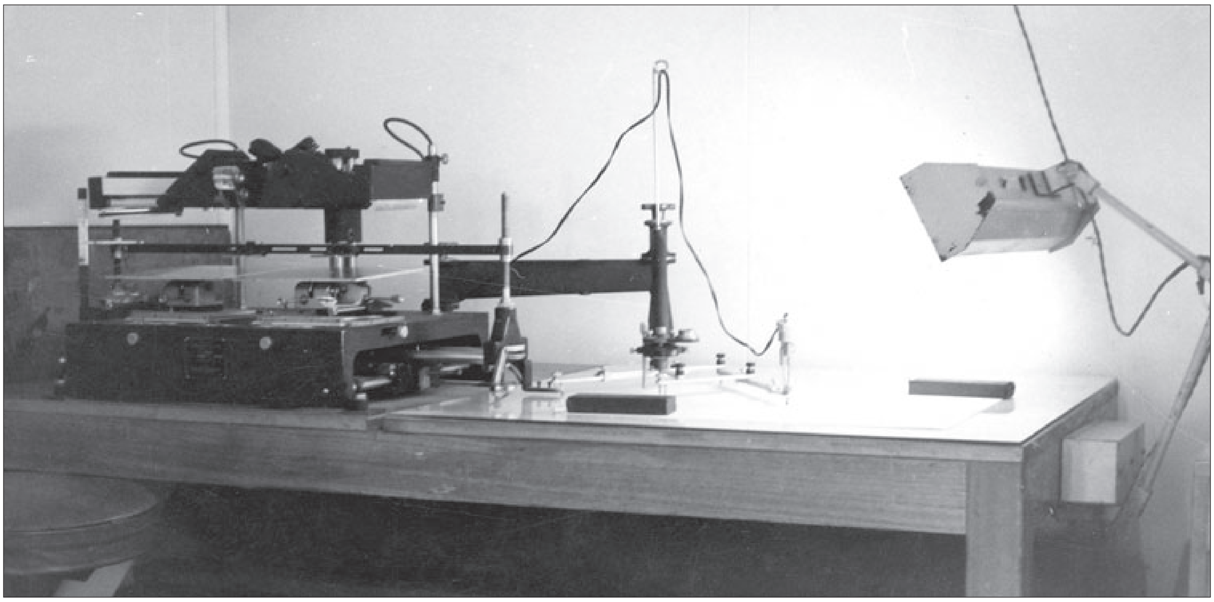
The first techniques used to transfer information from photographs to maps were simple and laborious, involving hand drawing and slotted templates. These methods have been described by Mike Brouder, the senior photo-interpreter with the Forestry Commission and Forestry Tasmania for many years (M. Brouder, cited in Cubit 1996). More automated techniques were

An example of a slotted template sheet made during the production of base maps for forest typing in the late 1940s and 1950s. The templates were made from celluloid sheets which were actually old X-rays obtained from the Royal Hobart Hospital (M. Brouder, cited in Cubit 1996), with identification removed! Each sheet corresponded to a photograph and had slots cut through control points (trigs and other key features) forming radial lines towards the centre point. A set of these overlapping templates was gradually assembled with studs through the control points to cover the area which had been photographed, thus enabling the accurate positioning of these points on a grid board. Images of the photographs were projected on the board with a stereoscopic plotter and areas of forest were then traced around to produce the type map.



A completed slotted template assembly of a forest area at Beaconsfield.

The first stereoscopic plotting machine, the Ryker PL-4, purchased by the Forestry Commission in 1953.



available and, in 1952, the Chief Commissioner, Alec Crane, inspected various models of plotting machines during a visit to Canada and the United States of America. In 1953, on his recommendation, a Ryker model PL-4 stereoscopic plotting machine was purchased and this greatly increased the speed and efficiency with which forest type maps could be produced. In 1993, this process was automated using a geographic information system (GIS; see next section) and digital map data. From that time, maps have been printed directly from computer databases, with electronic layers representing many forest characteristics stored on GIS and overlain as required.

The early maps from the Photo-interpretation Section showed broad forest types and approximate tree heights, but a more precise forest classification system was required before more of the potential of aerial photos for forest inventory could be realised. By 1948, a system of classifying the forest into height and density classes (measured by tree counts per acre) had been developed by Max Gilbert and Dudley Hemmings (Cubit 1996), with four height and five density classes for mature forest being originally designated (Hemmings 1949). These classes enabled the forest to be partitioned into actual or potential forest types, and information on each type could be further improved by notations such as 'o/m' (overmature) and 'f/d' (fire damaged). Sapling and pole-sized eucalypts were simply typed as 'Es' and 'Ep' respectively. In later years, an extra class (E1*) was added to signify mature trees over 250 feet (76 m) in height. In addition, the original 'E3' class was split into 'E-3' and 'E+3' to better indicate the ecological division between dry and wet eucalypt forest and to reduce the variation in sawlog volumes within the original E3 height class (Stone 1998). When irregular (uneven-aged) *Eucalyptus delegatensis* forests were first photo-interpreted, it was found that stand densities could only be classified using percentage crown cover because their multi-aged structure made it impossible to obtain tree counts per acre as had been done for the regular (even-aged) *E. regnans* and *E. obliqua* forests. Eventually, stand density classes based on percentage crown cover were used for all forest types (Lawrence and Walker 1954).

In 1951–52, the Photo-interpretation Section demonstrated that height classes could also be differentiated in stands of eucalypt regrowth, which was defined as having trees less than 110 years old. Regrowth eucalypt forest types based on current height were supplemented by information on the *potential* height class of each patch of this type based on the height of remnant live or dead trees in the stand. The first eucalypt regrowth forest mapped was an area of 12 000 acres (4 800 ha) at Southport using regrowth forest types ranging from ER1 [less than 49 feet (15 m) in height] to ER6 [greater than 165 feet (50 m)]. Field tests showed that the photo-interpretation was very accurate and volume estimates for the different regrowth types were obtained cheaply by using a small number of sample plots randomly located within each type (Forestry Commission 1952).

Box 3 compares the original classes used for height and density in 1949 with those that are now in use.

Once basic forest type maps showing area, height and density classes became available in the late 1940s, sample areas of each type were assessed. The percentage of each type assessed could be varied according to the quality of the stand, with high-quality stands receiving a greater percentage assessment (Hemmings 1949). By the early 1950s, the skills of the photo-interpreters had developed to the stage where the proportion of field sampling to check the validity of the height and density strata recognised from the photos was less than 1% of the total forest area being assessed. Sampling errors at the 95% probability level were estimated at less than 20% for individual forests and approximately 5% for the Statewide eucalypt resource.

Box 3

Height and density classes used for eucalypt forests.

1. Mature forests

1949 height classes		Current height classes	
E1	180+ feet (55+ m)	E1*	76+ m
E2	135–180 feet (41–55 m)	E1	55–76 m
E3	90–135 feet (27–41 m)	E2	41–55 m
E4	< 90 feet (< 27 m)	E+3	34–41 m
		E-3	27–41 m
		E4	15–27 m
		E5	< 15 m

1949 density classes (stems per acre)		Current density classes (live crown cover)	
a	> 15	a	70–100%
b	10–15	b	40–70%
c	5–10	c	20–40%
d	1–5	d	5–20%
e	< 1	f	< 5%
		(P)	patches/scattered

2. Regrowth forests

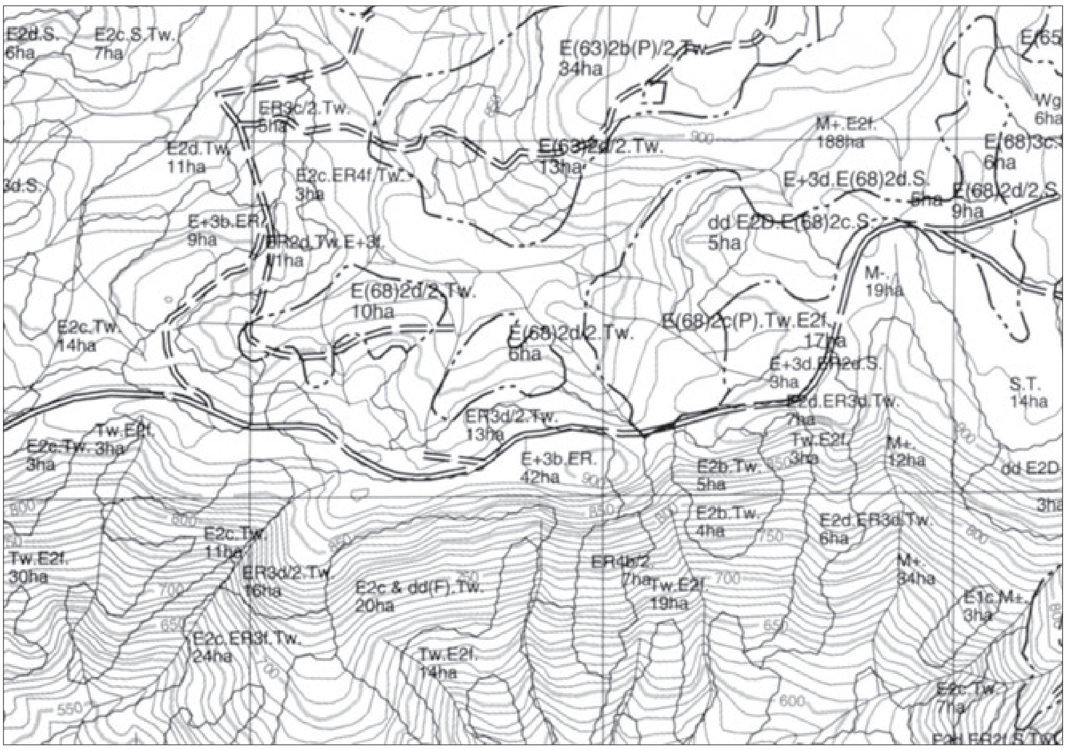
1949 height classes		1951 and current height classes	
Es	saplings	ER1	< 15 m
Ep	poles	ER2	15–27 m
		ER3	27–37 m
		ER4	37–44 m
		ER5	44–50 m
		ER6	> 50 m

Current density classes (crown cover)	
a	90–100%
b	70–90%
c	50–70%
d	10–50%
f	1–10%
(P)	patches or scattered

Over the years since the first type maps were produced, the coding of photo-interpreted types (PI types) has been modified to convey as simply as possible the highest priority information for each forest type. For example, codes for native forests can indicate height, density, understorey and stand condition (e.g. cut-over or fire damaged) for mature, regrowth and mixed mature/regrowth stands, and logged and regenerated forest is coded to indicate the year of regeneration and site quality (see Stone 1998 for examples of PI types).

The uses of PI typing have also expanded well beyond the original objectives of producing forest type and topographic maps and increasing

Interpreted aerial photograph showing delineated patches of vegetation marked with their PI-types. (From Stone 1998.)



Native forest series map (1: 25 000 scale) showing PI-types, contours, roads and other features. (From Stone 1998.)

Using a stereoscope to interpret aerial photographs and determine patches of homogeneous vegetation for forest typing, 1982. (Mike Brouder, interpreter.)

Field-checking vegetation against photo-interpreted forest types. (John Gardner, left, and Tim Madden.)

Using a Planitop plotting machine to produce forest type maps. (Tim Madden, operator.)

the efficiency of forest inventory. For example, PI typing has been a key tool for marking the boundaries of State forest, vegetation community mapping, mapping of oldgrowth, site productivity assessments and mapping for specific purposes such as fire ages and patterns of pest and disease infestations (Stone 1998). PI-type maps using the procedures developed by Forestry Tasmania have also become widely used outside State forest; in particular, they have been used extensively for mapping of National Parks and other conservation areas not administered by Forestry Tasmania.

Measuring tree heights in the forest to check those determined from aerial photographs. (Tim Madden, left, and John Gardner.)

Although most of the PI work was directed at the State's eucalypt forests, a reliable and effective stratification system was also required to obtain reasonable resource estimates for rainforests. In 1952, the Commission flagged an extension of the successful photo-interpretation work conducted on eucalypt forests into the rainforests:

> *Research will now be intensified in regard to the stratification of the myrtle forests in order that similar efficiencies* [to those achieved in photo-interpretation of the eucalypt forests] *can be achieved with low intensity sampling.* [Forestry Commission 1953, p. 4]

Early aerial photography of Tasmanian rainforests was initially interpreted and typed according to the proportion of myrtle (*Nothofagus cunninghamii*) in the stand; that is, 'M' indicated that more than half of the forest canopy was myrtle, 'T' indicated that rainforest trees other than myrtle predominated, and 'S' indicated scrub. Relative presence was typed using priority letters; for example, MT, TM, and so on. By 1964, three height classes (M1 = average height > 37 m; M2 = 24–37 m; M3 = < 24 m) were introduced in the hope that they would reflect merchantability. However, the classes were often difficult to pick because of the dense vegetation obscuring the ground, and the stratification systems based on proportion of myrtle and height classes were found to be ineffective (Walker and Candy 1983). Also, the height classes were inappropriate because there was virtually no M1 forest, and a very large number of code combinations (e.g. STM2, M2TS) were used to subdivide rainforest on aerial photos and most of these had little meaning for the majority of users. All these codes could be adequately summarised into two broad classes: tall rainforest on better sites and short rainforest on poorer sites (Hickey *et al.* 1993). Consequently, these early attempts to produce a complex classification of rainforest types interpreted from aerial photographs were abandoned (Hickey and Felton 1991).

By 1986, the typing for rainforest had been simplified into two classes: M+ (rainforest taller than 25 m with a sparse understorey, usually occurring on fertile sites), and M- (rainforest 8–25 m tall with a dense understorey, usually occurring on low to moderately fertile sites). The M+ type represented most callidendrous and taller thamnic rainforest and the M- represented shorter callidendrous, thamnic and all implicate categories (rainforest classification after Jarman *et al.* 1984). The use of the T-code was confined to stands where particular species could be positively identified; for example, silver wattle (*Acacia dealbata*) and blackwood (*A. melanoxylon*) (Hickey *et al.* 1993).

Accurate assessments of wood volumes in rainforests are made very difficult by the extent of stem defect (unmerchantable wood, usually a result of rot) present in myrtle trees and the difficulty of estimating internal defect from external features. Ground assessments of rainforest were compared with actual recovered volumes from defect plots[1] and found to be very inaccurate. For myrtle sawlog, recovered volumes were half of those assessed. Analysis of data of assessed versus recovered volumes from 52 rainforest plots, each of 0.08 ha, showed that a high proportion of defective wood in myrtle was correlated with poor drainage, soil type and the presence of species typical of thamnic rainforest such as leatherwood (*Eucryphia lucida*) (Walker and Candy 1983).

In 1985–86, a resource-level assessment of M+ rainforest was conducted in north-western Tasmania. The M+ areas were identified and mapped from 1:42 000 black-and-white aerial photographs, and then photo plots (0.2 ha) were randomly allocated within the M+ rainforest and photographed at 1:15 000 using colour photography. Photo interpreters then determined a 'volume correlate' based on mean dominant height and crown cover. A subsample of these photo plots was assessed on the ground, and myrtle trees on these ground plots that appeared to contain sawlogs were felled to determine true sawlog volume. This technique, using only a 0.03% ground sample, achieved reasonable estimates of actual volumes,

[1] Small areas where trees were felled and cut into sections to determine levels of defect.

the following standard errors at 95% confidence limits being recorded: sawlog 24%, pulpwood 18%, gross bole volume 14% (S.R. Davis and S. Candy, unpublished data; Hickey and Felton 1991).

Plantation mapping and global positioning systems

In contrast to the broadscale and interpretive methods used in native forest typing, mapping of plantations was focussed and precise. Plantations are discrete, relatively homogeneous units, with edges which can be readily followed by ground survey. Most importantly, they represent a high-value investment, thus justifying the cost of more detailed mapping. Accordingly, the Forestry Commission developed routine procedures whereby the boundary of each newly planted stand would be defined by an on-ground theodelite survey, then hand-plotted and transferred to a large-scale Plantation Series map.

By the late 1990s, the increasing accuracy and cost-effectiveness of satellite-based global positioning systems (GPS) allowed theodelite surveys to be discontinued. GPS surveys are precise, can be undertaken by a wide range of staff, do not require links to geodetic base stations or survey reference marks, and produce digital information that can be easily transferred directly into a geographic information system (GIS). In recent years, these same advantages have prompted the use of GPS ground surveys to replace aerial photography for the mapping of newly constructed roads and forest harvest boundaries.

A GPS is also increasingly used to allow inventory crews and operational planners to quickly navigate to precise locations in the forest in order to measure sample plots or mark boundaries or road lines. This capability has significantly improved the accuracy of such work and has largely eliminated the need to cut 'line-of-sight' survey lines through the forest, a slow, tedious and expensive feature of previous eras of mapping, inventory and planning.

Computerised mapping and geographic information systems

The storage and analysis of base maps, photo-interpretation data and the production of maps at any scale or in other formats from these data were revolutionised with the purchase of the then ground-breaking ARC/INFO GIS by the Forestry Commission in 1985. The GIS allows maps and mapping processes to be computerised, enabling efficient storage and easy update of information and reproduction of printed maps in any desired scale and style. More importantly for forest management, the GIS enables powerful spatial analysis of map data. For example, separate map layers of forest type, geology, slope and roads can be overlaid to produce a map of, for example, the area of 'E1b' forest on dolerite soils on moderately flat terrain within 200 m of a Class 3 road.

GIS work began with the mammoth task of hand-digitising the Commission's existing map layers into a computerised format. Initially, as proof of concept, small-scale maps (1:500 000) of the whole State were digitised to capture basic information such as land tenure, district boundaries and vegetation types (Kelley and Hinley 1989). This work was then extended to include map sheets at various scales, native forest type maps (at 1:25 000 scale), plantation maps (at 1:10 000 scale) and specialised project data such as the distribution of tall eucalypt forest, soil types, and rare and endangered fauna and flora. This information is a key input into Forestry Tasmania's systems for estimating the area available for wood production.

By the early 1990s, the production of all standard map series products was fully automated, and progressively more sophisticated spatial analysis was undertaken to support strategic planning projects. During this phase, GIS usage gradually extended from Head Office into each District.

Over the last decade, a third phase of GIS implementation has been undertaken, its thrust being to make GIS easy to use and directly available to foresters, planners and researchers. This has been achieved by developing software that allows users to simply select and request a wide variety of standard map scales and styles, reports of what non-wood values are known in a specified area, on-screen views of map layers, or 3-D visibility analyses. Demand is strong; over 30 000 maps are generated each year by Forestry Tasmania staff. The production of 3-D images by the GIS has become a particularly important function; for example, realistic perspective images or 'artist's impressions' can be generated to show where a potential harvest area is visible from, thus allowing informed consultation with neighbours and a basis to refine plans to minimise visual impacts.

The GIS has also been directly integrated into broader computerised business systems at Forestry Tasmania. Examples include the Property Rights Database, which manages information about land purchases, sales, leases, licences and registered forestry rights; and the Forest Operations Database, which manages information about each forest stand and its operational history, effectively providing a computerised version of the traditional hand-written compartment registers.

Assessing the Volume of Wood in the Forests

Ground sampling of forest types

The early forest assessments described at the beginning of this chapter, with their systematic grid of striplines (Box 4) over a whole forest, allowed a map to be produced at the same time as information on wood volumes. However, as a consequence of natural variations in the forest, there were huge variations in estimates of wood volumes per hectare. Once photo-interpreted forest type maps became available, their wealth of information could be used in sampling systems that gave more precise estimates of wood volumes with less field work. Theory showed that gains in effectiveness and efficiency would result from dividing the forest into discrete strata, each containing one or a small range of photo-interpreted types; for example, forest typed as E2b (mature eucalypt forest with an average height of 41–55 m and 40–70% crown cover). Within a stratum, sampling could use systematic strips or randomly allocated plots. From field

Box 4

Stripline assessments.

For many years, the commonly used technique for assessing the commercial potential of forests was to cut a series of (usually) parallel striplines through the area of forest being assessed. Assessment crews then walked these lines noting aspects of the forest and measuring stem sizes of the commercial timber tree species within a defined distance on either side of the line. This technique produced a field map of the extent of the forest and a statistically valid sample of the volume per unit area of the timber. In later years, pre-existing maps, such as those derived from aerial photography, enabled alternative and more efficient sampling designs to be used for assessments.

studies in the 1950s, Peter Lawrence and Jim Walker concluded there were advantages in using randomly allocated plots for the following reasons (Lawrence and Walker 1954):

- The need to keep costly field work to a minimum. Low sampling intensities (about 1%) achieved this, and an estimate of sampling error could be provided by using at least two plots per stratum.
- Information on any one stratum could be accumulated on a Statewide basis.
- Volume estimates from PI maps could be obtained without using field work.
- As random samples are unbiased, the results could be used to maintain a constant check on the consistency and accuracy of photo-interpretation of forest types, and valuable information on the efficiency of the sampling process could be obtained.

Cutting striplines through dense undergrowth (right and below). The basic technique for establishing assessment lines and gaining access to plots for over a century – cut a narrow strip through the scrub with a slash hook for two chains (40 m), pull the chain tight, mark, cut a peg, mark with the distance and start again!

In practice, however, both striplines and random plots continued to be used in forest assessments, albeit for different situations. As the process of cutting striplines enables detailed measurements to be made along the area traversed, the technique was suited to exploratory assessments in remote areas with limited access roads in order to maximise the area assessed per kilometre of access cut. Striplines were also preferred in operational-level assessments of harvesting units where there was a need to systematically traverse the harvesting unit to measure and map the variation in wood volumes and other variables. Random plots had advantages for strategic inventories by requiring only a low intensity of assessment per hectare of forest; for example, in the Continuous Forest Inventory system described later (see pages 36–38).

In sampling a large area of forest with all its inherent variability, there was a need to balance the level of resources (i.e. the number of plots) against an acceptable sampling error. Lawrence and Walker (1954) showed that, for certain forest types, error values (standard error of the mean) of about 10% for gross bole volume and 16% for sawlog volume were achieved by using a minimum of 120 plots. Volumes within individual strata, especially in large areas, were usually desired, and this necessitated a larger number of plots. For small areas of a few hundred acres, precise estimates could not be obtained without putting in many plots at prohibitive cost. Therefore, ocular estimates by experienced local staff were used or the results from similar areas applied to the strata involved. Lawrence and Walker (1954) concluded that, in general, overall sampling errors of less than 15% for gross bole volume and 20% for sawlog volume should be easily obtainable for eucalypt forest when areas greater than 3000–4000 acres (1200–1600 ha) were assessed with sampling intensities of 1% (forest types E1 and E2), 0.5% (E-3 and E+3) and 0.3% (E4). These sampling intensities became normal practice for large-scale assessments such as those conducted in mature forest from the 1950s to the 1970s.

Thus, stratifying the forest into different forest types through photo-interpretation greatly reduced the size of field samples needed to estimate volume to a given level of accuracy (Lawrence 1957). A later analysis (Thompson 2000) showed that there was an overall reduction of 37% in number of plots required and an annual saving of $75 000 by using photo-interpretation to stratify the forest for inventory purposes compared with no stratification.

Ground sampling is currently used in strategic and operational inventory. For strategic inventory purposes, permanent and temporary plots are measured to provide data for long-term growth projections and differentiation of wood product volumes for estate modelling. At the operational scale, plots are measured in coupes scheduled for harvesting or for pre-commercial thinning to identify recoverable product volumes, diameter distributions and average tree sizes (Baalman 2001). The detail of ground-based sampling systems for determining the standing timber resource and for monitoring growth, in both native forests and plantations, is discussed under 'Predicting Stand Growth' (see p. 35).

Volume tables and taper models

The normal sequence for determining the size and nature of the wood resources in a particular area was to map the area, measure sample plots and use a volume table to obtain estimates of total volumes. Volume tables (or tree volume equations) provide estimated volumes of individual trees from diameter and height measurements, and they reflect sizes and rates of tree taper which obviously can vary with species, stocking, tree size and locality. Therefore, a wide range of volume tables had to be developed to reflect this variation across the State.

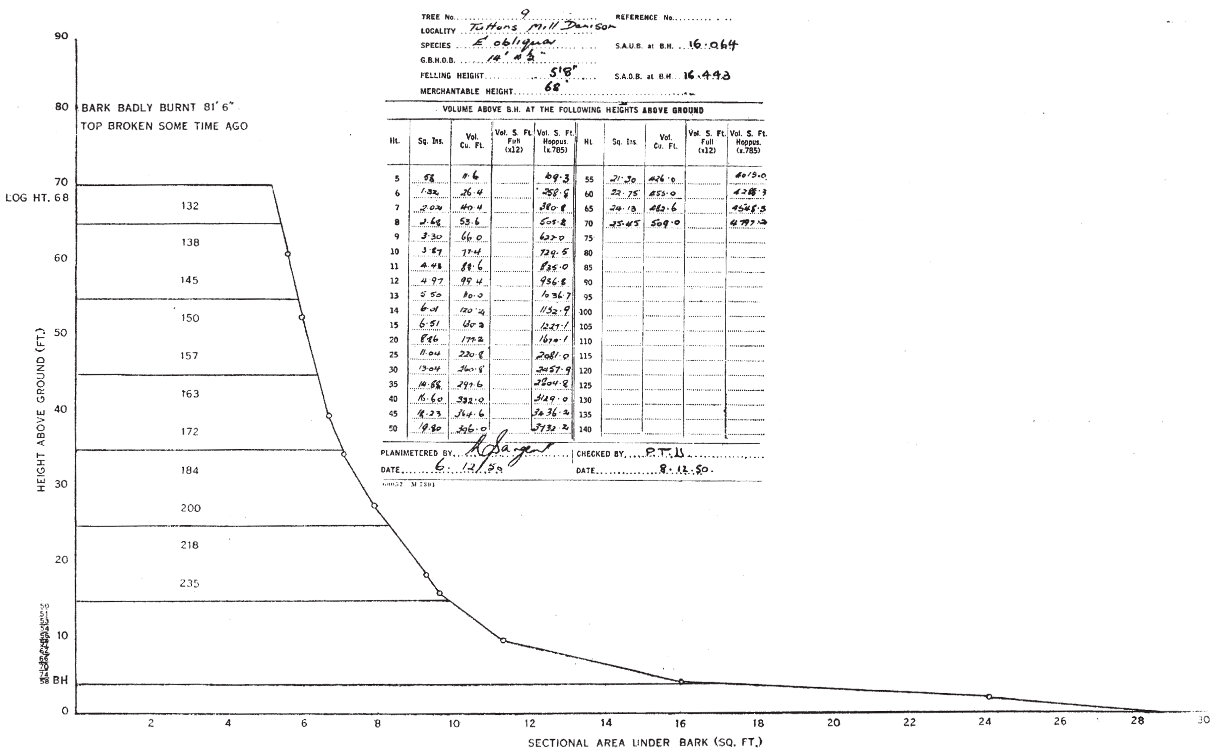
The first reported volume table prepared for Tasmanian forests was compiled for blackwood in Circular Head, although its subsequent demise was noted in the Department's 1933–34 Annual Report:

> *In 1930, a volume table for blackwood (in Circular Head) was prepared but the field notes and all details of trees from which the table was prepared have been lost and the table is therefore not considered as sufficiently reliable.* [Forestry Department 1934, p. 4]

Volume tables were also prepared in 1933 and 1934 for sassafras (*Atherosperma moschatum*) and stringybark (*Eucalyptus obliqua*) in the Russell Valley in southern Tasmania.

After World War II, work on volume tables restarted. They were developed for commercial eucalypts by the Working Plans Branch of the Forestry Commission in the late 1940s (Unwin and Bowling 1951). The aim of this work was to provide a table giving merchantable volumes for standing mature trees using three measurements readily made by assessment crews: girth at breast height, merchantable height and stump height. The information in the tables was derived from measurements taken on felled sample trees which allowed data on volumes to be accumulated for successive logs in a single tree. A small number of sample trees for each species and location were used and, where possible, sample trees were selected to cover the girth range required and to have the greatest possible log lengths.

Once a sample tree had been selected, its girth at breast height over bark and merchantable height were measured. After falling the tree, under-bark measurements of girth were made along the trunk until the end of utilisable timber was reached. These girth measurements were not located at set intervals (e.g. 10 feet,



An example of a volume line graph. After plotting sectional area under bark against height above ground, log volumes were obtained by counting squares on the graph sheet between breast height and each height level up the tree. The number of squares was then multiplied by a scale constant to give the volumes which were then entered in the table on the graph sheet. (From Unwin and Bowling 1951.)

20 feet, etc. above the ground) but at waists in the trunk. Measurements on protrusions and swellings were avoided because the objective was to measure the basic shape of that part of the trunk usable by a sawmiller.

Back in the office, heights above ground were plotted against cross-sectional area under bark. The aim was to calculate stump volumes above breast height for each foot of stump up to 15 feet (4.6 m) and log volumes above stump height for each five feet (1.5 m) of log. The volume above breast height for each of the heights was then calculated for each of the sample trees. The mean volume above breast height for any given height was plotted against the cross-sectional area at breast height for all trees on a common graph to produce a volume line. Early volume tables were produced from these calculated volumes by fitting straight lines by eye. Later, the lines were fitted by mathematical regression, and volume tables were produced more automatically.

Development of volume tables for eucalypts was also a priority research project of the Forestry and Timber Bureau (F&TB), formerly the Commonwealth Forestry Bureau, which established a Tasmanian Branch in 1941 and worked closely with the Forestry Commission for over 40 years. At about the same time as the volume tables for mature trees were being developed, Phil Bowling, of the Tasmanian Branch of F&TB based in Dover, developed a volume table for eucalypt regrowth.

The volume table for regrowth eucalypts was compiled using data from 362 trees which had been felled adjacent to sample plots in regrowth stands. Individual volume lines were produced from the data for each tree. It was originally planned to produce separate tables for each species but there was considerable variation between volume lines, even within species. Therefore, producing a reliable estimate would have required too many trees to be felled and measured to be practical. Consequently, a general volume table was compiled from the data covering all sample trees, mainly *E. regnans* and *E. obliqua* but also some trees considered to be *E. obliqua/E. regnans* hybrids, and *E. globulus, E. delegatensis* and *E. viminalis*. These trees came from several different localities in Tasmania, mainly the Southern Forests but also from the north-west and north-east. When individual eucalypt species were tested against the general table, it was found that on an under-bark basis, there was little difference between species and localities (Bowling 1951). This important development achieved by the co-operative efforts of the F&TB and the Forestry Commission was recorded in the Forestry Commission's Annual Report:

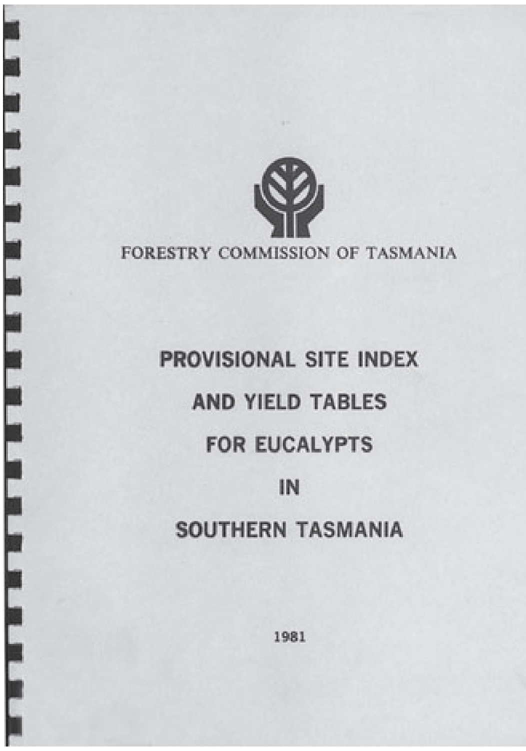
> *The year under review also saw the production of a revised, highly accurate volume table for regrowth. Previously, tables for estimating the volumes of mature trees of the important species as well as regrowth had been compiled by the Working Plans Branch.* [Forestry Commission 1953, p. 4]

From this time on, priority for the development of mensurational tools for eucalypt forests was given to regrowth stands. Significant areas of eucalypt regrowth resulting from wildfires existed across the State and this was increasing progressively from regeneration established after harvesting mature forests.

In the early 1960s, volume tables were prepared for eucalypts, silver wattle (*Acacia dealbata*) and radiata pine (*Pinus radiata*) of particular ages from specific forests; hence, they were known as 'local' volume tables. Research was also conducted on tree form with a view to simplifying and reducing the work involved in producing local volume tables. Also at this time, provisional volume tables were compiled for unthinned radiata pine stands planted at 6 ft x 6 ft (1.8 m x 1.8 m) and 8 ft x 8 ft (2.4 m x 2.4 m), and also for thinned stands.

In the 1970s, volume tables were issued for silver wattle, *E. obliqua* below 6 ft (1.8 m) in girth, and east coast eucalypts, and a revised set of tables for radiata pine was completed. Fifty-two local volume tables were prepared for measuring the volume of radiata pine thinnings and clear fellings for sale purposes. A merchantable volume table for swamp-grown blackwood was also prepared. Sample tree measurements continued in the 1970s and 1980s, but mensurational tools were developed for general application rather than being area specific. In the 1980s, the old volume tables for mature eucalypts, which gave volumes from stump height to each of a set of fixed heights, were replaced with mathematical models that could give volume to any height up the tree and which were more compatible with yield-regulation software.

The shapes of trees at different growth stages (regrowth versus mature) and indeed different species (e.g. eucalypts versus rainforest species) are critical functions that need to be incorporated in calculations of tree volume. In the mid 1980s, Steve Candy developed models of individual tree volume and stem taper for radiata pine in Tasmania based on information from the conifer literature and data from Tasmanian sample plots (Candy 1989a, b). These models were also fitted to the main eucalypt species. Once a taper function was developed, a volume table was not needed because adding tree shape to the easily obtained variables of species, diameter and height completed the mathematical picture of a tree. Taper functions were refined by Adrian Goodwin, who used additional plot data to modify the functions for pines for use with Tasmanian native forest eucalypts. These taper functions for eucalypts worked well and were introduced for native forests in the late 1980s; they are still used today, with some refinements. To enable more accurate estimation of tree and stand volumes and yield of particular products from eucalypt plantations, taper functions for *E. nitens* and *E. globulus* were developed (Goodwin and Thomson 2002).


FORESTRY COMMISSION OF TASMANIA

PROVISIONAL SITE INDEX AND YIELD TABLES FOR EUCALYPTS IN SOUTHERN TASMANIA

1981

The metric version of the Southern Forests site index and yield tables, published in 1981.

Predicting Stand Growth

Site index and yield tables

The first predictions of the growth of regrowth eucalypts were contained in the yield table[2] reported by the Forestry Commission in 1953:

> *During the year also, the results of field plot sampling in the eucalypt regrowth forests of Southern Tasmania over the last four years were collated and tested and a preliminary yield table for these stands was completed. This is believed to be the first yield table made in Australia for natural regeneration of hardwoods. The Commission is now in a position to give reliable estimates of the productivity of the new forests for many decades ahead.* [Forestry Commission 1953, p. 4]

[2] A table providing expected volumes for a stand on a particular site quality at a given age.

This preliminary yield table was superseded when formal site index and yield tables for Southern Forests regrowth eucalypts were produced by the Forestry Commission in 1964. Site index was defined as the mean dominant height of a stand at age 50 years, and could be obtained for stands of different ages and heights. The volume per acre of an individual, fully stocked stand could then be obtained from the yield table by entering the site index and stand age. These early site index and yield tables were prepared using graphical methods but, in 1978, Peter Lawrence, the Principal Management Research Officer, produced a metric version (Forestry Commission 1981a) using computers, after deriving regression models to replace the original graphical methods.

The 1964/1978 site index table was based on measurements of small samples of trees from the Southern Forests, but the table figures were used well beyond their original 'source forest'. They were applied for many years in different parts of the State and in stands often containing different eucalypt species from those used to compile the original data in the Southern Forests. Long-term averages of timber yields used for strategic predictions by the Forestry Commission until the late 1980s were based on these 1978 tables.

Systems for measuring stand growth

Native forests: continuous forest inventory

In order to calculate sustainable yield, an estimate of the likely growth of the different forest types was required. In the wet eucalypt regrowth forests which contained mainly one or two age classes (also known as regular forests), growth could be estimated using site index tables and yield tables. The application of clearfell, burn and sow silviculture to these wet forests allowed successive rotations to be modelled as single-aged stands using a yield table.

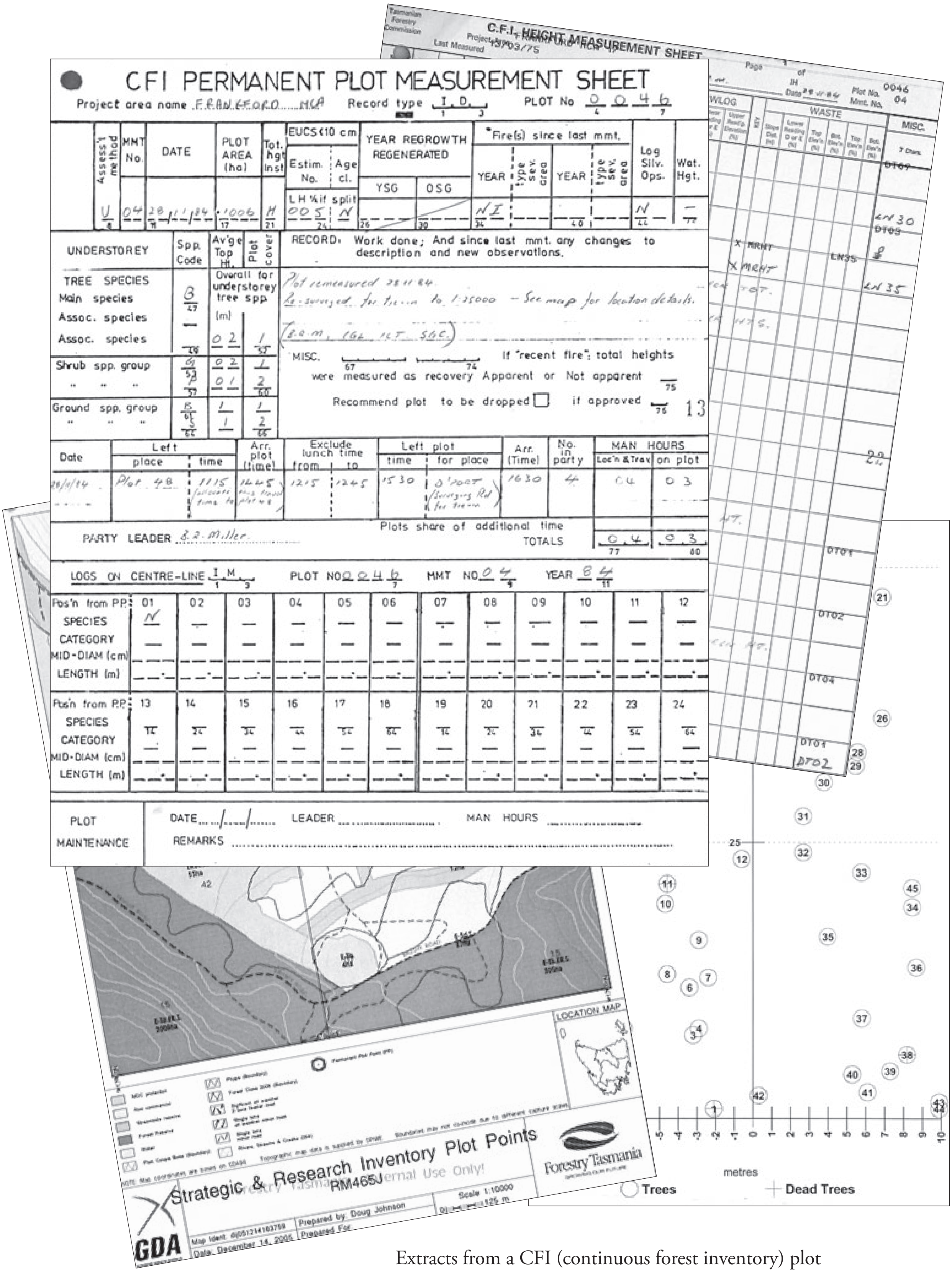
This technique for estimating increment was not applicable in the drier forests with several age classes (irregular forests). Not only were the dry forests multi-aged, but selective logging of these forests preserves their multi-aged structure into the future. Consequently, in the early 1960s, a continuous forest inventory (CFI) approach was implemented (Box 5). In the late 1960s, CFI measurement plots were extended to the regular forests to check on increment estimates from the yield tables (Lawrence 1978) and to provide data for derivation of improved growth models.

In order to implement a CFI system suitable for Tasmania's forests, the State was divided into

Box 5

Continuous forest inventory (CFI).

The essential logic of CFI is to compare successive measured volumes of samples of a forest estate over a period of years. An increase in volume across the wood production estate over time indicates that harvesting levels could be increased, and vice versa. Using a series of sample plots, CFI measurements provide increment data for individual plot trees, and from these data the change in total stand volume can be calculated. Permanent and temporary plots were established in irregular forests (uneven-aged) using a system of sampling with partial replacement of plots in successive remeasurements, based on work in similar uneven-aged forests (but different species) in North America.



Extracts from a CFI (continuous forest inventory) plot file showing examples of the measurement data sheets, location map, and a map of tree positions on the plot.

measurement cycle areas (MCAs) which were treated separately for sampling purposes. Within each MCA, a complex stratification hierarchy was developed. The primary stratification was by mature forest height classes, or potential height classes for regrowth forests. Within each stratum, four substrata were recognised, depending on the presence or absence of regrowth and the regrowth height class; they represented broad growth stages. Within a substratum, temporary plots could be allocated across a third level of stratification which separated different density classes. Permanent plots were randomly allocated within strata, with temporary plots randomly allocated in substrata, except that plots were not allowed to fall within 50 m of a forest-type boundary.

The CFI system thus included a number of permanent plots remeasured on scheduled visits, and the intention was to establish a new set of temporary plots on each occasion. The original sampling intensity was 10 plots per 400 ha, of which two plots were permanent and eight were temporary. They were rectangular and 0.1 ha or 0.2 ha in size depending on the height class of the regrowth, taller forest receiving the larger sized plots. At each measurement, the diameters of all trees on the plots were recorded, with a sample of total heights covering the range of diameters, allowing entire stem volumes, and pulpwood and sawlog volumes to be calculated from volume tables.

In the early 1970s, modifications were made to the CFI system to better match the resources available to the system. Split plots were introduced where all trees were measured on one side of a plot and only trees greater than 40 cm diameter on the other side, sampling intensity was reduced to two permanent plots per 500 ha, no temporary plots were established, and measurements were placed on a ten-year cycle instead of a five-year cycle. At about this time, a method was developed to optimise allocation of permanent and temporary plots among substrata in order to satisfy maximum sampling errors for volume and increment prescribed for the whole MCA.

The CFI system in the eucalypt forests rapidly built up a very large database. It was an expensive system to implement, being based on high-cost permanent plots. From the 1980s, the use of CFI as a sampling strategy and yield regulation tool was phased out because of the cost and because expanded pulpwood harvesting resulted in larger areas of even-aged regeneration. This was more amenable to modelling techniques that required only low-cost temporary plots.

The long experience with CFI has produced two enduring legacies for Forestry Tasmania: a strong culture of quantitative management based on high-quality measurement, and an extensive database of time-series measurements which has been a vital input into the development of the sophisticated growth models now used for yield projection.

Plantation inventory and growth plots

Up to the early 1960s, the plantation estate was small in extent and mostly located on high-quality ex-farmland in the north-east and north-west, having been established mainly in the late 1940s and 1950s (see Chapter 5). As the plantations grew, a systematic basis for inventory and growth measurement was required. The plantation yield plot (PYP) system was designed to meet this need.

Once plantations had reached crown closure, tree heights were measured in a systematic grid across each plantation, and site index maps were derived from these data. On the basis of these maps, the plantations were stratified into site classes. Within each site class stratum of each compartment, one PYP was established, positioned subjectively to be as representative as possible of the surrounding plantation. PYPs were permanent plots, measured regularly (before and after each thinning, and at least every three years). Their dual purpose was to provide inventory estimates of current volume, and time-series data from which yield tables and growth models could be derived.

The rapid and major expansion of the plantation estate in the 1960s and 1970s resulted in a very costly remeasurement program, and the PYP system was abandoned in the late 1970s. Shortly afterwards, radical changes in silvicultural regimes for softwoods (see Chapter 5) rendered the accumulated growth remeasurement data much less useful for development of future growth models.

In response to these pressures, the plantation inventory system (PIS) was developed and implemented in the early 1980s. The use of expensive permanent plots was drastically reduced; henceforth, growth models were developed from a small number of carefully designed and replicated research plots and plantation growth plots (PGPs). PIS plots, on the other hand, were designed for maximum effectiveness for providing inventory measurements; they were temporary plots (measured only once), 20 m x 30 m in size, and laid out on a systematic grid across the plantation estate at an intensity of one plot per five hectares. The plots were measured immediately following the final thinning treatment; measured volumes were projected into future years by using growth models. This system was used successfully for the pine estate until Rayonier Tasmania took over the management of the joint venture pine resource in 1999.

In the mid 1990s, Forestry Tasmania's rapidly expanding eucalypt plantations required a cost-effective inventory system. Under the 1999 Wood Inventory Strategy, the successful principles of the PIS/PGP systems were continued: small numbers of permanent eucalypt growth plots and regime research trials are used to provide time-series remeasurements for plantation growth models, whilst inventory is based on temporary plots established at one plot per five hectares on a grid layout across the plantations. These plots are able to be projected over time for strategic-level planning purposes over most of the life of each plantation. However, once plantations approach final harvest age, a more intensive pre-harvest inventory is undertaken to provide the detail needed for sales contracts and harvest scheduling.

Growth models and yield projection

Native forests models

The advent of early computer technology in the 1960s enabled efficient processing and manipulation of growth data which could be used to build mathematical models (a set of equations describing the interaction of variables) for prediction of future wood yields. These models superseded the yield tables discussed earlier. Peter Lawrence was the first in the Forestry Commission to recognise the potential of computers; he was acutely aware that so much measurement data for eucalypt forests had accumulated that it was becoming impossible to process it efficiently. In those early days before computers were installed in-house, he had to plead with other organisations (including the Cadbury's chocolate factory) for time on their computers. It is important to note that, prior to the advent of computerised growth modelling, there had been several studies of various aspects of the growth of forest stands in Tasmania which contributed to the data used later for model building. For example, the Forestry Commission's 1961–62 Annual Report noted the production of a bulletin written by the Chief Commissioner, Alec Crane, entitled *The Normal Increment-Spacing Relationships of Even-aged Forest Stands* (Crane 1962).

The sophisticated growth models now used by Forestry Tasmania were developed by an incremental process. Specific programs were written in-house, tailored to the datasets available and the outputs required, with experience being gained with programs that dealt with variables such as bark thickness and stem form. The first recorded step in model building was taken in 1962–63 with the writing of a generalised program for the I.C.T. 1301 computer for the building of mathematical models by regression analysis.

The first objective in the implementation of computerised growth modelling was to transfer data from paper records to systems suitable for analysis by computers. A start was made on transferring all data on sample trees to a punched card system. In the latter part of the 1960s, work began on programming to set up a library of completely measured sample trees on magnetic tape.

As described earlier, the first computerised growth model was essentially a re-compilation in 1978 of the Southern Forests Yield table. This model was then used as the basis for most strategic planning of native forests until the early 1990s. During this period, modellers began to analyse the growing pool of CFI and research measurement data that spanned an increasing number of time intervals. The resultant new-generation growth model was composite in structure, separately estimating basal area and height based on site index and mean dominant height, with sub-models for other factors such as mortality. This single-age model was implemented in the mid 1990s, and was used as the basis for sustainable yield calculations for the 1997 Regional Forest Agreement (RFA 1997).

Once good models had been produced for even-aged eucalypt stands, attention turned to developing models for uneven-aged stands, a far more difficult problem. Adrian Goodwin had begun investigating models for multi-aged stands in the 1980s. His work resumed in the late 1990s. Equivalent elements of the even-aged growth model were applied to uneven-aged forests by iteratively subdividing each stand into its component age-classes, then projecting each cohort separately before producing an integrated projection of the total stand. The resultant models are now routinely used for modelling sustainable yield calculations for the native eucalypt forests.

An early Prime 'minicomputer' used by the Forestry Commission in the mid 1980s. The acquisition of this technology gave the Commission the capacity for in-house processing of inventory data and implementation of geographic information systems. (Martin Stone, left, and Max Gentle.)

Because of their strategic significance, monitoring and predicting growth of the eucalypt forests was the first priority. Parallel work for forests of other native species then followed. The first stage, establishment of permanent CFI plots in wattle stands and blackwood swamps, took place in the 1970s and 1980s. During the 1980s, as described in Chapter 4, there was increasing interest by the Forestry Commission in obtaining data on the growth and silviculture of blackwood in north-western Tasmania. By 1993–94, a growth model for blackwood had been developed and this was extensively used in producing a Management Plan for the blackwood swamps.

Forestry Tasmania's growth models are now being further refined by concentrating on some of the most significant parameters of the stands. For example, the mean dominant diameter gives an improved representation of the most important part (for wood production) of the natural variation within a forest—the larger trees. Thus, the introduction of this parameter into growth models improves the estimates of high-value products (A. Goodwin, pers. comm.).

Plantation growth models

Radiata pine plantations were the relatively simple first target for development of actual growth models by the Forestry Commission due to their even-aged nature, availability of information on growth and yield, and their general uniformity. In 1972, the first model describing growth in mean dominant height (MDH) of radiata pine plantations was completed, together with a table giving site index from age and MDH derived from the model. At about the same time, a new density index was developed for radiata pine which expressed the basal area of a stand as a percentage of that expected in a fully stocked stand. In the mid 1970s, stem-form equations for radiata pine were developed which enabled estimations of log assortments from a particular stand.

Robust mathematical models were in place to estimate growth and yield for pine, including the effects of stand manipulations, such as thinning, on yield and log assortments. When thinning and pruning regimes in radiata pine plantations were modified in the 1980s to incorporate very heavy thinning at age four years to leave 250 stems/ha, the growth models also had to be modified to take account of the consequent changes in yields and log assortments at different stages of plantation growth. As an interim measure, models developed in New Zealand were adopted while measurement

The model was based on an assumed stocking at 10 years of 1750 stems ha^{-1}, the known stocking at age 42 of 570 stems ha^{-1} and an estimated entire stem volume at age 42 of 1045 m^3. The predicted volume (m^3 ha^{-1}), basal area (m^2 ha^{-1}) and stocking (stems ha^{-1}) are shown for each 5-yearly age level and diameter (DBHUB) class, together with the periodic annual increments (PAI) and mean annual increments (MAI) in volume

Age (years)		Diameter class (cm) 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	Total	PAI (m^3 ha^{-1})	MAI (m^3 ha^{-1})
10	Volume	0·7	12·3	48·9	68·7	3·6	0·0	0·0	0·0	0·0	0·0	0·0	0·0	134	13·4	13·4
	Basal area	0·2	2·5	7·7	9·5	0·5	0·0	0·0	0·0	0·0	0·0	0·0	0·0	20		
	Stocking	170	528	626	412	14	0	0	0	0	0	0	0	1750		
15	Volume	0·2	6·4	34·3	88·3	145·2	135·4	6·1	0·0	0·0	0·0	0·0	0·0	416	56·4	27·7
	Basal area	0·1	1·1	4·2	9·3	13·8	12·1	0·5	0·0	0·0	0·0	0·0	0·0	41		
	Stocking	44	218	335	381	349	210	7	0	0	0	0	0	1544		
20	Volume	0·1	3·6	22·4	65·1	126·9	184·1	177·7	21·6	0·0	0·0	0·0	0·0	601	37·1	30·1
	Basal area	0·0	0·5	2·4	5·8	10·1	13·7	12·6	1·5	0·0	0·0	0·0	0·0	47		
	Stocking	13	108	189	238	254	231	155	15	0	0	0	0	1203		
25	Volume	0·0	2·1	15·3	48·5	102·5	167·5	216·7	182·0	6·4	0·0	0·0	0·0	741	27·9	29·6
	Basal area	0·0	0·3	1·5	3·9	7·3	11·0	13·4	10·9	0·4	0·0	0·0	0·0	49		
	Stocking	3	59	118	159	182	185	163	100	3	0	0	0	972		
30	Volume	0·0	1·2	10·7	36·7	82·3	143·8	207·3	239·9	131·0	0·0	0·0	0·0	853	22·4	28·4
	Basal area	0·0	0·2	1·0	2·7	5·4	8·6	11·6	12·9	6·8	0·0	0·0	0·0	49		
	Stocking	0	32	78	111	133	144	140	117	50	0	0	0	805		
35	Volume	0·0	0·7	7·6	28·0	66·1	121·4	186·6	243·2	244·2	48·4	0·0	0·0	946	18·6	27·0
	Basal area	0·0	0·1	0·7	2·0	4·0	6·7	9·7	12·0	11·6	2·3	0·0	0·0	49		
	Stocking	0	17	53	80	100	113	117	109	83	14	0	0	686		
40	Volume	0·0	0·4	5·4	21·5	53·3	101·8	163·9	228·7	270·5	180·3	0·0	0·0	1026	15·9	25·6
	Basal area	0·0	0·1	0·5	1·5	3·1	5·3	8·0	10·9	12·0	7·8	0·0	0·0	49		
	Stocking	0	8	36	59	77	89	96	96	85	45	0	0	591		
45	Volume	0·0	0·2	3·8	16·6	43·0	85·2	142·3	208·4	268·2	277·7	50·8	0·0	1096	14·1	24·4
	Basal area	0·0	0·0	0·3	1·1	2·4	4·3	6·6	9·1	11·2	11·3	2·0	0·0	48		
	Stocking	0	4	25	44	59	71	79	82	79	64	10	0	517		

Yield prediction for *Eucalyptus globulus* prepared using data from the 1939 plantation at Stoodley. (From Candy and Goodwin 1986.)


The *Eucalyptus globulus* plantation at Stoodley, aged approximately 40 years. (Bill Neilsen in foreground.)

data from Tasmanian plantations accumulated for the new silvicultural regimes. After some ten years, measurements from trials of a suite of different silvicultural regimes in radiata pine plantations provided adequate Tasmanian data for modified growth models (still based on Steve Candy's original models) which could cover the different treatments such as thinning at different ages. These models, with occasional updating, are in current use.

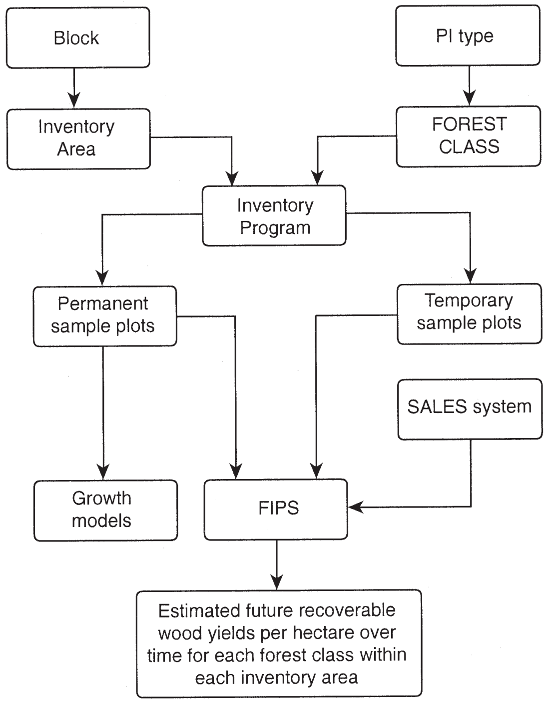
Eucalypt plantations have become an increasingly important resource for Forestry Tasmania. In 1982, a stand yield model was developed for the *E. globulus* plantation established in 1939 at Stoodley in northern Tasmania (Candy and Goodwin 1986) as an indication of how this species could be expected to grow on a good site. The study involved complete analysis of 36 stems and modelling of growth from those data. In the 1990s, as part of the Intensive Forest Management Program flowing from the Forests and Forest Industry Strategy (FFIC 1990), initial growth models for *E. nitens* plantations were developed. The data for these models were from silvicultural regime trials in Tasmania and eucalypt plantation data from other forest growers in New Zealand and mainland Australia (Candy 1997). These models have also been used for *E. globulus* and were updated in 2002 to incorporate the more extensive records of growth measurements that were by then available from the maturing eucalypt plantation resource.

Native forest yield projection systems

For the even-aged eucalypt forests, tree volume equations for the ten common commercial species had been developed by the late 1970s. A stand density index and methods of assigning bark thickness, total height and estimated standing volume per hectare to eucalypts on sample plots in native forest were available by the early 1980s. This information was necessary for the development of simulation systems that projected plot data forward for estimating future growth. Martin Stone wrote the plot projection computer program GROWER, later significantly refined by Adrian Goodwin, which could 'grow on' the average volumes in each forest-type stratum to estimate future volumes. Areas, standing volumes per hectare, operational factors, and cutting strategies were the inputs into this simulation program, which calculated sawlog and pulpwood yields for each ten years of a 200-year period. The growth model at the heart of GROWER was the 1964/1978 Southern Forest yield table (see pp. 35–36). Volumes actually achieved in logging operations were recorded in a computerised compartment analysis system, and analysis of these data improved the area and volume estimates in Working Plans. It also improved the predictions of sustainable yields from GROWER (Van Saane and Gordon 1987).

In 1996, the forest inventory projection system (FIPS) was introduced. This system, based on the models developed for uneven-aged forests, was designed by Adrian Goodwin, Martin Stone and Steve Davis, with assistance from information technology and planning and resources staff. For the first time, Forestry Tasmania could grow on individual plots for long periods and aggregate the grown-on data within forest classes. FIPS was a revolutionary development and marked the time that Forestry Tasmania came of age as a forest modeller. At the time of its development, FIPS was the most powerful tool for estimating future volumes of sawlog and pulpwood by forest class and area in Australia, and it is still at the forefront of the available tools in this field.

FIPS identifies the age classes (cohorts) in a mixed-aged stand (e.g. regrowth from the 1898 and 1934 fires in the Southern Forests), grows on each cohort and then modifies its total growth according to the presence of other cohorts. The idea of concentrating on the main cohorts in the stand has also spread to measurement methods. Assessors now identify cohorts and their specific characteristics rather than recording



A flow diagram outlining the procedure for estimating wood yields per hectare. (From Whiteley 1999.)

general attributes of the overall stand, which was the original method (see p. 13). FIPS contains a collection of modules which utilise measurement data from all inventory systems such as permanent and temporary plots, assigns values for all missing data, calculates plot site index, assigns bark thickness and height to trees if these variables have not been measured, and uses growth models and taper functions to identify trees as they become large enough for processing. Plots can be grown on for specific products which can be made available at specified times. FIPS has been described by Whiteley (1999).

Currently, Forestry Tasmania is developing an advanced version of FIPS which will take account of more specific tree characteristics such as branching, wood quality and timber colour, where this information is collected on plots. This development reflects a general move by Forestry Tasmania and other forest managers towards development of more market-based inventory systems which project tree and log characteristics over time in order to estimate the future volume of trees suitable for sale of specific products.

Calculating Annual Harvestable Yields

Determining the harvestable area

Earlier sections of this chapter have described the development of methods for estimating wood volumes available now and in the future from patches of forest with particular features. However, before a sustainable yield can be calculated, it is necessary to know the exact area of forest for which wood production is the primary or secondary management purpose. Since the formation of the Forestry Department in 1921, there have been many decisions made at National, State, regional and local levels that have discounted the area of State forest which can be harvested due to operational constraints and provision for the conservation of non-wood values.

Operational constraints

Whilst the development of PI-typing provided an effective tool for identifying the most suitable forest areas for wood production, some parts of these areas were unavailable for harvesting due to management priorities for other values and operational factors such as steep slopes, rockiness and difficult burning boundaries.

Early Working Plans took account of such constraints by simply assuming a gross area discount (e.g. 5%) based on the judgement of forest planners. However, such small subjective discounts were increasingly considered by planning staff to be leading to overestimates of sustainable yield. Therefore, considerable effort was directed into obtaining quantitative data so that more reliable discount factors could be applied. Initially, data from inventory plots on factors which limited the area that could be logged were used as a sample of the condition of the forest estate. Then, a systematic grid of sample points across standard topographic maps was applied to each forest area. At each sample point, slope was estimated from map contours and accessibility of the sample point was assessed in relation to rivers, ridges and road systems. This system was used to discount total areas in the assessment of the forest resources on privately owned land conducted in the early 1980s (Forestry Commission 1984).

The next initiative was to map independently the extent and severity of each operational constraint and overlay the maps on those of forest-type stands and patches. Whilst this method had long been discussed, its practicability was only ensured with the development of modern geographic information systems. It was primarily this need that drove the Forestry Commission's procurement of the ARC/INFO GIS in 1985.

Conservation of non-wood values

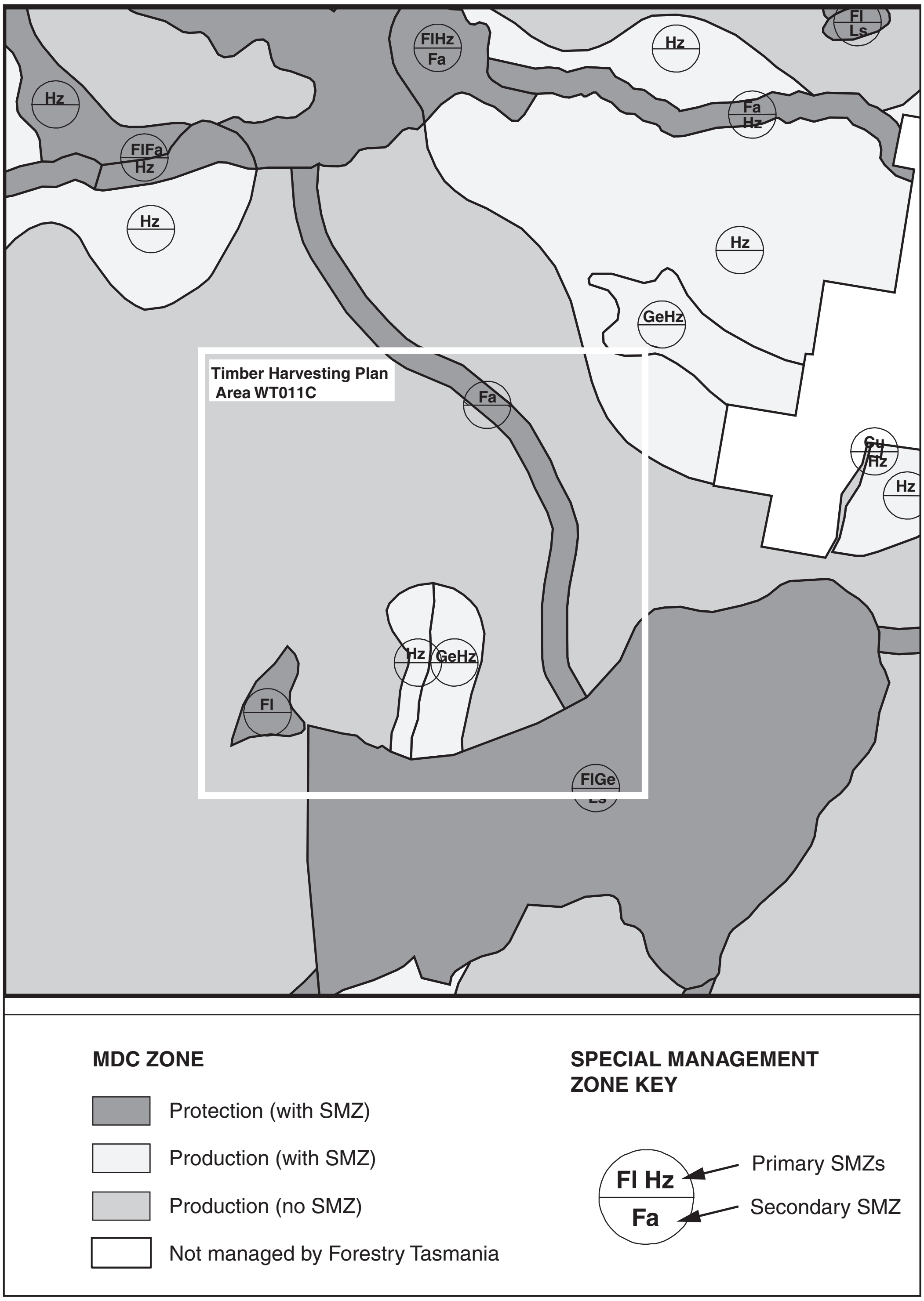
In addition to wood production, Forestry Tasmania must undertake many other functions under Section 7b of the *Forestry Act 1920* — '… optimise the benefits to the public and the State of the non-wood values of the forests'. This requirement results in the need to conserve flora, fauna, water, soil, landforms and cultural heritage, as well as to provide opportunities for recreation. To cater for these values, some areas of State forest are reserved from wood production or managed by specific prescriptions which may give priority to one or more non-wood values, thus limiting wood production activities.

To assist the development of a policy on the management of State forest, in particular the balancing of competing values, the Forestry Commission developed a zoning method known as the management decision classification (MDC) which records decisions made by managers on land use. The MDC process started in 1990 and, by mid 1993, all the land managed by Forestry Tasmania had been mapped according to the system (Orr and Gerrand 1998).

Many of the zoning decisions made under the MDC system are required under other legislation, in particular the *Forest Practices Act 1985*, which requires adherence to measures set out in the Forest Practice Code to protect environmental values. These measures include streamside reserves, wildlife corridors, protection of specific values within some harvesting units (e.g. eagle nests or karst formations) and any other environmental protection prescriptions set out in Forest Practices Plans for individual harvesting units (Forest Practices Board 2000).

The MDC identifies three Primary Zones and 18 Special Management Zones. The Primary Zones define whether the land is to be primarily managed for production or protection, or is to be placed into a temporary conditional zone in which timber harvesting is not allowed until use for the land is reviewed and it is reallocated into one of the two other Primary Zones. The Special Management Zones identify the particular value to be emphasised such as fauna, flora, forest health or cultural heritage.

MDC zones are stored on the GIS, thus enabling integration with other planning systems. For example, the GIS can delineate patches of forests within areas where there are conflicts between resource use and protection objectives, and can produce scaled outputs that can be used to analyse such conflict areas. Additional resource and/or zoning options can be added at any time. The fine resolution of the system enables policy decisions to be translated directly into operational plans for land units such as logging coupes or reserves.



Extract of MDC (Management Decision Classification) mapping from Wielangta State forest on the east coast of Tasmania, showing some Primary and Special Management Zones (for illustrative purposes only). This extract of MDC mapping includes areas requiring management for wildlife habitat strips (Fa), areas prone to landslides (Hz), an historical site (Cu), rainforest areas of particular conservation importance (Fl), areas with high landscape values (Ls) and sandstone outcrops important for geoconservation (Ge). (From Orr and Gerrand 1998.)

Computer mapping of Timber Harvesting Units for strategic wood planning. (Jamie Keene pictured.)

Determining provisional harvesting units

The techniques described above allowed improved estimates of physical accessibility and the proportion of forest intended for wood production. However, sustainable yield calculations were not able to reflect the reality that harvesting takes place within discrete management units (coupes) which are subsequently regenerated to a new forest by sowing or planting. The location of coupe boundaries is significantly affected by topography and the over-riding need for safe burning boundaries. Coupes also commonly contain a mosaic of forest types which are not all at optimal harvest age and condition, and the actual harvest is constrained by the requirement to disperse harvesting impacts in space and time (Forest Practices Board 2000).

Consequently, there was a major effort in the 1990s to derive indicative coupe boundaries for the whole of State forest based on the expert judgement of District planners, taking account of the constraints described above. This process became known as 'couping-up'. The boundaries of these provisional coupes were then recorded on the GIS and used to simulate a further level of operational reality on sustainable yield calculations (Whiteley 1999). Whilst this approach has been commonly used in plantation planning, Forestry Tasmania's application of the methods to native forests is unique in Australian forest management.

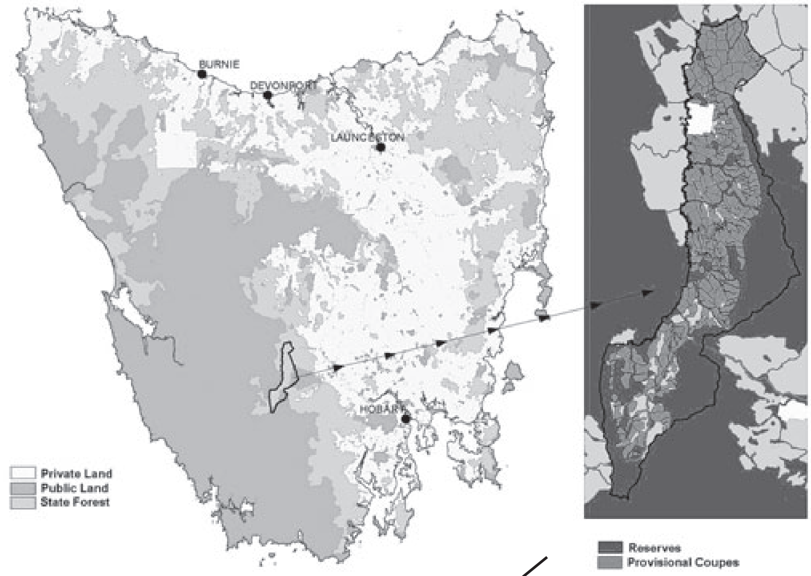
After deducting areas which are zoned as Protected within the MDC system, and areas which fall outside harvestable coupe boundaries, only 54% of multiple-use State forest is currently mapped within indicative coupes. In addition, the difference (area discount) between the area of provisional coupes and the area actually harvested is significant. A recent analysis of harvested coupes in all Districts over four years showed that area discounts ranged from –10% to –27% (M. McLarin, pers. comm.). This is due to the combined impact of unmappable and operational constraints within the indicative coupe boundaries.

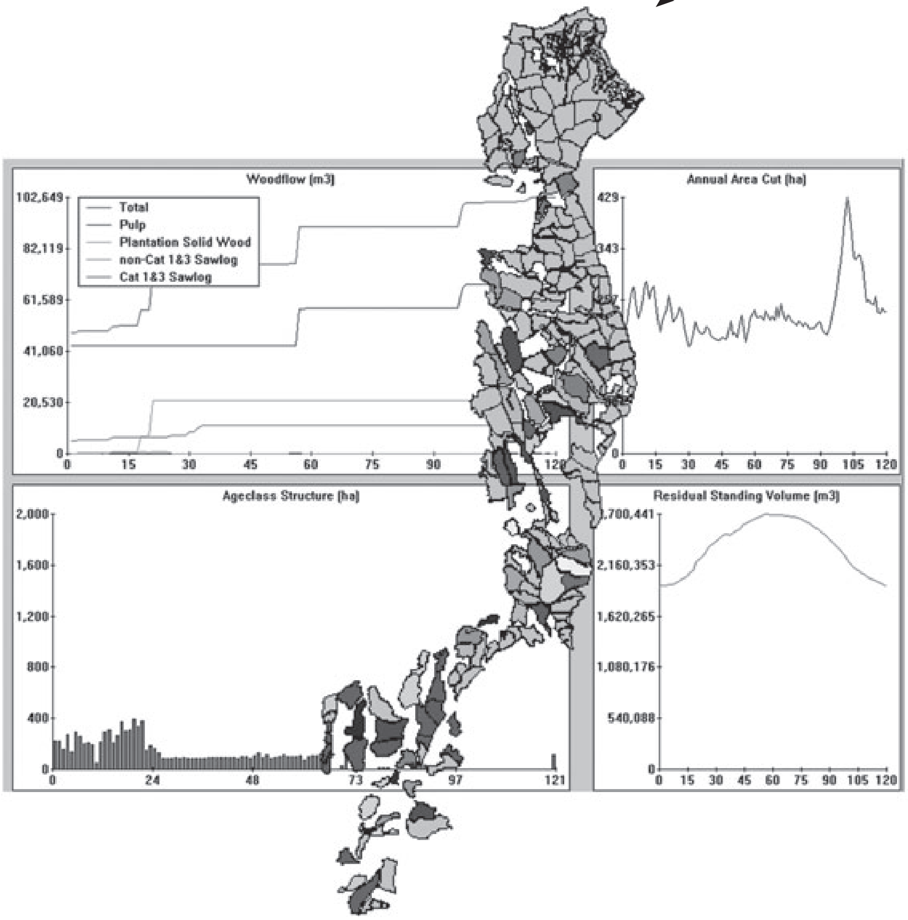
Modelling the yield from the forest estate

The progressive development of the maps, inventory measurements, models and management systems described through this chapter essentially produced the pieces of a complex puzzle. In order to use this information to estimate annual harvest levels or sustainable yields for a large region or the whole of State forest, one further capability was required—estate modelling. This is a process which systematically generates alternative harvest and management options for each forest area, calculates their outcomes, compares them to the overall objectives that had been set, and identifies the best option.

Until the late 1970s, calculations of sustainable yield were based on relatively simple aggregations of standing volume and growth rates, applied to each area of forest type, and then discounted to allow for unharvestable areas. A new era began with the development of computer simulation systems such as Grower (for native forests) and PynGrow (for plantations). These

An example of the output from the GIS and other programs in sustainable yield modelling: the age class structure, projected annual green cut, wood yields and residual volumes for provisional wood production coupes. (From the Division of Forest Management, Forestry Tasmania.)





systems allowed planners to rapidly recalculate the outcomes of alternative harvesting and management strategies, from which the best could be chosen manually after multiple iterations. By the late 1980s, advanced 'linear programming' algorithms had been added to the simulation systems, enabling planners to specify explicit targets and constraints, for which the system then calculated the best solution. This optimisation technology, embodied in systems such as Woodshed, not only automated the search for the best outcome, but also coped with the exponential increase in the volume and complexity of the information on which decisions had to be based.

In recent years, high-quality, purpose-built forest-estate modelling systems have become available commercially. In 2000, Forestry Tasmania began using Remsoft's Spatial Planning System software which has allowed even greater degrees of complexity and realism to be incorporated into strategic planning projects. Of particular note is its ability to reflect constraints, such as the requirements of the Forest Practices Code that adjacent stands may not be harvested in close succession.

Sustainable Yield: A Complex Journey

The principle of managing Tasmania's forests on a sustainable yield basis was clearly stated by Conservator Irby in the report on the Forestry Department's first full year of operation (Forestry Department 1922). Sustainable yield is defined as the level of cut that is sustainable in perpetuity by growth increment of the forest resource (EIS 1985), or the maximum level of the harvest of commercial timber (or product mix) that can be maintained under a given management regime (Forestry Commission 1994c). The developments discussed in the preceding pages in inventory, aerial-photo interpretation, standing-volume assessment, growth modelling and land-use policy have all been directed at achieving the pledge that Irby made, and they illustrate the complexity of the journey.

The biggest barrier to achieving sustainable yield at the time the Forestry Department was formed was the widespread, uncontrolled cutting of the forests. The provisions of the *Forestry Act 1920* were the first steps in dealing with this problem. Implementation of the provisions of the Act continued steadily until the war years, when the sustainable yield policy was suspended for the obvious reason of pressing wartime requirements for timber. However, the Conservator at the time, Sam Steane, noted the importance of still controlling the overcutting so that the period of post-war rehabilitation could be minimised.

> *It is particularly necessary, therefore, to exercise the most careful control possible over the present exploitation in order to reduce to a minimum the period required for such re-habilitation after the war.* [Forestry Department 1942, p. 3]

When the Forestry Commission was formed in 1947, the sustainable yield policy was reinforced as follows:

> *It is essential that forest management be developed along lines leading to sustained yields and permanent rural establishments, with operations proceeding in an orderly, planned manner.* [Forestry Commission 1947, p. 3]

In the following year, the Commission noted in an appendix to the Annual Report entitled 'Forestry in Tasmania':

> *The problem is to ascertain first the remaining virgin forest stand, together with the extent and development of present advanced regeneration stands in the State; and secondly, the real growth rate of the new forests.*
>
> *Only by equating these factors locally, regionally, and for the State as a whole, can a decision be made as to whether the State's timber resources are adequate to carry on the industry until new forests can be produced, or whether it is necessary to carry out*

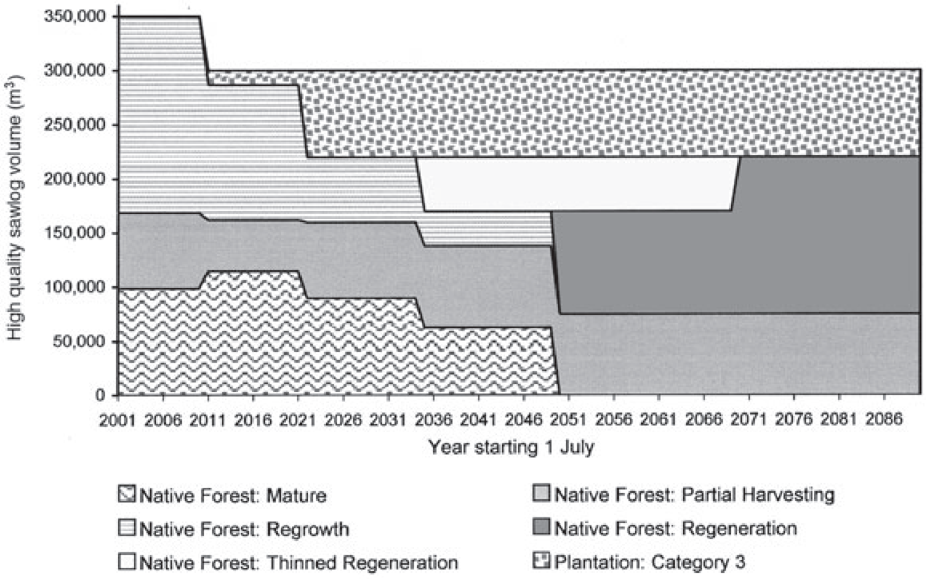
intensive improvement work in the forests to speed up diameter growth and shorten the slow struggle for survival in dense forest stands under natural conditions. [Forestry Commission 1948, p. 19]

Later, as techniques for determining standing timber volumes and modelling growth were developed, very significant adjustments to allowable harvests were required. The Commission's Annual Reports of the late 1940s and 1950s often made reference to the limited supply of Crown logs, with warnings to any sawmillers seeking new cutting rights and existing millers dependent on Crown supplies that mature logs were not available for expansion of the industry. However, the Crown cut increased considerably due mainly to very high demand for timber for housing in the post-war years. This prompted the Commission to express strong concern about future sawlog supplies:

Tasmania, in the last three years, has reached its maximum permissible production. This fact must be faced. This level is a peak and not a valley or mountain-side, and here the Commission must rest until time makes good the deficiencies of the past. [Forestry Commission 1961, p. 4]

Eventually, by the late 1970s, the necessary components to calculate defensible estimates of sustainable yield had reached sufficient maturity to allow the Commission to commence a systematic review of timber harvesting quotas.

In November 1978, the Forestry Commission produced a green paper 'The Sawmilling Industry and the Wesley Vale Concession Area' which drew attention to the severe rate of overcutting at the time and the need for reductions to extend the life of the sawmillling industry in northern Tasmania. Crown sawlog allocations were reduced in the Wesley Vale Concession Area by 30% from January 1980 and by a further 30% from January 1983. In the following year, there were significant further reductions in Crown sawlog allocations in eastern, central and southern Tasmania. The reductions were mainly a reflection of the progress made in inventory, PI-mapping, area discounting and yield modelling. Progressive changes to sustainable yield since then mainly reflect transfers of State forest land to conservation reserves and also improved modelling of wood volumes and forest areas available for harvest.



An example of computer-based modelling showing projected yields of sawlog volumes from different forest types and silvicultural treatments. (From Forestry Tasmania 2005a.)

Though the sawmilling industry accepted the need for the reductions in allowable cuts, there was concern that reductions in the area available for timber harvesting would further reduce log supplies. To provide security of the timber resource, the Tasmanian Parliament legislated a minimum high-quality sawlog production from Crown forests of 317 000 m^3/yr with the passing of the *Forestry Amendment Act 1984*. Following the development of the Forests and Forest Industry Strategy (FFIC 1990), a revised minimum target of 300 000 m^3/yr of high-quality sawlog was set, the reduction in yield to be made up through intensive management of public forests (thinning and plantation development) to improve sawlog yields over time. The Strategy also outlined a commitment to a sustainable veneer and sawlog strategy as a major objective of public forest management, together with conservation of non-wood values. More recently, the Regional Forest Agreement (RFA 1997) and the Tasmanian Community Forest Agreement (TCFA 2005) were major agreements between the State and Commonwealth Governments that confirmed the sustainable yield policy and contained several important conservation initiatives.

Of course, sustainable management of the State's forests today means a lot more than managing the wood supply in perpetuity. The *Forestry Act 1920* requires Forestry Tasmania to optimise the economic returns to the State from wood production and also the non-wood benefits from forest management activities. This requirement necessitates a broadening of the concept of sustainable yield to one of sustainable forest management. The Regional Forest Agreement (RFA 1997) confirmed the importance of the concept of reporting the state of the forests (Tasmania had initiated legislated state-of-the-forests reporting in 1993), and added the

A thinned *Eucalyptus regnans–E.obliqua* regrowth forest in the Arve Valley. Thinning is an important method of intensive management in such forests and was a key plank of the Forests and Forest Industry Strategy.

regular reporting of a range of quantitative and qualitative indicators of sustainable forest management based on the Montreal Criteria and Indicators (Commonwealth of Australia 1998). These indicators covered the essential natural values of forests such as soil, water and biodiversity. Forestry Tasmania's information and technical expertise has enabled them to be reported for the whole of Tasmania's State forests. From 2001, the organisation has published an annual Sustainable Forest Management Report which details performance in many areas of State forest management against objectives outlined in the organisation's Environmental Management System (Forestry Tasmania 2004a). The significant developments described in this chapter have enabled efficient assemblage of the data required each year for this detailed report.

Llewellyn Irby enunciated a vision which has been shared by many others who came later and who continue to explore the pathway to sustainable management of forests in Tasmania. The journey will continue indefinitely as extra knowledge becomes available, and in response to changes in circumstances, environments and objectives, particularly the dynamics of community opinion on forest use. Many of the stages seen so far have been the result of research and development at Forestry Tasmania; some came from external advancements in technology, with the development of air photo-interpretation and affordable and effective computer technology being paramount.

The sustainable yield for State forests in Tasmania is the product of the inputs discussed in this chapter: a matrix of available forest area, stratification and mapping, tree volumes, increment data, taper models and growth models. Sustainable yields are currently available for the native eucalypt forests, plantations, and for the blackwood swamps. In addition, there are also broad estimates for other resources such as red myrtle and Huon pine.

Examples of the *Sustainable Forest Management Report*, published by Forestry Tasmania each year since 2001. The report provides detailed information on the management of wood and non-wood values.

Chapter 2

Silviculture of Native Eucalypt Forests

Introduction

It took over 100 years following European settlement before significant areas of forest were protected from exploitation and set aside so they could be managed for ongoing timber production. Maintenance of the resource depended on continuing protection from bushfires. Prior to the formation of the Forestry Department, there were some silvicultural[1] treatments applied to small areas of eucalypt forest. These treatments consisted mainly of thinning, cleaning (a treatment to reduce competition and improve access) and coppicing of cut stems. For example, in 1899, the Chief Forest Officer, Mr Compton Penny, made the following recommendations to the Secretary of the Lands and Surveys Department, Mr Counsel, on the management of young eucalypt regrowth on a short coppice rotation:

> *There are in many places some fine belts of sapling timber that have sprung up on land from which the matured trees have years since been removed. These young forests should be preserved for future timber supply. If this class of timber is allowed to be utilised for this purpose, the trees should be cut at not less than three or four feet from the ground. In the course of five or six years they will have grown up from the stumps, and be again available for cutting.* [Lands and Surveys Department 1899, p. 22]

Tasmania's extensive eucalypt forests have always been the principal resource for the forest industry. Once the Forestry Department was formed in 1921, it assumed management responsibility for the large areas of native forest that were progressively dedicated as State forest. Since then, the silviculture of the eucalypts has been the major focus of research in native forests by the Forestry Department and its successors, the Forestry Commission and Forestry Tasmania.

Progress in understanding the silvicultural requirements of the eucalypt forests was initially slow, although the requirement for operational treatments was clearly recognised. In the mid 1930s, the Conservator of Forests, Sam Steane, emphasised the urgent need to proceed with

[1] Silviculture: the science of growing and tending forests.

cleaning and thinning treatments in spite of the lack of silvicultural knowledge:

> *Sylvicultural treatment of the eucalypts is still in its infancy, and the requirements of the various species, in matters of detail have still to be determined. At the same time there is an enormous amount of obviously urgent work crying out to be done. Over thousands of acres of regrowth the competition due to crowding is so keen that growth is already being seriously retarded, and the young trees are losing their vigour and their power to respond to treatment. We may not know, as yet, the precise density most suitable to each diameter class in any given circumstances, but the cleaning and thinning of these obviously overcrowded crops need not be delayed on that account. If the work is not done in the very near future, many hundreds of acres of splendid regrowth will be wasted, because it will be impossible to bring it to maturity in time to ensure the desired continuity of supply.*
>
> *There are many sylvicultural problems requiring study, but this fact need not delay urgent practical work. Really intensive sylviculture must wait until the more important forests, at least, have been brought under systematic treatment. In matters of detail, sylviculture must feel its way pending the results of experience, and working plan prescriptions must be sufficiently elastic to permit this.* [Steane 1935, pp. 40–41]

A scrubbed and thinned area in the Lefroy State Forest, north-eastern Tasmania, in the early 1920s.

A Forestry Department initiative during the 1930s, which no doubt improved the quality of future harvests, was the exercising of more control over which stems were harvested within each forest area. As Steane (1947, p. 24) notes:

> *A system of tree marking was introduced, where suitable field staff was available, providing for the selection and marking of trees by a forest officer, before felling. At first this met with strong opposition from sawmillers but they quickly came to accept it - finding that it did not work to their serious disadvantage. Previously the selection of trees for felling had been left to the sawmiller's bushmen who, naturally, took all the best trees and left any they considered not sufficiently profitable.*

Unfortunately, suitable field staff were rarely available so that tree marking was only practised on a small scale.

From the 1940s, silvicultural investigations in the eucalypt forests accelerated rapidly. The major driver for increased knowledge was the move from selective logging for sawlogs to integrated logging of sawlogs and pulpwood, the latter product being harvested to supply the

Inspecting blue gum regrowth at Strathblane, southern Tasmania, in 1925, using the Department's first car, a T-model Ford christened Waltzing Matilda.

paper mills at Burnie and Boyer. This large-scale, more intensive harvesting required new information in order to determine the best methods for cost-effective harvesting and regeneration operations. Thus, it was in this era that the first detailed research trials of eucalypt silviculture were initiated.

The results from specific research trials have played a very important role in advancing the way eucalypt forests are managed. However, the experience gained from harvesting and regeneration operations conducted in the normal course of supplying wood products to industry has also been a vital component of our knowledge of eucalypt silviculture. There is a long history of strong co-operation between operational staff in the forest Districts and researchers in developing the silvicultural treatments for eucalypt forests. The results of this co-operation are comprehensively documented in the form of operational prescriptions and ecological information in extension literature; in particular, in the series of technical bulletins dealing with eucalypt silviculture in native forests.

This chapter documents the history of development of silvicultural methods for the main types of commercial eucalypt forests, from the early exclusive use of natural regeneration to the wide range of regimes, often modelled on responses to natural disturbances, now used to manage different forest types.

Natural Regeneration

In the early years of the Forestry Department, establishing the area and commercial potential of the forest types to be managed was the primary task and there was limited attention given to eucalypt ecology and regeneration processes. There were some early operational trials of silvicultural treatments at Brickmakers forest in the north-west. In these trials, trees burnt by wildfire were ring-barked to encourage a heavy seed crop before they died, and younger, burnt *Eucalyptus obliqua* were coppiced, with subsequent thinning of the dense coppice shoots to keep only the most vigorous on each tree. Coppicing of *E. obliqua* burnt by wildfire was also carried out at Pioneer in north-eastern Tasmania (Forestry Department 1933, 1934). But references to regeneration in the early reports of the Department tended to concentrate on observations of the ability of eucalypt stands

A series of thirteen Native Forest Silviculture Technical Bulletins has been published covering operational prescriptions and ecological information on commercial native forests, mainly eucalypt types. Most of the authors, or main compilers, of the Bulletins gathered in 1999 to celebrate the achievement. (From left: Tony Mount, Eric Lockett, Neil McCormick, Gary Brown, Mark Neyland, Leigh Edwards, Lindsay Wilson, Graham Wilkinson, Sue Jennings and John Hickey.)

to regenerate naturally after the intense fires which commonly followed selective logging. In the early 1930s, the regeneration of cut-over hardwood stands was summarised thus:

> *Speaking generally, the native timber species reproduce themselves very successfully but far too frequently the young crop is either destroyed or hopelessly damaged by fire within a few years of becoming established. Given suitable protection there should be no difficulty in obtaining natural reproduction. The light demanding nature of the eucalypts will render concentrated fellings possible and this conclusion is supported by observation of the tendency of these species to reproduce themselves over considerable areas in even-aged crops.* [Forestry Department 1932, p. 4]

As indicated in this statement, the early confidence for obtaining natural regeneration no doubt arose from observations of vigorous regeneration following the frequent wildfires that occurred across the State. Good regeneration also often resulted from burning conducted before logging to improve access, and after logging to reduce the fire hazard from logging slash. However, the importance of obtaining the coincidence of a receptive seedbed and seed source was probably not fully appreciated at the time (see pp. 63–65).

Natural regeneration continued to be relied upon into the 1940s, with protection from fire still seen to be the limiting factor:

> *The natural regeneration of the eucalypt forests on both cut-over and burnt areas is largely a matter of adequate fire protection.* [Forestry Department 1942, p. 5]

Even when the Forestry Commission assumed office on 15 April 1947, natural regeneration was seen as the means of perpetuating eucalypt forests rather than the use of any silvicultural treatments. However, the need for the latter was flagged by the Chief Commissioner, Alec Crane, in the first Annual Report of the Forestry Commission:

> *Natural regeneration is relied on for the restoration of cut-over areas and in general satisfactory to excellent results are reported. … Regeneration results, however, vary sufficiently to indicate the need for close study of the problem to ascertain the important controlling factors and indeed to establish the best technique for treating hardwood forests as well as establishing plantations.* [Forestry Commission 1947, p. 7]

In the following year, the regeneration of hardwood forests, still using natural regeneration but with a deliberate silvicultural system (seed-tree retention), was addressed by the Commission in more detail:

> *The restoration of the mature eucalypt forest by natural regeneration is a practicable and indeed the only economic method in view of the satisfactory results obtained. It involves the reservation of adequate seed trees, the disposal of logging debris by safe burning, and for the best results the complete*

Natural regeneration of *Eucalyptus obliqua*, aged seven years, after a fire in 1943 along the Marrawah Road in north-western Tasmania.

utilisation of overmature trees. A problem arises where brush undergrowth or rain forest understory share the area with the eucalypts.

To restock such areas with eucalypts, the brush or rain forest must be destroyed at a time when eucalypt seed trees are available. It is, of course, first essential to harvest every merchantable tree in the rain forest understory. There appears to be no doubt, however, that the best possible use of narrow fringing strips of land carrying rain forest is their regeneration to eucalypt except where such a strip or a creek or road may have local scenic or recreational use. [Forestry Commission 1948, p. 10]

Later, the Chief Commissioner directly addressed the need for research into eucalypt silviculture, emphasising the importance of developing silvicultural treatments to achieve good regeneration (Forestry Commission 1950, p. 10):

Silvicultural practice in Tasmanian eucalypt forests must continue to be limited to extensive measures aiming at adequate regeneration of cut-over stands until the information can be obtained which will justify more intensive silvicultural treatment.

The discovery of these facts depends on patient research which, because of the many years necessary for forest crops to reach maturity must extend over a long period.

The scope of silvicultural research has been widened during the past two years by the provision of additional technical assistance. More will be needed, but must await the recruitment of trained staff.

The main lines of research at present being undertaken have as objects the determination of:

1. *The effects of differing ground cover (e.g. the existence of ferns and scrub species in wet areas, or an understory of myrtle and sassafras) on the regeneration of cut-over eucalypt forests;*
2. *The rates of growth of eucalypt regeneration on sites of various qualities;*
3. *The results of thinning such stands and the spacing to be adopted to give best results; and*
4. *The rate of growth of virgin stands, and the effects of trade cutting on the rate of growth of residual trees.*

Eucalyptus obliqua regrowth originating from seed falling from trees left after logging and burning at Togari block in the north-west. The area was treated in 1960/61; the photograph is from 1968. (Wes Beckett pictured.)

These statements foreshadowed an era of rapid expansion of research into the ecology and regeneration mechanisms of eucalypts, particularly in the wet forests, by Forestry Commission staff.

Developing Regeneration Treatments for Wet Eucalypt Forests

Prior to the start of harvesting operations by Associated Pulp and Paper Mills in the north-west in 1938 and Australian Newsprint Mills in the Florentine, Styx and Tyenna Valleys in southern Tasmania in 1941, selective logging was practised in Tasmania's wet eucalypt forests and specific regeneration treatments were not usually applied. Although successful establishment of a new forest depended on the coincidence of a receptive seedbed, the presence of mature seed on the remaining trees or in logging slash, and adequate light and moisture, this combination of factors did not always occur. Thus, suitable conditions for regeneration establishment were more accidental than deliberate. Fire used by loggers was not usually directed at obtaining regeneration, though it often created a receptive seedbed and enabled good regeneration to establish. Observations of abundant regeneration after wildfires, such as the 1934 fires in Tasmania and the 1939 fires in Victoria, and where fire had been used in the cut-over areas, were often noted in reports, but a better understanding of the ecological requirements for successful regeneration was needed.

> *Generally, natural regeneration is abundant, but certain lags in time and some degree of missing or capture of the site by wattle or brush are not understood and some research is necessary to establish the best technique of handling cut-over forests, particularly in the highest quality sites. It is true that the highest quality forest presents the greatest problems in good management.* [Forestry Commission 1948, p. 18]

The Florentine Valley from the slopes of Lanes Peak looking west, 1993. The Thumbs is in the background (far left) and the Tiger Range is the long, low range directly across the valley. This valley formed part of the Australian Newsprint Mills Concession Area and its highly productive eucalypt forest has been a major resource for the Boyer Newsprint Mill since the 1940s.

These 'highest quality forests' have a dense wet sclerophyll or rainforest understorey which severely reduces any available seedbed, even when a seed source is present. The issue was summarised very clearly in the organisation's Annual Report:

> *The problem of the regeneration of eucalypt in the forests of the higher rainfall zones in Tasmania, where there is a dense understorey of myrtle, sassafras, and associated tree species, is becoming more acute as logging is pushed steadily westward into the wetter regions now being made accessible by the development of logging roads. It is one that directly concerns not only the Commission in stands such as those in the Arve Valley; Australian Newsprint Mills Ltd. are affected also in parts of the Company's concession areas in the Derwent and Florentine Valleys. Briefly, the problem is how best to secure a second crop of eucalypt after virgin stands of eucalypts are felled, leaving behind a dense growth of partly merchantable, but mainly useless, rain forest and scrub.* [Forestry Commission 1955, p. 8]

Typical wet sclerophyll forest in the Florentine Valley, with *Eucalyptus regnans* over a dense understorey of musk (*Olearia argophylla*).

The Gilbert and Cunningham years

The first significant experiments aimed at determining how to regenerate wet eucalypt forest in Tasmania were conducted in the 1950s. Importantly, there was a foundation for the trials: the observations of many foresters which provided a valuable background on the general ecology of the forests and their reactions to natural occurrences, particularly fire, and human interference. One such observation was that roading of wet forests usually produced a screen of excellent regeneration along the roadsides where disturbance had created a seedbed. However, this regeneration, derisively called 'Director's regrowth', screened many unregenerated, logged areas (A.B. Mount, pers. comm.).

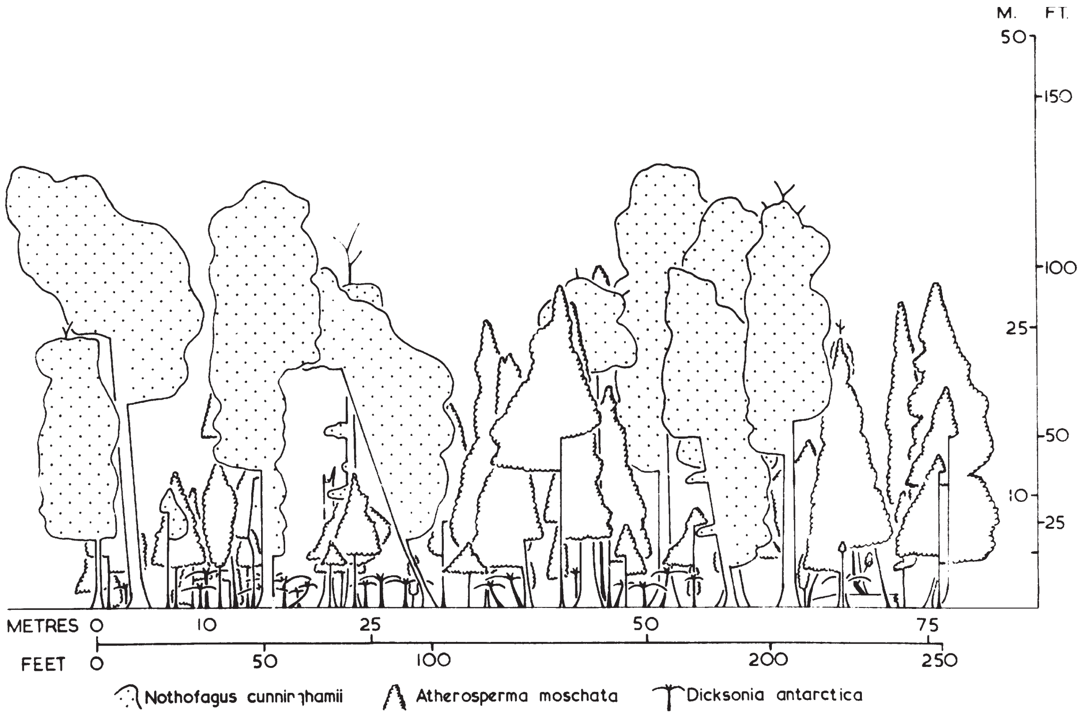
The years 1954–55 marked a turning point in the history of forestry research in Tasmania for it was then that Max Gilbert and Murray Cunningham were both awarded Ph.D. fellowships to study wet eucalypt ecology and management. Both Max and Murray had a great love of the bush and were keen observers of the dynamics of eucalypt forests. They also had a strong desire to unravel the complexity of the processes involved in forest regeneration.

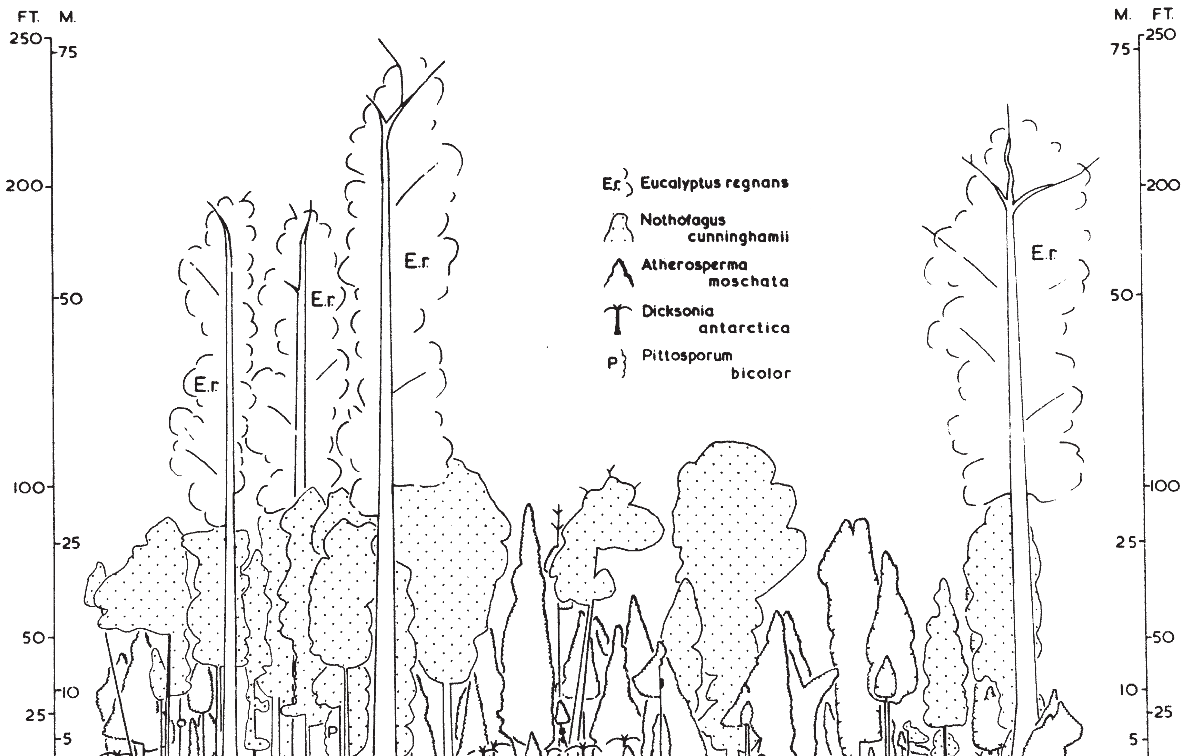
Max had been with the Forestry Department and Commission for some twenty years working on silviculture and fire management when he received the first Australian Newsprint Mills Fellowship to be awarded. It was to study regeneration of wet eucalypt forests in the company's forest concession areas, particularly the Florentine, Styx and Tyenna Valleys. Murray, who had been working with the Forestry Commission since his graduation in 1949, received a research fellowship from Australian Paper Manufacturers and went to Victoria to study at the

University of Melbourne, using study sites in Victorian wet eucalypt forests. The research studies of Max and Murray were complementary as Max's had an ecological emphasis and Murray's a silvicultural emphasis. And so silvicultural investigations began to accelerate in what was the beginning, for the Forestry Commission, of a golden era of research into the regeneration of wet eucalypt forest.

Max Gilbert's post-graduate studies, the first Ph.D. on forest ecology awarded in Tasmania, were a landmark event in the history of ecological research generally, and particularly in forest ecological research in Tasmania. Max made a detailed analysis of the geology, climate, forest types and role of fire in the mixed eucalypt–temperate rainforests of the Florentine Valley. He concluded that the ecological processes

A typical example of tall mixed forest (eucalypts over a rainforest understorey) at Lady Binney Corner on the Florentine Road, 1950. Governors and other dignitaries were often taken to the Florentine Valley to see tall trees and forest operations, and this site was named after the wife of Sir Thomas Hugh Binney, Governor of Tasmania from 1945 to 1951.



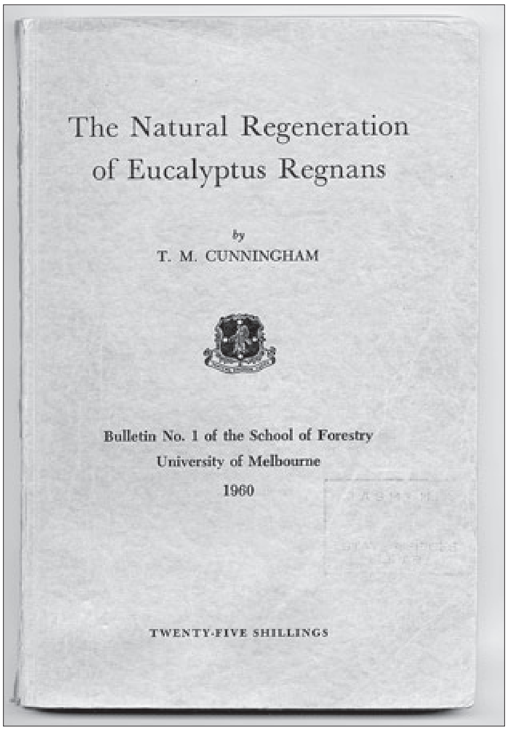


Top: Profile of *Nothofagus*-dominated rainforest. Below: Profile of mixed forest (*Eucalyptus*-dominated wet sclerophyll forest with a rainforest understorey). (From Gilbert 1958.)

operating there were best explained by the traditional 'succession and climax' theory first mooted by Clements (1916) and later modified by others to the 'fire climax' theory, where fire was a re-occurring event. In the mixed forests of the Florentine valley, the hypothesis was that fire is the major factor preventing the general attainment of climax vegetation (temperate rainforest). His story of succession in these wet, mixed forests on soils of moderate to high fertility is summarised from his much quoted Royal Society of Tasmania paper (Gilbert 1959):

- If an area of mixed forest (eucalypt forest with a rainforest understorey) remains unburnt for 350–400 years (the life span of the main eucalypt species) then the climax condition (rainforest) is achieved.
- If an area is burnt infrequently, but with an interval of less than 350 years, it remains under mixed forest. The forest is destroyed by each fire but the species present in the fully developed mixed forest regenerate immediately after the fire.
- With a fire frequency of once or twice per century, mixed forest is replaced by eucalypt forest with a broad-leafed understorey characterised by *Pomaderris*, *Olearia* and *Acacia* instead of climax rainforest species.
- Still more frequent fires, perhaps at 10–20-year intervals, will not only prevent eucalypt forest progressing to mixed forest but will maintain *E. obliqua* and *E. delegatensis* at the expense of the much more fire sensitive *E. regnans*.
- There is evidence that very frequent fires were responsible in the past for the maintenance of savannah-like conditions in the middle Florentine until perhaps 100–200 years ago.

Murray's Ph.D. studies greatly advanced the understanding of the silviculture and management of *E. regnans* forests. From 1955 to 1958, he worked on the problem of the failure of *E. regnans* to regenerate satisfactorily after logging in some situations in Victoria.



Murray Cunningham's important work on the silviculture of *Eucalyptus regnans,* based on his Ph.D. studies.

An initial inspection of stands aged 50–200 years showed that many areas which had been virtually clearfelled with scattered cull trees left as seed trees were understocked even after 7–10 years and that other areas had a delay of 5–10 years before achieving adequate stocking.

Murray's work during these three years centred on studies of the factors controlling the establishment of seedling regeneration. These factors included seed development, seedfall and the fate of dispersed seed, seed germination and seedling survival, and seedbed preparation. His work also involved determining a stocking standard for regenerated forests, and testing a partial cutting system. Key results of his studies (summarised from Cunningham 1960) are given below.

- *Eucalyptus regnans* seed matured one year after flowering and was shed during the second and third years, with a peak seedfall in late summer and autumn.

Murray Cunningham at a trial site in Victoria during his Ph.D. studies. The trial was established to monitor revegetation after tractor logging.

- Eighty per cent of the shed seed could be removed by seed-harvesting insects.
- Approximately 75% of the seed which germinated did so in late autumn, and very little of the seed shed in summer and autumn remained viable until spring.
- The spring peak of germination which occurred resulted largely from seed shed in winter and spring, or from felled heads.
- Mineral soil needs to be exposed if seedlings are to establish. Approximately 10% of seed sown on mineral soil seedbeds can be expected to germinate to the cotyledon stage and this can be doubled if insects are controlled by spraying with insecticide.
- Artificial seeding could be used and the seed-harvesting insect problem reduced by mixing the seed with an insecticidal dust such as DDT (dichloro-diphenyl-trichloroethane).
- Browsing by native animals is a significant cause of seedling deaths in some areas.
- 30% milacre[2] stocking was used as the minimum requirement for adequate regeneration. To obtain 30% stocking on areas where 50% of the area has a suitable seedbed, between 200 000 and 400 000 viable seeds would be needed per acre. (By comparison, modern silvicultural practices routinely achieve adequate stocking with applications of less than 60 000 seeds per hectare, equivalent to 24 000 seeds per acre).
- Improved regeneration could be achieved by preparing a seedbed before logging and using seed shed before logging or seed from felled heads.
- Approximately two years after logging, an estimate of the regeneration should be made based on a quantitative assessment of established and new seedlings, the receptive seedbed and the remaining seed sources. Following this assessment, any need for remedial treatments should be determined.
- Before logging commences, the stand should be examined in the light of current knowledge of regeneration requirements.

[2] 1 milacre = 0.001 acre = 4.047 m^2 (about 4 m^2).

Tall *Eucalyptus regnans* seed trees left after tractor logging in the Florentine Valley in the early 1960s. Seed trees in the foreground were scheduled to be logged after the eucalypt regeneration was established. Mount Field West is in the background.

When Murray Cunningham returned to the Forestry Commission in Tasmania in 1958, his findings, combined with those of Max Gilbert, laid the basis for developing the operational techniques for harvesting and regeneration of wet eucalypt forests. These techniques essentially concentrated on preparing a mineral soil seedbed and ensuring an adequate seed supply. There were initial attempts using small coupes that were given a post-logging slash burn, relying on seedfall from adjoining mature trees for regeneration. However, after some initial success, these small coupes were not successful because of variable seedfall and loss of seedlings resulting from rapid build-up of native mammal browsers. A Legislative Council Select Committee appointed at the time reported that previous regeneration of the wet forests with dense understoreys had not been adequate and that recent research findings should immediately be implemented to pursue a vigorous policy to establish regeneration (Select Committee 1959).

In 1959, based on observations of natural regeneration and the work of Gilbert and Cunningham, the Forestry Commission and Australian Newsprint Mills (ANM) adopted a two-stage (seed-tree) logging system for obtaining regeneration in the wet forests of southern Tasmania. This system was described by Don Frankcombe, the Logging Manager for ANM (Frankcombe 1961):

- All merchantable understorey trees logged;
- About five dominant, well-spaced eucalypts per acre marked for retention as seed trees in coupes of 20–50 acres (8–20 ha);
- Unmarked eucalypts felled and removed;
- Slash burnt when the seed trees were found to carry an adequate seed crop;
- Browsing animals poisoned or trapped while the seedling regeneration was vulnerable;
- Seed trees removed when adequate regeneration had become established.

An aerial view of well-stocked eucalypt regeneration, c. 30 years old, in the Australian Newsprint Mills Concession Area. White stags above the regenerated forest are the remains of seed trees left when the area was logged in the 1960s.

This move to an operational scale was also recorded in the Forestry Commission's Annual Report of 1959–60:

> *Research into the regeneration of eucalypts in the difficult and complex wet, mixed rain forest-eucalypt types, has proceeded from as it were, the laboratory scale, to extensive field trials involving hundreds of acres.* [Forestry Commission 1960, p. 5]

Later, the successful application of the two-stage logging system, in which seed trees were removed once regeneration established, was noted:

> *Studies have shown that in cutting virgin forests, provided good regeneration is obtained following treatment after the first cut, logging of five mature trees per acre, yielding 20,000 super feet, may be carried out by normal methods without excessive damage to the regeneration. The final cut needs to be made as soon as possible after successful regeneration while the seedlings are still small.* [Forestry Commission 1963, p. 10]

The seed-tree system produced some excellent stands of regeneration, but there were operational problems with the use of retained trees as a natural seed source. The cost of salvage logging the retained seed trees after regeneration had established was high, and they posed an additional fire hazard during the regeneration establishment burn (which usually killed them) and afterwards as dead stag trees above the new forest (Korven-Korpinen and White 1972). Also, the system was not very flexible because there was often a long interval between good seed crops; the need to delay the burning of slash until a good crop was present resulted in fuel deterioration, poor burns and consequently a poor seedbed.

Improved silvicultural techniques for wet forests were gradually developed during the 1960s through the operational experience gained by ANM and the Forestry Commission, and by research conducted at the Maydena Station. Another Legislative Council Select Committee

The presentation to the inaugural winners of the Gilbert–Cunningham trophy for excellence in growing native forests, presented in December 2004. From left: Michael Mahoney, Nigel Foss, Geoff Morris, Heath Ralston, Mike Farrow (all from Murchison District), Dr Max Gilbert and Dr Hans Drielsma; Phyl Cunningham is in front. Inset: Murray Cunningham, 1986.

established to examine forest regeneration reported that 'a well planned programme of continuous regeneration and restocking of newly harvested areas in addition to the old forests' was occurring (Select Committee 1972).

In recognition of their work, Max Gilbert and Murray Cunningham were awarded the N.W. Jolly Medal in 1973 and 1985 respectively, the highest honour bestowed by the Institute of Foresters of Australia. The award citation reads: 'Awarded as the Institute's highest and most prestigious honour for outstanding service to the profession of forestry in Australia' (www.forestry.org.au/ifa). In 2005, the Perpetual Gilbert–Cunningham trophy was introduced in Forestry Tasmania. This trophy is awarded each year for excellence in growing native forests, and it recognises the key roles that Max Gilbert and Murray Cunningham played in developing a solid silvicultural foundation for sustainable forest management in Tasmania (*Branchline* 2005).

The Maydena Station

In 1954, a Forestry Commission research station was set up at Maydena to study aspects of the wet forests of the ANM Concession, including evaluation of the vigour of regeneration, regeneration survey techniques, and sowing methods. The first Officer-in-Charge at the Station was Robin Levingston, who was appointed to do regeneration surveys of all clearfelled areas. These surveys showed that only the burnt or lightly disturbed sites had seedlings, and remeasurements showed that the numbers were declining each year. Robin was followed by Tony Mount, Kurt Cremer (Kurt initially had an ANM Research Fellowship and was then on the staff of the Station) and Ken Felton. Eric Lockett and then Dick Chuter were in charge of the Station in its latter years. The activities of the Maydena Station are legendary in Forestry Tasmania, not just for the huge contribution of its staff to the understanding of eucalypt ecology and incorporation of this

Dick Chuter (left) and Ken Felton, two of the staff at the Maydena Station who worked on developing techniques for regenerating wet eucalypt forests.

knowledge into silvicultural practice, but also for their involvement over many years in the social activities of the small Maydena community.

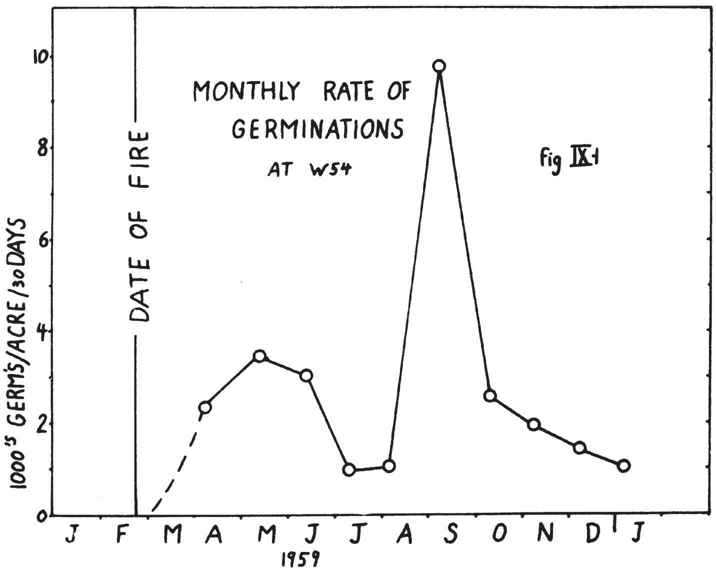
Tony and Kurt worked at the Maydena Station in the late 1950s and early 1960s. Their combined talents resulted in a greatly increased understanding of the dynamics of the wet forests of the ANM Concession. An important joint project during this period was a pioneer study of plant succession following logging and burning. It recorded the recolonisation of burnt ground in the Florentine Valley, initially by mosses and liverworts, and then by taller vegetation, successively dominated by fireweeds, ferns and woody perennials (Cremer and Mount 1965).

Kurt's principal contributions (summarised from Cremer 1962) were in the following areas:

- The importance of fire and prolonged dry weather in promoting abscission of capsules and consequent seed shed. He provided detailed explanations of physiological and morphological aspects of seed shedding.
- The importance of basing the timing of the regeneration establishment burn on a previous assessment of the seed crop. Techniques were developed for assessment of seed crops through flowering surveys and mapping of flowering trees.
- The use of fire for regeneration and its effect on retained seed trees.
- The pattern of germination and the timing of regeneration assessments.
- The impact of browsing on the height growth of seedlings and the animals responsible. He also studied the effects of timing (season) on the ability of young eucalypts to recover from cutting or defoliation (Cremer 1965).
- Determining the quantity of seed required to achieve a satisfactory stocking of seedlings and the best time of year for artificial sowings.
- Pelleting of eucalypt seed for broadcast sowing, including experiments with different insecticides, fungicides and pellet materials.

Tony Mount's research studies at the Maydena Station were more ecologically focussed, providing further insights into the general ecology of the wet forests of southern Tasmania. They also covered important aspects of forest management, including the use of fire, sowing, and assessment of regeneration. Some of his main findings and hypotheses (summarised from Mount 1964) were:

- In the absence of logging, each vegetation type is related to a definite but different range of fire frequencies and develops fuel that will allow fires to burn it in suitable conditions when an ignition source is present. The vegetation and its litter largely control how the fire burns. Fuel produced by the vegetation determines the success of fires that occur.
- In the natural eucalypt forests, regeneration occurs only after fire except for a few individuals of a very few species. No eucalypt

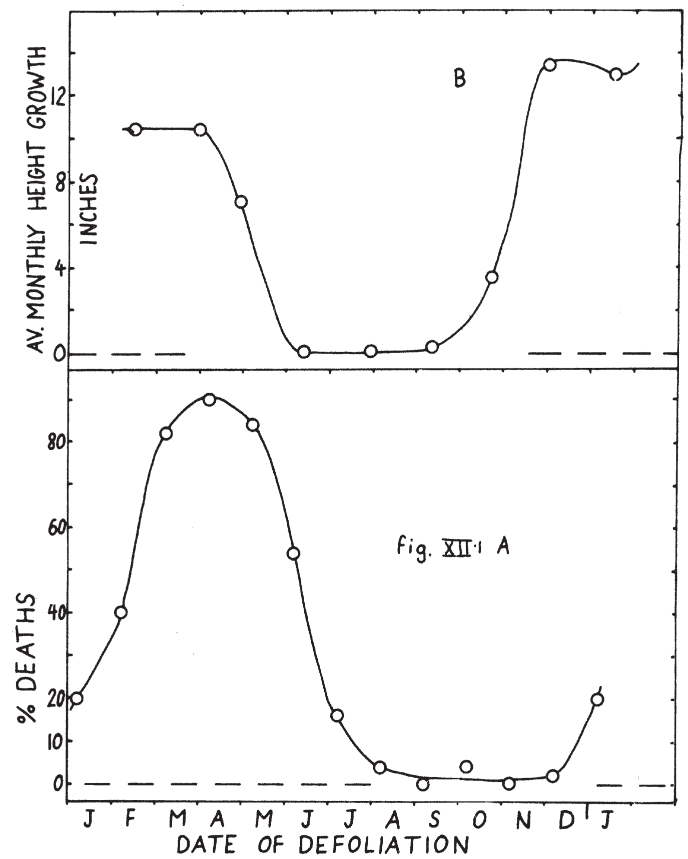


The results of studies of germination of *Eucalyptus regnans* under live seed trees following burning of a logged coupe in the Florentine Valley. These and other studies by staff at the Maydena Station in the 1950s and 1960s were used to evaluate the effectiveness of a two-stage logging method (seed trees left after logging and then removed when regeneration established). (From Cremer 1962.)

regeneration occurs under old wet sclerophyll forest, which appears to have developed a pre-disposition to a fire frequency intermediate between those of dry sclerophyll forest and rainforest. Fires in the areas studied have occurred sufficiently regularly over the last 5000 years to prevent the species now present from dying out between fires but not too often to destroy them.

- The association of vegetation, site and fire frequency is the most reasonable explanation for the phenomena of 'islands of eucalypts in the rainforest'; they are stable types perpetuated by their particular site and burning history.
- Regeneration survey techniques were developed for established regenerated areas and for newly sown areas (see later section: 'Developing Stocking Standards').
- Surveys of all wet forest coupes logged by ANM showed that, just as had been discovered for unlogged wet forests, there was little effective regeneration without fire.

Professor Bill Jackson from the University of Tasmania was Tony Mount's supervisor during his M.Sc. studies. Bill made major contributions to the understanding of vegetation patterns and forest dynamics (e.g. Jackson 1968) and inspired many botany/ecology students and researchers. Tony and Bill both had an intense interest in the ecology of the major vegetation types in Tasmania and each developed theories to explain the distribution and dynamics of these types. These became known as the Mount and Jackson theories and were hotly debated for many years. In summary, both researchers recognised the central role of fire acting in concert with climate and soils in the determination of vegetation type. Bill believed that vegetation succession occurred in the landscape and was related to the frequency of fire. Chance long or short intervals between fires in a particular vegetation type altered the successional pathways and could result in a change in the nature of the vegetation at a site (ecological drift). Tony differed from Bill Jackson in that he believed each vegetation type largely determined its own fire frequency



Studies of the effect of artificial defoliation (to simulate browsing) imposed at different times of the year on the death rate of small *Eucalyptus regnans* seedlings within one year of treatment (bottom graph). The top graph shows the normal pattern of growth of *E. regnans* in the Florentine Valley. These studies demonstrated the greater sensitivity to browsing in autumn when a tree's food reserves were low after the growing season. (From Cremer 1962.)

by the rate of accumulation and character of the forest fuels, and that the areas of vegetation types were essentially static in the landscape, like replacing like after fire.

The difference between these two theories related mainly to the differing views on the pattern of succession from one forest type to another. Bill Jackson believed that rainforest was the stable end point or climax of successional stages, which was reached when the interval between fires became long enough. Tony Mount believed in a system of fire cycles related to fuel accumulation, with no or little succession. The areas where the two worked would also have influenced their interpretations. Tony Mount's study area was largely the wet eucalypt forests on fertile sites in the Florentine and Styx Valleys whereas Bill Jackson had studied a wide range of vegetation types, including the sedgeland-heaths, scrubs and low rainforests on infertile sites in western Tasmania. On these infertile sites, with most nutrients contained in peat overlying quartzitic gravels, fire and subsequent leaching removes much of the nutrient pool. But in the forest soils of the Florentine Valley, where there is a larger pool of nutrients, the losses from burning are less important because ions are captured in the soils and much less leaching occurs.

A clearfelled and burnt coupe in the Hastings area in southern Tasmania, 1967. It was burnt in April 1967 and aerially sown with *Eucalyptus obliqua* seed in the same month.

The research conducted at the Maydena Station and the observations on forest practice in the ANM Concession and elsewhere had clearly established that mixed forest and wet sclerophyll forest could be successfully regenerated; success depended on preparation of a suitable seedbed by burning the large amounts of slash generated by harvesting, and then applying enough eucalypt seed to the area to produce a fully stocked stand. The main areas where more research was required were the safe use of fire to burn the slash, and seed treatments and sowing methods.

Preparing a seedbed

The only options available for creating a seedbed in the wet forests were to heap up the slash by mechanical means and cultivate the clear areas, or to burn the slash with a high-intensity fire. Heaping and cultivating would have created huge piles of slash, retaining a fire hazard and occupying a large part of the forest floor, to the detriment of eucalypt seedling establishment. Also, soils would have been damaged by repeated passes of machines. So fire was really the only viable means of disposing of the large volumes of slash and creating a receptive seedbed following harvesting in these forests. A major problem in the early 1960s facing researchers examining the use of fire to burn the slash after harvesting was that while sawlogs and, in the case of the ANM Concession, good quality logs for ANM's groundwood process[3], could be sold, there was no market for chemical-grade[4] pulp-wood. Therefore, with ratios of sawlog to pulp-wood averaging about 1:6 for many Tasmanian

[3] Groundwood pulping is a process in which the wood is pressed against a grinder to physically separate the wood fibres.

[4] Chemical pulping uses chemicals such as sodium hydroxide and sodium sulphide to dissolve the lignin (the glue holding the fibres together), leaving the wood fibres behind.

wet forests, large amounts of slash were present after harvesting. The energy released by burning large harvesting units of 100 ha or more of dense slash was enormous, so controlling these operations was a formidable task requiring some innovative thinking and brave testing!

Early trials of lighting strips through the coupe were generally unsatisfactory and often dangerous for the fire lighters inside the coupe because of the unpredictable and often very high rates of spread of the fire in some fuels. Later efforts concentrated on lighting the perimeter of the coupe but, again, although this was a generally safer technique for the fire lighters, the results were not consistent and fires often escaped beyond the coupe boundary. After many years of research, central ignition and production of convection columns became the standard technique for safe regeneration establishment burning in wet forests and, where applicable, in dry forests. The history of fire research at Forestry Tasmania, including the development of burning techniques for regeneration establishment, is covered in detail in Chapter 3.

Pelleting eucalypt seed, Geeveston, 1972.

Seed treatments and sowing methods

Once a receptive mineral soil seedbed had been prepared by burning, an efficient method of depositing seed evenly across the coupe was required. The early work by Gilbert and Cunningham, and by researchers at the Maydena Station, showed that a very high proportion of seed falling from trees, dropping from felled heads or broadcast sown, was taken by insects, mainly the Dieuches or strawberry bug, *Nysius vinitor* (formerly *Dieuches vinitor*), and ants. This research also showed that seed loss was much reduced by applying insecticide to the seedbed or by incorporating insecticides and fungicides in pelletised seed. Importantly, many of the seedbeds in the 1950s and 1960s were 'old'; that is, considerable time had elapsed since the regeneration establishment burn, and mosses, liverworts, grasses and other vegetation had colonised the seedbeds, leaving them poorly receptive for eucalypts (K. Felton, unpublished).

Research in the Florentine Valley in the early 1960s showed that seed dusted with DDT reduced insect attack. Australian Paper Manufacturers in Victoria had been experimenting with large pellets containing several seeds, fertiliser and insecticide. At Maydena, trials were conducted using small pellets containing single seeds which were first coated with a latex adhesive, with kaolin being added as a carrier for DDT, plus fertiliser and fungicide. These small pellets could produce twice as many seedlings as seeds dusted with DDT. Thus, in 1962, seed pelleting with DDT and the fungicide tetramethyl thiuram disulfide (TMTD) was introduced for routine seeding (Cremer 1962). This, combined with better seedbed preparation, enabled the seed quantities needed for satisfactory regeneration to be reduced from 2 lb to 1 lb per acre (1.14 kg/ha). Over the next few years, there was much research into different 'inclusions' in seed pellets. In the mid 1960s, soaking seed in the insecticide chlordane was shown to be more effective than the pelleting technique in reducing seed losses to insects.

Because of drift observed when aerial sowing in windy conditions, heavy pellets were developed in Victoria and used for a while in Tasmania. Their production was labour intensive, a spray-painting gun being used to apply gum arabic solution to seed rotating in a concrete mixer, followed by addition of kaolin to produce the pellets. Successive applications of gum and kaolin steadily increased the size of the pellets. The technique had to be abandoned when gum arabic became unavailable. Attention then turned to avoiding sowing in windy conditions and, later, to sowing from low-flying helicopters.

In the years following the introduction of seed pelleting that incorporated DDT as a routine measure, the use of DDT began to be questioned worldwide. Trials were conducted of pellets containing smaller quantities of the insecticide. Between 1973 and 1979, trials of different seed pellets incorporating a range of insecticides, fungicides and seed-coating materials were conducted, mainly by Eric Lockett and Keith Orme. When raw seed controls were included in the trials, it was found that, in field sowings across a range of sites, the untreated seed gave results as good or better than those from any of the pelletised seed.

Probably the main reason for the success of sowing with raw seed relates to the seedbed rather than the seed treatment. In the early experiments in the Florentine Valley, sowings were made on long unburnt seedbeds (see p. 72) in which populations of seed-robbing insects had built

Sowing eucalypt seed on a recently burnt coupe using a fixed-wing aircraft.

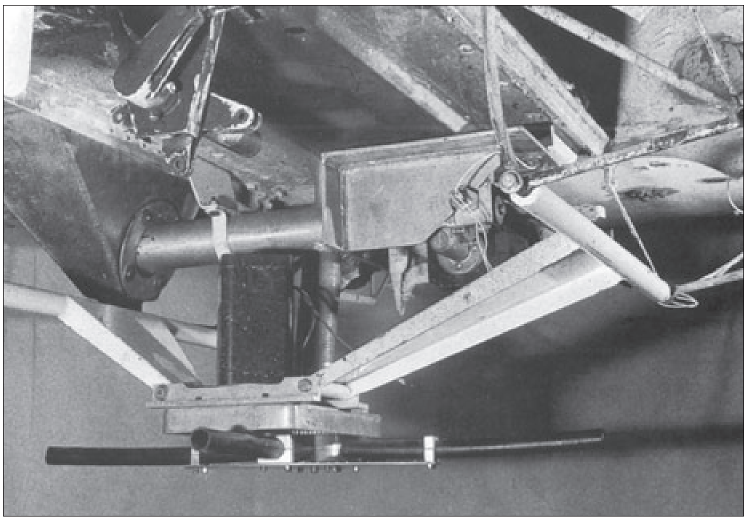
The early ground-based method of marking aerial sowing runs using flag wavers. This method was abandoned when on-board aircraft guidance systems became available.

up. With the later development of efficient burning methods to prepare seedbeds, sowings were made on recently burnt areas which had far fewer insects present. In addition, although seed loss was very high in the initial trials in the Florentine Valley, there is likely to be wide variability in the activity and effects of seed-robbing insects and other causes of seed loss between different areas of the State, forest types and seasons.

From 1979 to the present day, raw seed has been used for all aerial sowing of eucalypt seed with very good results, greatly assisted by the development of better aircraft delivery systems. A lower sowing rate, as low as 0.5 kg/ha, for wet forests was also introduced in the late 1970s. This reduced sowing rate resulted from operational experience and long-term studies using plots established with a range of initial stockings by Eric Lockett at Brockley Road in eastern Tasmania (see 'Developing Stocking Standards', p. 100). Prior to these studies, it was believed that there was significant mortality of eucalypt seedlings from year one onwards, but this was shown not to be the case.

Aerial sowing was introduced by the Forestry Commission in 1966, based on experience in

A close-up view of the Brohm seed auger that was installed in the PL-12 Airtruck.



Victoria. The initial Tasmanian sowings used fixed-wing aircraft that were specially modified for seeding operations and hired from Victoria.

> *There was a marked reduction in seeding costs compared with previous years due largely to the introduction of sowing by aircraft. Costs can be reduced still further by cheaper ground marking. Hand sowing by ground parties will still be required in a few areas, but aerial seeding will be used in future on most clear-felled sites.* [Forestry Commission 1966, p. 12]

For some years, the pilot of the aircraft was guided to fly along parallel paths by staff on the ground waving flags. This technique was very costly, positions for the flag-wavers having to be pre-marked. It was abandoned when on-board guidance systems became available.

When hand sowing was conducted, seed was diluted with sand and sawdust and strewn as evenly as possible by hand across the seedbed. Later, hand sowing was semi-automated by using a disc with vertical fences which, when rotated by hand, flicked out the seed.

After 1969, aerial sowing of pelleted eucalypt seed had largely replaced the seed-tree system in the ANM Concession (Korven-Korpinen and White 1972). In the early days of aerial seeding, seed was commonly mixed in a cement mixer and combined with yellow dye (which also covered staff and machinery!) so that the distribution of seed on the ground could be checked. Aircraft and seed delivery systems were progressively modified under the supervision of Brian Hodgson during the 1970s and 1980s, with the result that much greater control and easier adjustment of sowing rates were achieved. By the late 1980s, a seeding unit suitable for use with helicopters (the Brohm Heliseeder) was introduced (Hodgson and McGhee 1992). Although fixed-wing aircraft are much cheaper to hire, helicopters have advantages in today's smaller coupes and in topographies where fixed-wing aircraft have difficulty manoeuvering. As well, helicopters do not require an airstrip so they can land near the coupe to be sown. Currently, helicopters are used for aerial-sowing operations.

Sowing eucalypt seed on a recently burnt coupe using a helicopter equipped with a Brohm heliseeding unit.

A 1989 photo of a recently clearfelled and burnt, wet eucalypt forest coupe (Picton 39A) in the Picton Valley.

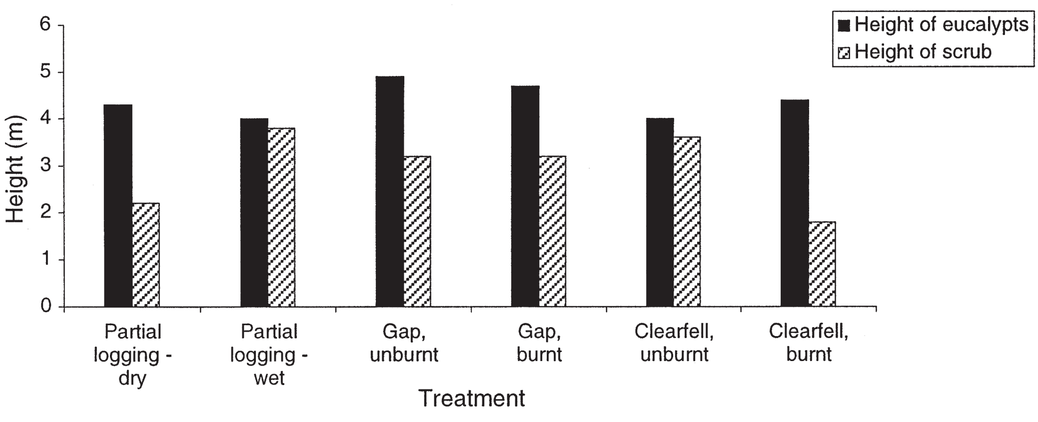
The area shown in the top image, photographed in 1994, with excellent growth of eucalypt regeneration resulting from clearfell, burn and sow silviculture.

Testing alternative silviculture in wet forests

Research trials and operational practice from the 1960s to the 1980s had clearly demonstrated the effectiveness of clearfell, burn and sow (CBS) in wet forest types as a method of obtaining well-stocked, fast-growing eucalypt regeneration. However, there continued to be concerns expressed by some in the community about the effects of the widespread use of CBS on biodiversity, aesthetics and other matters. In the late 1980s, Forestry Tasmania decided to evaluate alternatives to clearfelling in wet forests, with a view to developing an expanded range of silvicultural treatments which could be applied in appropriate circumstances.

The first priority was to establish whether alternative treatments could satisfactorily regenerate the forest. An initial silviculture trial, established by Neil McCormick and John Cunningham in moist forest on Forestier Peninsula, compared the effectiveness of various silvicultural treatments in obtaining well-stocked and vigorous eucalypt regeneration on the harvested areas. They included the conventional CBS, partial logging, and group selection (harvesting to create small gaps in the forest) treatments. Successful eucalypt regeneration was obtained only on the areas which were clearfelled, burnt and sown, heavy browsing by native mammals being the main cause of regeneration failure in the alternative treatments (Neyland *et al.* 1999). Seedfall of *E. obliqua* was monitored for seven years at the Forestier trial site in what is probably the longest reported study of eucalypt seedfall (Neyland *et al.* 2003).

Following the development of the Forests and Forest Industry Strategy (FFIC 1990), the Forests and Forest Industry Council allocated funding for a Community Research Project in the Southern Forests in response to community concerns about the effects of clearfelling and burning on the availability of special species timbers. This project included the establishment of a range of harvesting treatments in mixed forest (tall eucalypts over a rainforest understorey) in the Arve Valley in the early 1990s by David Allen, the Community Research Forester.



Height growth of eucalypt regeneration and competing scrub five years after harvesting in the Forestier alternative silviculture trial. Only the clearfelled, burnt and sown treatment was considered well stocked with eucalypt regeneration at the five-year measurement (data not shown). (From Neyland *et al.* 1999.)

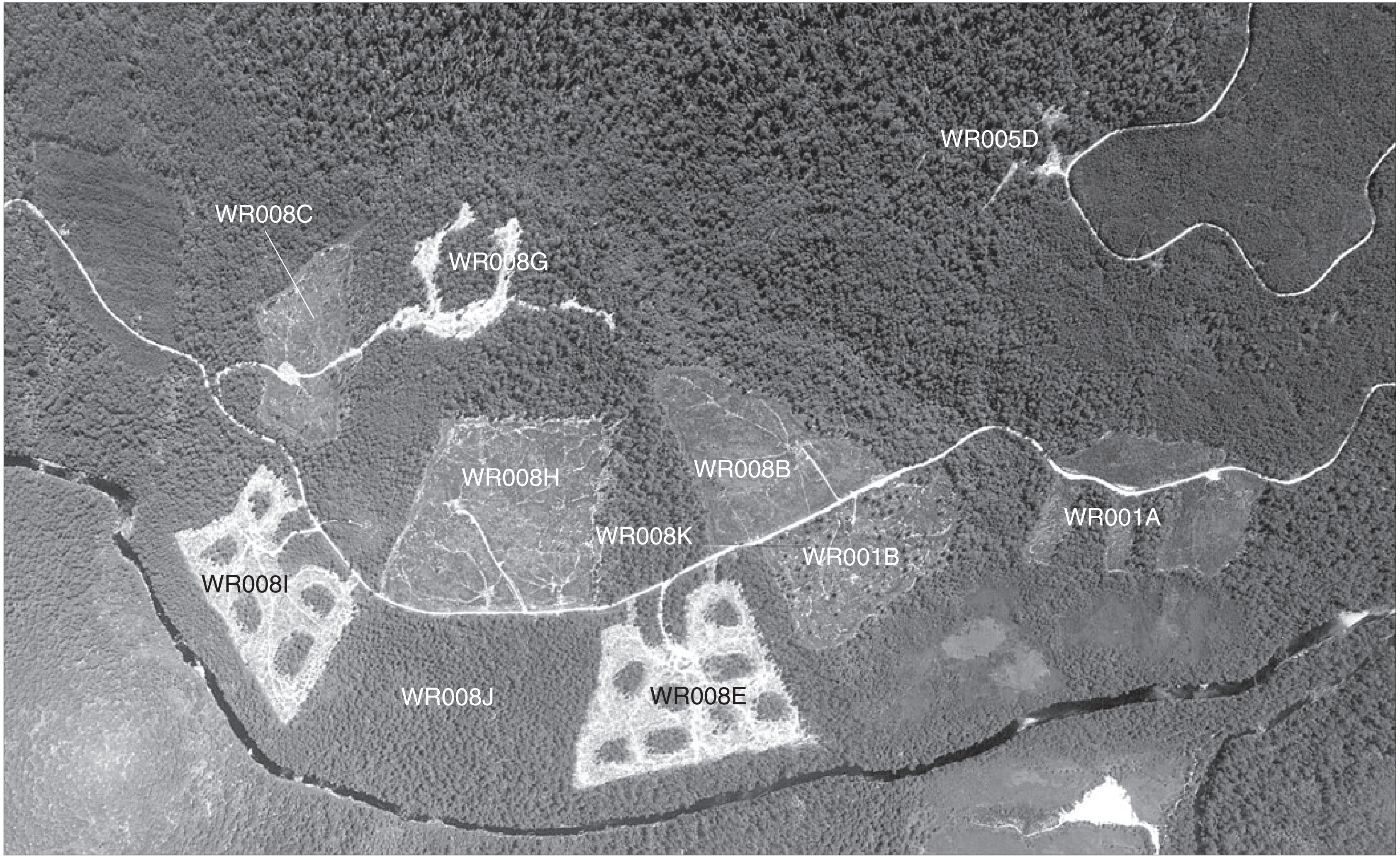
The treatments comprised clearfelling, retention of three or four oldgrowth trees per hectare, a shelterwood system (16 m^2 basal area per hectare retained), large (0.7 ha) and small (0.25 ha) gaps, and single-tree selection. Four years after establishment, all treatments were stocked with eucalypt regeneration. However, seedling density and height decreased with increasing overwood retention and decreasing gap size, while the density of rainforest species regeneration increased with increasing overwood retention and decreasing gap size (Bassett *et al*. 2000). Thus, although eucalypt regeneration was established in the non-clearfell treatments, the costs of these treatments were very high, fire hazard was greater, and there were safety concerns.

The study demonstrated once again that clearfelling and high-intensity burning in wet forests was a very effective means of establishing well-stocked, vigorously growing eucalypt regeneration. However, the study also showed that alternative silvicultural treatments may meet particular management objectives where eucalypt timber production was not the primary aim.

Seed traps installed in the Forestier alternative silviculture trial to monitor seedfall from retained trees. (Graham Wilkinson pictured.)

The Forestier and Arve trials provided useful information on the relative effectiveness of a range of treatments in obtaining a satisfactorily regenerated forest. However, it was clear that more detailed investigations were required to enable valid comparisons of all aspects of alternative treatments, including economics, worker safety and biodiversity conservation as well as eucalypt regeneration establishment. This need for information on a much wider range of parameters associated with any change in silvicultural practices was also relevant to the development of indicators of sustainable forest management, as discussed under 'Sustainable Yield' in Chapter 1.

Thus, in 1995, the Warra Long-Term Ecological Research Site was set up by Forestry Tasmania in the Southern Forests. Its aim is to foster long-term ecological research in Tasmanian forests and facilitate the development and demonstration of sustainable forest management practices (Packham 1995; Brown *et al.* 2001). Within the tall wet eucalypt forests of the 16 000 ha Warra site, a large and comprehensive silvicultural trial has been coordinated by John Hickey, and established by native forest researchers, particularly Mark Neyland and Leigh Edwards, and by Huon District staff. This trial is designed to compare alternative silvicultural systems with the clearfell, burn and sow (CBS) system currently used in wet forests, and to develop silvicultural alternatives for areas where habitat, special species timbers or aesthetic values have additional



An aerial view of the silvicultural systems trial at the Warra LTER Site, south of Hobart, 2006. Treatments: Clearfell, burn and sow with understorey islands, WR008B, WR008H. Stripfell, WR001A. Dispersed retention, WR001B, WR008C. Aggregated retention, WR008E, WR008I. Single tree/small group selection, WR005D, WR008G. Control, WR008J, WR008K.

emphasis (Hickey *et al.* 2001, 2006). The alternative treatments to CBS being tested are:

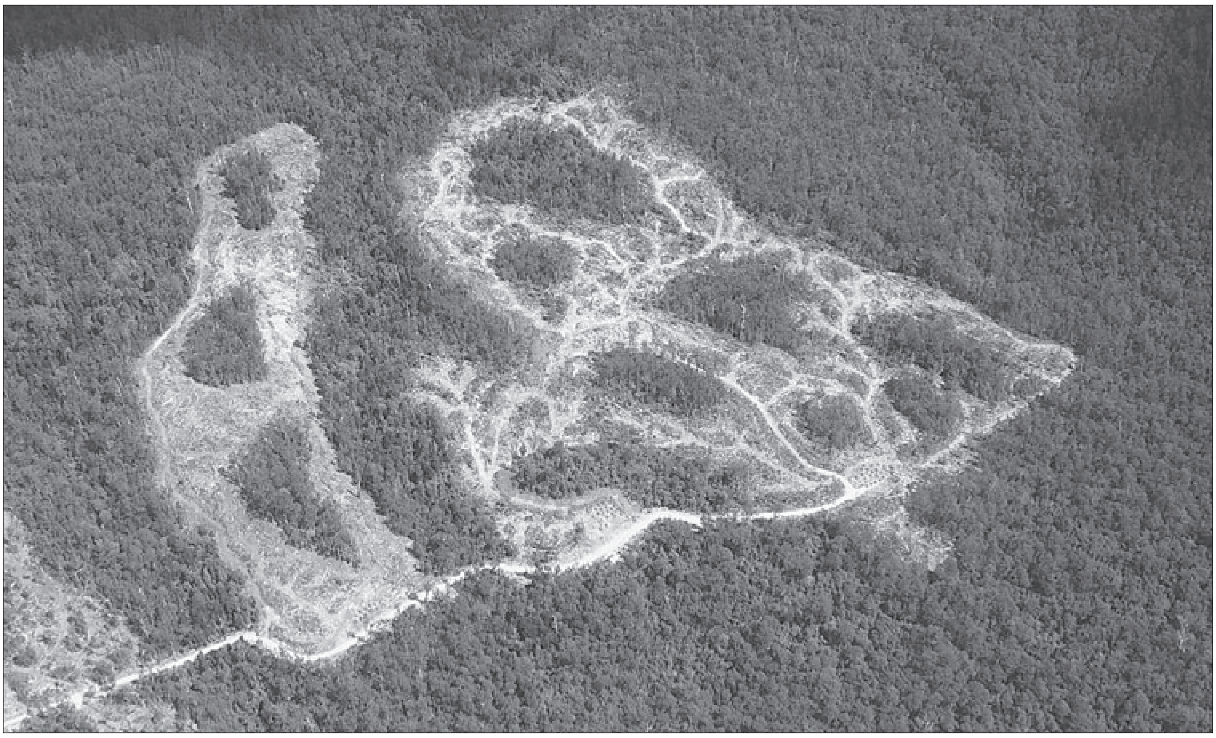
- CBS with understorey islands (four, 40 m x 20 m patches of understorey retained within the coupe);
- Stripfell (strips of forest harvested);
- Patchfell (small patches of forest harvested);
- Dispersed retention (10% of pre-harvest basal area retained);
- Aggregated retention (0.5–1.0 ha patches of forest retained, totalling 30% of the coupe area);
- Single tree/small group selection (at least 75% of forest canopy retained);
- Control area (no harvesting).

A comprehensive assessment of the performance of the silvicultural treatments being tested at Warra is planned in 2008. The results to date indicate that the clearfell, burn and sow treatment has again been the most successful in terms of establishing good eucalypt regeneration. However, there are benefits for conservation of biodiversity and aesthetics from the treatments which retain standing forest within the logging coupe. Variable retention silviculture, based on the aggregated retention treatment at Warra, is now being tested operationally in the forest Districts and several wet forest coupes have been harvested and regenerated this way. The experience gained so far from the Warra silvicultural trial formed much of the basis for Forestry Tasmania's advice, requested by the Tasmanian Government, on the phase-out of clearfelling within most oldgrowth forest on public land by 2010 (Forestry Tasmania 2005a). More information on the conservation research associated with the Warra silvicultural trial and at the Warra site generally is given in Chapter 7.

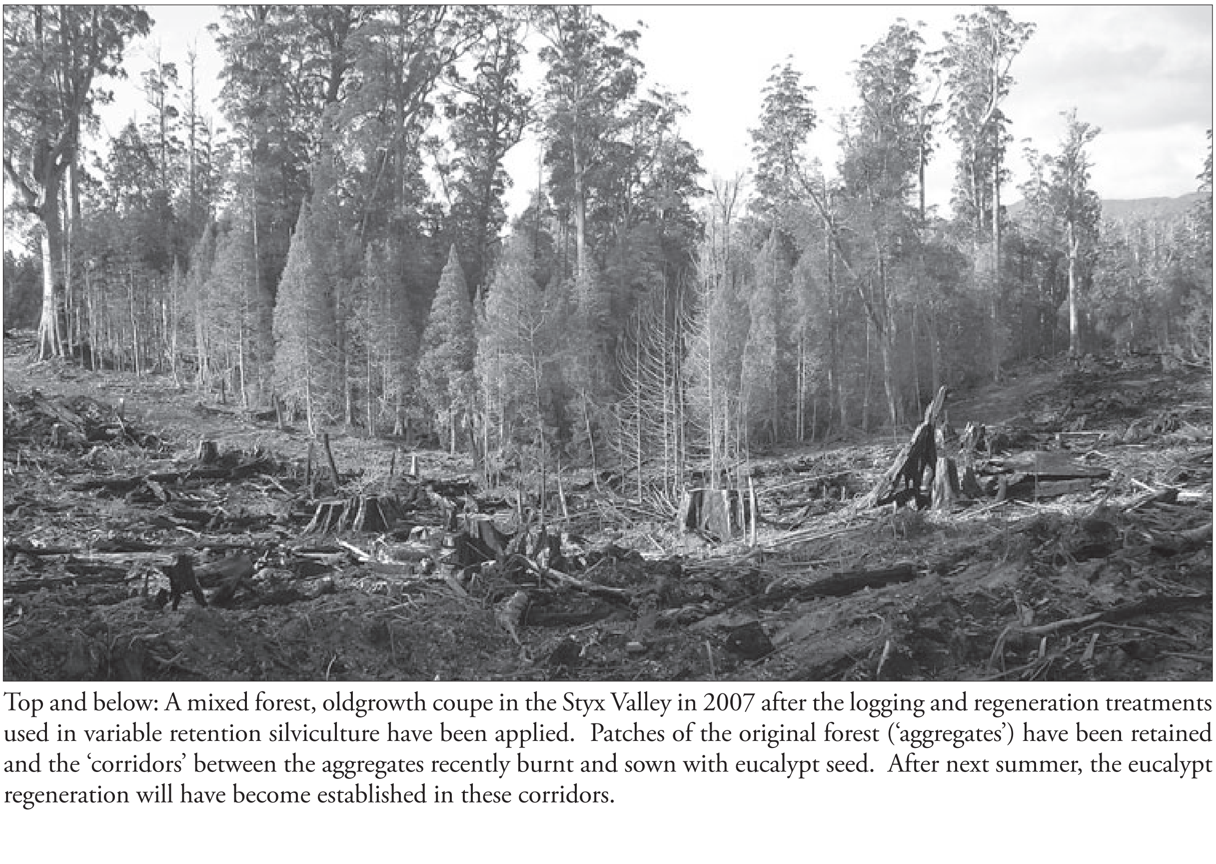
Data gained from all the alternative silviculture trials in wet forest conducted since the late 1980s provided much of the information on silvicultural prescriptions and ecology presented in Native Forests Technical Bulletin No. 8, *Lowland Wet Eucalypt Forests* (Forestry Tasmania 1998a).

Staff from the Division of Forest Research and Development worked closely with Huon District staff to turn the concept of the Warra silvicultural systems trial into an operational reality. Much of the Division's responsibility fell to, from left, John Hickey, Mark Neyland and Leigh Edwards.

An area in the Warra silvicultural systems trial harvested using dispersed retention silviculture. This treatment retains about 10% of the basal area of the eucalypt forest, providing an on-site seed source, tree hollows and log habitats.



Aggregated retention silviculture in the Huntsman 322L coupe, northern Tasmania. This was the first operational implementation of aggregated retention in the State after the harvesting technique had been developed in research trials at Warra.



Top and below: A mixed forest, oldgrowth coupe in the Styx Valley in 2007 after the logging and regeneration treatments used in variable retention silviculture have been applied. Patches of the original forest ('aggregates') have been retained and the 'corridors' between the aggregates recently burnt and sown with eucalypt seed. After next summer, the eucalypt regeneration will have become established in these corridors.

High-Altitude Forests: Special Silviculture for Extreme Environments

Until the 1960s, most of the silvicultural research in eucalypt forests in Tasmania had been undertaken in lowland wet forests, mainly *E. regnans* and *E. obliqua*. While studying the causes of dieback of high-altitude *E. delegatensis* forests in north-eastern Tasmania (see Chapter 6), Bob Ellis, then a forest ecology researcher with the Forestry Commission, investigated regeneration problems noted by field staff, particularly where seedlings were growing in multi-aged forests in exposed locations. These high-altitude *E. delegatensis* forests experience harsh weather conditions, including extreme cold, snow and drought. Sawmillers' selection was the harvesting method used in them for many years but, with the development of a pulpwood market in the early 1970s, it became possible to harvest trees rejected by the previous sawlog-only operations, and prepare for the establishment of eucalypt regeneration.

Operational experience showed that clearfelling forest types on upland plateaux with a grassy ground layer often resulted in stunted and very slow-growing regeneration and, in some cases, partially or completely failed areas (Ellis and Lockett 1987). The grass had been established and maintained by burning, originally by Aborigines, and was associated with a limited amount of eucalypt advance growth that had very poor form and vigour, mainly because of the effects of grass competition, fire and frost. The stunted and slow-growing eucalypt regeneration occurring after clearfelling on such sites was described as having 'growth check'. This condition did not occur where the topography provided good cold-air drainage and there had been a hot slash burn following logging of forests with wet sclerophyll understoreys.

Investigations began in the mid 1970s by District and research staff into harvesting methods which provided some protection for young regeneration. A system of retained trees, or shelterwood, was tested in trials established at Tooms in the Eastern Tiers and Roses Tier in the north-east. Initial results of natural seeding from these retained trees were encouraging; shelterwood plots at the Tooms trial produced some 60 000 seedlings/ha one year after the regeneration establishment burn, reducing to 10 000 seedlings/ha over the following summer. Later, further trials of shelterwoods and clearfelling treatments with and without burning were established at Clarence River in the Central Highlands.

Concern over high-altitude forest management was such that, in 1981, a Delegatensis Research Fund was set up to support research into problems with regeneration of *E. delegatensis* at higher altitudes. This fund was financed by the Forestry Commission and the timber companies Associated Pulp and Paper Mills and Forest Resources. Rod Keenan, working at the Forestry Commission, was supported by the Fund from 1981 to 1984, followed by David Minifie and Anne Duncan from 1985 to 1986. Their studies and later work by Michael Battaglia and Lindsay Wilson (Battaglia and Wilson 1990), combined with the operational experience and research inputs from District staff, provided a basis for the development of more appropriate harvesting and regeneration prescriptions for these forests. Studies of the limiting factors, particularly browsing pressure, grass competition and extreme cold, by Bob Ellis from CSIRO (Ellis and Lockett 1987) and University of Tasmania researchers David Bowman, Manuel Nunez and Jamie Kirkpatrick (Bowman and Kirkpatrick 1986; Nunez and Bowman 1986) greatly assisted this work.

Rod Keenan established significant correlations between reduced growth of *E. delegatensis* and the main site and climatic factors involved: understorey vegetation, altitude, poor drainage,

Multi-aged *Eucalyptus delegatensis* in State forest at Travellers Rest, east of Lake St Clair.

Growth-checked *Eucalyptus delegatensis* seedlings aged 20–25 years at Maggs Mountain, about 800 m elevation, in north-western Tasmania, following clearfelling and subsequent invasion by grass. A shelterwood treatment was developed for high-altitude *E. delegatensis* sites that prescribes the retention of some trees after logging to provide protection for young regeneration and the removal of the retained overwood once regeneration is well established (Forestry Commission 1990a, 1994a).

relief, exposure and soil parent material (Keenan and Candy 1983). The factors were mapped, and a model developed which, when applied to a particular land unit, allowed a predicted height of *E. delegatensis* regeneration to be determined. Hazard classes, indicating the susceptibility of each site to growth check, could then be derived, based on these predicted heights.

The causes of growth check and possible treatments were investigated in a trial at Maggs Mountain in the Mersey Forests, in which herbicide was applied to the grass, and fertiliser to affected regeneration. These treatments produced a significant response in terms of height growth, but severe frost experienced at the trial site was a very significant factor in inducing growth check, and mortality was high in all treatments (Forestry Commission 1984b).

The early shelterwood trials showed that the critical factors requiring further investigation for successful regeneration of *E. delegatensis* at high altitudes were:

- The appropriate level of overwood retention;
- The length of time that the shelterwood should be retained;
- The best method of seedbed preparation.

More trials were established in the mid 1980s at Lake Echo, Clarence Lagoon, Mount Foster and Snow Hill, comprising a clearfell treatment, shelterwood retention levels ranging from 25% to 75%, and an unlogged control area. Stocking and growth rates of regeneration on these trials were assessed for several years. Following a review of the results, Michael Battaglia and Lindsay Wilson developed the following

Retained *Eucalyptus delegatensis* after harvesting, at 650 m altitude under Clumner Bluff in the north-west. The logging slash has been heaped with excavators and burnt.

prescriptions for harvesting and regenerating high-altitude *E. delegatensis* forests:

- Retain advance growth and small growing stock where possible;
- Retain a forest environment as much as possible to minimise grass invasion and browsing, and ameliorate climatic pressures;
- Provide a seedbed that remains viable for as long as possible;
- Minimise competition so regeneration can quickly reach a size big enough to withstand climatic pressures and browsing.

The prescriptions formed the basis for the recommendations on the silvicultural management in Native Forest Technical Bulletin No. 2, *High Altitude* Eucalyptus delegatensis *Forests* (Forestry Commission 1990a). The recommendations emphasised the importance of retaining growing stock in stands where maintenance of an uneven-aged structure was desirable and operationally possible. In even-aged forests with insufficient advance growth present to give satisfactory stocking after logging, shelterwood systems were recommended, retaining about 12 m^2/ha of basal area, the retained trees to be removed in a second cut once the regeneration is over about 1.5 m in height. In some areas, for operational reasons, the retained trees were not removed, resulting in a partial logging treatment rather than a shelterwood treatment.

The optimum basal area retention level varies according to site conditions, more being retained in higher rainfall areas (M. Neyland, pers. comm.), but it should be the lowest level capable of achieving full stocking, while providing protection for the regeneration without depressing later age stocking and growth

Potential sawlog retention at Mount Connection, 2004, pictured following harvesting and top-disposal burning. This *Eucalyptus delegatensis* stand was harvested using uneven-aged treatment (UAT) protocols involving pre-harvesting assessments, quantitative targets for tree retention and progressive assessments of the stand during harvesting.

(Battaglia and Wilson 1990). Importantly, no logging was recommended for exposed areas experiencing severe frosts which did not carry sufficient advance growth to give full stocking after logging (Forestry Commission 1990a).

Small areas of another high-altitude eucalypt forest type, the *E. pauciflora*/*E. dalrympleana* association, were available for harvesting on State forest, subject to the development of appropriate silvicultural techniques. Larger areas exist on private property. This forest type also experiences severe climatic stress so preservation of existing growing stock was known to be an important factor when considering silvicultural approaches. Trials of harvesting and regenerating this forest type were conducted by Lindsay Wilson at Lake Echo in the late 1980s and early 1990s. The trials tested clearfelling with and without burning, and canopy retention with no burning. All treatments produced a satisfactory stocking of regeneration where adequate advance growth or lignotuberous stock were present before harvesting. The lignotuberous stock contributed a higher proportion of final stocking than seedlings across all seedbeds and treatments. Consequently, a heavy reliance on advance growth formed the basis for silvicultural prescriptions for this forest type (Forestry Commission 1990b).

The development of silvicultural regimes for highland forests was also considerably advanced by the work of the forestry companies Northern Woodchips (later Forest Resources and then Gunns Ltd) and APPM (later Gunns Ltd). These companies harvested and regenerated large areas in the highlands on private property, particularly from the 1970s to the 1990s, and in the course of these operations they encountered a wide range of forest types that required different silvicultural treatments.

Although appropriate silvicultural regimes, including shelterwoods, potential sawlog retention and various forms of advance growth retention, had been developed for the uneven-aged highland forests, the results from their implementation were variable and often sub-optimal. To correct these problems, Mark Neyland and John Cunningham developed uneven-aged treatment (UAT) protocols which established performance indicators and targets for shelterwood retention and removal, advance growth retention, and potential sawlog retention (Neyland and Cunningham 2004).

Under the UAT system, a pre-logging assessment (PLA) must be undertaken prior to the preparation of a Forest Practices Plan. The method of harvesting is then determined using assessment information from the PLA and information in Native Forests Technical Bulletin No. 2 (*High Altitude* Eucalyptus delegatensis *Forests*). The Forest Practices Plan must include quantitative targets for tree retention and other factors, against which the implementation of the system on the coupe can be judged. A progressive-harvesting assessment (PHA) is used to provide feedback to the contractor on retained basal areas and damage levels so that timely corrective action can be taken. The UAT system has greatly improved the quality of silvicultural management in highland *E. delegatensis* forests by ensuring that specific information is gathered prior to logging and that performance is judged using a quality standards system.

The UAT procedure was developed for high-altitude dry *E. delegatensis* forests but can also be applied to other multi-aged forest types. In 2001, Forestry Tasmania endorsed the use of this procedure for partial harvesting in all *E. delegatensis* forests because they represent the next most valuable sawlog resource after lowland wet eucalypt forests. The system is not regularly applied to other forests, partly because sawlog yields are often quite low and supervision costs must accordingly be kept low.

Dry Sclerophyll Forests

Some 35 major dry forest communities in Tasmania have been recognised, 32 of which are dominated by eucalypts (Duncan and Brown 1985). Most of the drier forests are less uniform than the wet forests, with a greater range of eucalypt species, ages, understoreys and overall structure. Even within a single coupe, there are often several different forest structures. Until the 1970s, many dry eucalypt forests were in poor condition. Those on more productive sites had experienced years of selective logging for sawlogs only, with trees not clearly containing a sawlog being left, and excessive burning and grazing by domestic stock had limited regeneration and created depauperate understoreys.

At the start of the export woodchip industry in the early 1970s, although the highly variable, multi-aged structure of dry forests was well recognised, the clearfell, burn and sow system (CBS) was the recommended silvicultural treatment because of several issues seen to be important at the time with the application of partial logging systems. These included:

- Insufficient growing stock available for retention in some areas;
- Difficulties in burning logging slash without damaging retained trees;
- A lower quality seedbed resulting from lower intensity fires compared to CBS (Gilbert and Cunningham 1972), with a possible sacrifice of the benefits to growth of eucalypt regeneration from a fully developed ash bed;
- A lack of logging crews with the necessary equipment and skills to harvest without causing excessive damage to retained trees;
- The extent of forests with an open understorey was unclear.

Before operations to harvest pulpwood from the drier forests began in 1970, trials were conducted by Ken Felton in the large areas of this forest type being converted to pine plantations in the Fingal District. Seed of several eucalypt species was sown on northern aspects in the middle of very large logged areas to test the hypothesis that summer droughts would result in the death of many eucalypt seedlings. This hypothesis was disproved; in fact, the seedlings grew rapidly, including those of species sown well outside their natural range


An uneven-aged stand of dry sclerophyll forest suitable for potential sawlog retention.

(off-site). In a second series of trials, growth of coppice shoots and advance growth were investigated, with encouraging results.

The initial coupes in the Triabunna area were managed with the CBS system, including those in the Impact Zone of the Army Training Area, north of Buckland. There, the Army asked that an attempt be made to remove forest cover from some areas so the fall of artillery shells could be monitored. Hot slash burns with no subsequent artificial sowing produced excellent eucalypt regeneration, cull trees providing the seed source.

Once it became clear that good regeneration could be reliably established in such areas by the CBS system, attention turned to alternative silvicultural approaches in some of the multi-aged forests so that existing younger growing stock could be retained. Partial harvests were also needed on dry sites susceptible to regeneration failure due to drought or grass invasion.

The Triabunna Station

When the woodchip export industry began in 1971, Triabunna District became an operational centre for large-scale, integrated harvesting and regenerating operations in eastern Tasmania. The harvesting covered a wide range of eucalypt species and forest structures on different sites, but the silvicultural requirements for many of these forests were not well known. In 1973, a research unit was located at Triabunna to conduct silvicultural research which would assist operational staff. The specific tasks were to study regeneration techniques in dry forests, monitor their effectiveness and suggest refinements where necessary.

The unit was originally staffed by Eric Lockett, who was soon joined by Neil McCormick in November 1973. Neil moved to Perth Nursery in May 1975 and was replaced at Triabunna by Tim Geard and, later, Eddie Payne. In January 1977, Eric moved to Head Office in Hobart and

Collecting seed-bearing material from felled *Eucalyptus delegatensis* at Triabunna, 1972. When the woodchip export industry was established in the early 1970s, Triabunna District became the centre of a large regeneration program which required increased stocks of seed of the main eucalypts being harvested.

was replaced at Triabunna by Murray Jessup, who remained there until the Triabunna Station closed at Easter 1979, dry forest research being conducted thereafter by Hobart staff in co-operation with the Districts.

Research work at the Triabunna Station included determining appropriate stocking rates in dry forests, seed-crop assessment techniques, spot sowings for remedial treatments, comparison of burning and no-burning regeneration treatments and potential sawlog retention trials. As well as dry forest silviculture, silvicultural regimes for high-altitude forests were also investigated (see earlier section). With the Station being located within the District, there were very close links between operational and research staff, and this ensured that the primary operational problems were jointly addressed. The operational experience of the Triabunna District staff and the research staff at the Triabunna Station in the 1970s formed the basis for many of the prescriptions contained in the *Silvicultural Manual* issued in 1978. This was the first such manual published by the Forestry Commission and it was the forerunner to the more detailed Native Forest Silviculture Technical Bulletins initiated in 1990 by Graham Wilkinson; these are now the principal reference for native forest silviculture.

Evaluating the need for regeneration establishment burning in dry forests

Many of the dry forests being harvested in eastern Tasmania in the 1970s and 1980s had relatively short, open scrub layers and seedbeds which tended to remain receptive for lengthy periods. Thus, the argument for using burning to facilitate establishment of regeneration in these forests was not as strong as in the wet forests. However, there was a wide range of dry forest types and therefore a blanket prescription for the use or non-use of fire was not appropriate, although regeneration establishment burning was commonly used because of its value in assisting future fire protection. Long-running experiments which became known as the burn/no-burn trials were established by Eric Lockett between 1975 and 1977 in Launceston and Fingal Districts. Paired plots were used to compare the growth of regeneration on areas burnt and left unburnt since harvesting.

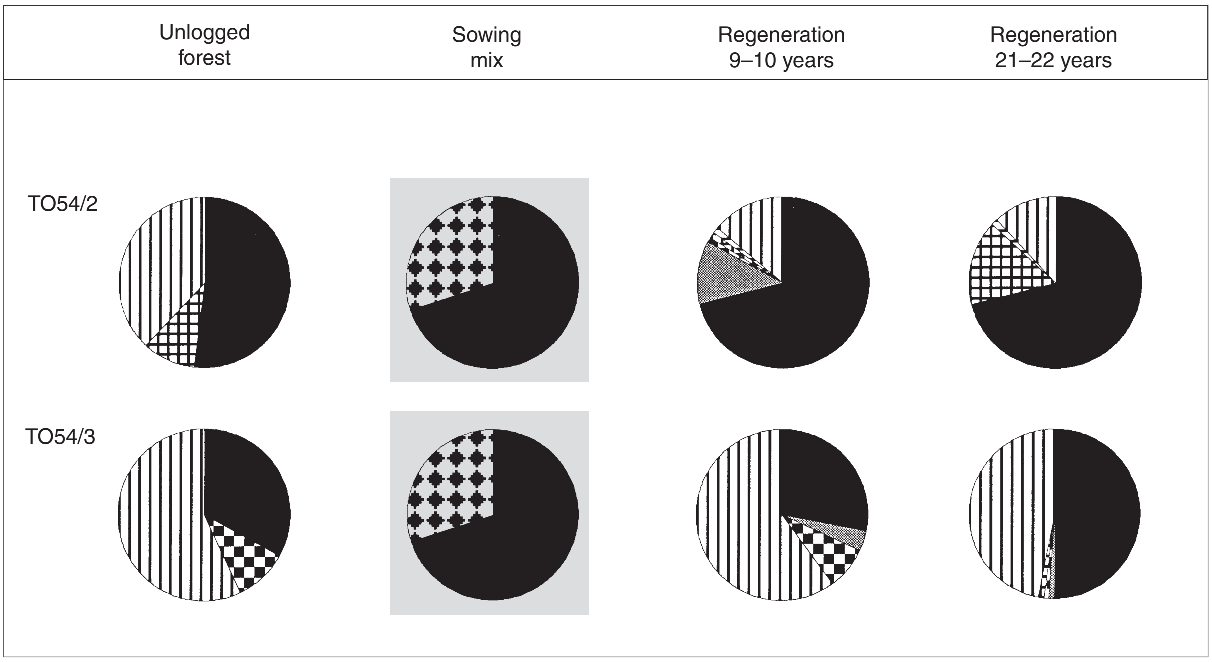
The initial results from the trials indicated that early height growth at the wetter sites was significantly faster on the plots receiving the clearfell, burn and sow treatment. However, at the dry sites, growth rates did not differ significantly between treatments (Lockett and Candy 1984). Later measurements showed that the early positive effect of slash burning on rate of height growth compared with no burning at the wetter sites progressively declined and finally disappeared between years 10 and 15. Overall, it was concluded that the net effect of burning would be a shortening of the rotation by a maximum of five years (Forestry Tasmania 1997a).

Operationally, decisions on whether to burn or not are now made at the coupe level. In addition to any predicted positive effects of burning on growth, other very important factors such as preservation of any existing advance growth, the likelihood of achieving satisfactory stocking and the need to reduce risk of wildfire have to be considered.

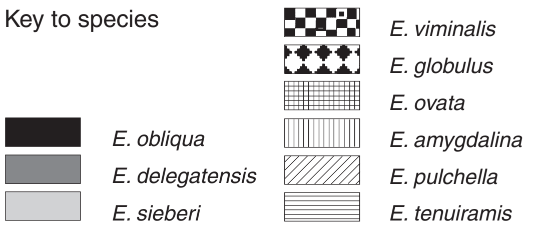
Seed mixes for dry forests: could productivity be improved

Where artificial seeding was used in dry forest silviculture, seed mixes were prepared and usually aerially sown as described earlier for wet forests. However, whereas the harvested wet forest areas were usually on good sites with favoured commercial species such as *E. regnans* and *E. obliqua*, the dry forests usually contained a greater mix of species, often including a high proportion of gums and pepermints which are not favoured commercially. In the early 1970s, there was optimism amongst some foresters that the productivity of the dry forests could be improved by using a sowing mix with a higher proportion of favoured species than had been present in the mature forest. Consequently, in the early years of dry forest harvesting, eucalypt sowing mixes with a high proportion of ash species and an enhanced component of blue gum were often used to sow areas which had been predominately peppermint-gum forests. Field experience indicated that 'upgrading' the sowing mix to favour commercially preferred species did not lead to an increase in the proportions of these species in the regeneration. The practice was discontinued by the Forestry Commission in the late 1970s, after the introduction of the policy of preparing sowing mixes with the same proportion of species as the unlogged forest, based on assessment data.

In the 1980s, Adrian Goodwin investigated the performance of species which had been sown off-site in east coast coupes. In general, species sown outside their natural range did not have greater growth rates than the naturally occurring species, although many of the introduced species were co-dominant in size with the local species. He recommended that the long-term survival of species sown off-site should not be relied on unless research indicated otherwise (Forestry Commission 1982a). Later comparisons of the species compositions of the unlogged forest, seed mix and the regenerated forest showed that the species composition of the regeneration assessed up to about twenty years after sowing tended to be closer to that of the original forest rather than that of the sowing mix (Elliott *et al.* 1991, 2003).

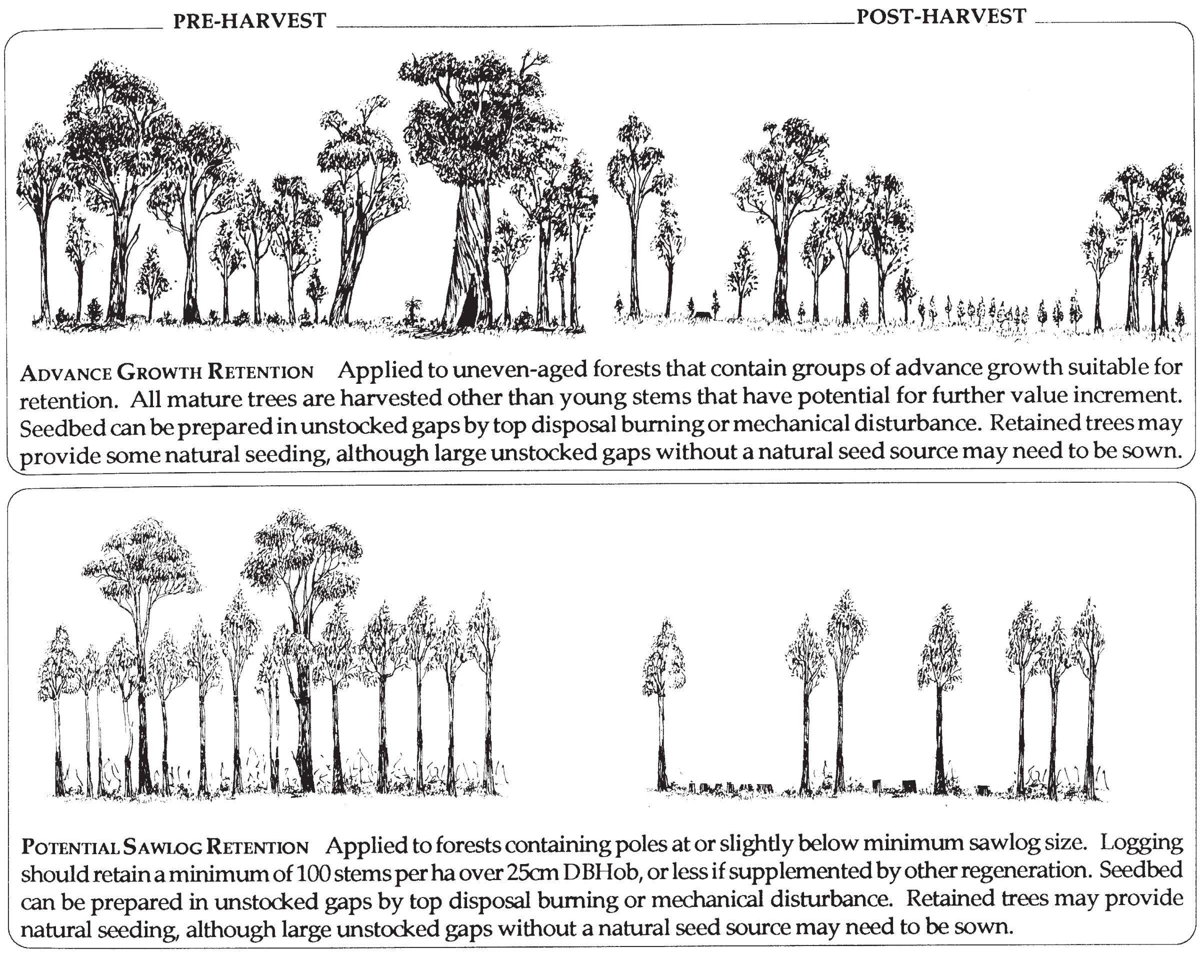


A comparison of eucalypt species composition in unlogged forest, the sowing mix used after harvesting, and the regeneration at age 9–10 years and 21–22 years in a dry eucalypt coupe (TO54) on Tasmania's east coast, near the Lake Leake Highway. Note that the high component of *Eucalyptus globulus* in the sowing mix has not been reflected in the species composition of the new forest. (Fom Elliott *et al.* 2003.)



Silvicultural systems for dry forest

In the 1970s, increasing attention began to be directed at developing a range of silvicultural systems that could be applied to dry forests with irregular age and size structures. There was already some basis for this work because the principles used in developing such systems for the high-altitude forests were applicable to the dry forests. There was concern that small trees of good form, which could become sawlogs if grown on, were being taken as pulp logs during harvesting because of their small size. A potential sawlog retention trial was established in 1972 at Wielangta by Ken Felton and Graeme Clark. This was the first operational-scale alternative to clearfell, burn and sow implemented in these forests. Following the partial harvesting, a regeneration establishment burn was conducted. Many trees died from damage caused by harvesting or the subsequent burn and, by 1977, only 54% of the retained trees survived. Damage to retained trees was a problem with early partial logging trials but was greatly reduced by the development of operational monitoring systems (see 'Thinning Eucalypt Regrowth', p. 104) and the use of excavators; death from post-logging burning can be reduced by using cool burns or avoided by not burning (which results in a greater risk of damaging wildfires).

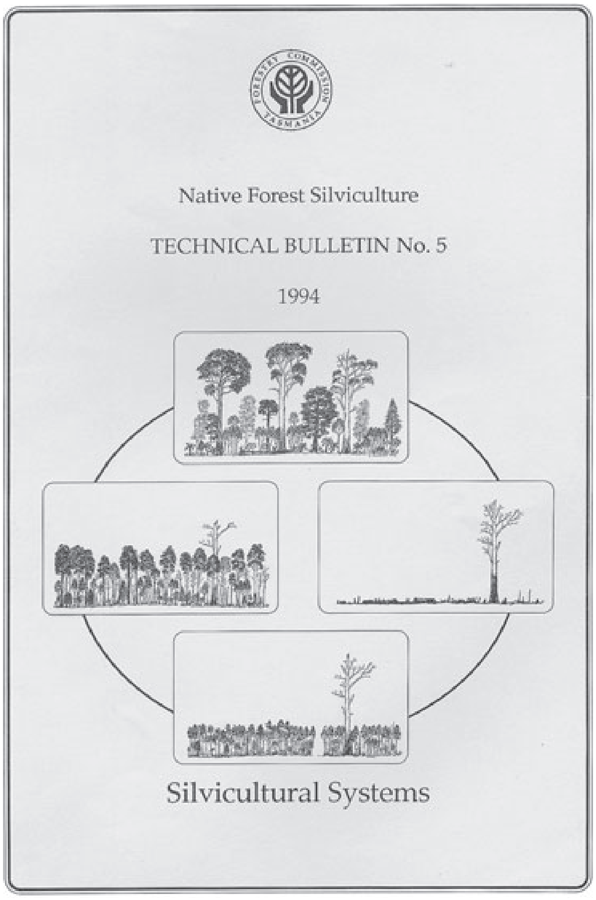


ADVANCE GROWTH RETENTION Applied to uneven-aged forests that contain groups of advance growth suitable for retention. All mature trees are harvested other than young stems that have potential for further value increment. Seedbed can be prepared in unstocked gaps by top disposal burning or mechanical disturbance. Retained trees may provide some natural seeding, although large unstocked gaps without a natural seed source may need to be sown.

POTENTIAL SAWLOG RETENTION Applied to forests containing poles at or slightly below minimum sawlog size. Logging should retain a minimum of 100 stems per ha over 25cm DBHob, or less if supplemented by other regeneration. Seedbed can be prepared in unstocked gaps by top disposal burning or mechanical disturbance. Retained trees may provide natural seeding, although large unstocked gaps without a natural seed source may need to be sown.

Diagrams and explanations of two of the partial harvesting systems commonly used in dry forests. (From Forestry Commission 1994a.)

There were some initial operational trials of partial logging in dry forests conducted by District staff during the 1970s. In 1980, Adrian Goodwin established a potential sawlog trial at Nile in north-eastern Tasmania, in which some 25% of the trees on 3.5 ha were retained to grow on for future sawlogs. Subsequent diameter measurements of the retained trees over the next few years showed that they would reach a sawlog size of 60 cm in seven years, compared with 24 years had the stand not been logged. Growth-ring analysis of retained trees grown on for 24 years after a partial logging at Roses Tier demonstrated a substantial growth response across a wide range of size classes following their release from competition by the logging (A. Goodwin, unpublished).



Native Forest Silviculture Technical Bulletin No. 5 provides a summary of the harvesting and regeneration systems used in the major Tasmanian commercial eucalypt forests.

During the 1980s and 1990s, District and research staff continued to test alternative silviculture in dry forests, developing a range of harvesting and regeneration methods which were applied selectively to suit different dry forest situations at the coupe level (McCormick and Cunningham 1989).

Clearfelling was still found to be the most appropriate harvesting technique for some dry forests types that had a denser shrubby under-storey. Assessment of the extent and vigour of the advance growth often present in the more open, multi-aged forests was found to be very important in determining the most appropriate regeneration method. Depending on the results of advance growth assessment, regeneration could be achieved by retention of growing stock, sowing, or a combination of both. Clearfelling was not appropriate for dry forest with a grassy understorey because the grass sward tended to proliferate under this regime.

The great variability in the structure of the dry forests made the process of choosing the best silvicultural system for each harvesting unit quite challenging for both research and operational staff. For example, the structure of some stands enabled well-formed seed trees to be retained, with a seedbed being prepared from scarification by machines or top-disposal burning, or by simply using the disturbed ground from the logging operation. In other stands, various selective logging methods were appropriate, including overstorey removal, potential sawlog retention and advance growth retention. All of these methods were developed and documented in the 1980s and 1990s by research and operational staff through experience and trial establishment in the wide range of dry forest types encountered (Forestry Commission 1991a, 1994a). The experience gained from research and operational application of alternative silvicultural systems in dry forest was invaluable when testing of similar systems commenced in moist and wet eucalypt forests at Arve, Forestier and Warra (see p. 77).

Conditional forests

Stocking and growth of regeneration following harvesting in some of some of the dry forest types, particularly the lower productivity forests, encountered in the 1970s and 1980s were not satisfactory. Grassy black peppermint forest (*E. amygdalina* with a grassy understorey) and low-quality peppermint forest on granite soils were two such types. Regeneration difficulties and other forest management problems such as erosion led to the creation of a conditional forest category. Forest was unavailable for harvesting until problems had been overcome, when it could then be removed from the conditional category.

In the Management Plan for the Tasmanian Pulp and Forest Holdings Concession Area in eastern Tasmania, all 'E4' forest (eucalypt forest with a height range of 15–27 m) was classed as conditional forest. Studies of such forests were made to give information on those forest types which should be permanently excluded from logging and those where harvesting could be allowed, perhaps subject to particular conditions. Attention focussed on stands which might exhibit one or more of four problems:

- Well-stocked, healthy regeneration not assured after harvesting;
- Slow growth of the regenerated forest resulting in excessively long rotations;
- Sites prone to erosion;
- Management of the forests would not be economically viable.

The extent of conditional forest types was mapped. Regeneration trials were established in the mid 1980s by Neil McCormick to investigate methods of achieving satisfactory stocking and growth of seedlings following harvesting. The trials tested a range of treatments including clearfell, burn and sow, clearfelling with no burning, seed-tree retention with and without burning, and pre-logging burning with and without seed trees. It was also necessary to determine size/age relationships in these forests and calculate what rotation lengths would be required. Analysis of growth rings on discs cut from sawlog-sized trees showed that the normal 90-year rotation would be barely adequate to achieve a regrowth eucalypt sawlog of minimum size (Forestry Commission 1989a).

The trials showed that in most years, regeneration was able to be established by most treatments, although stocking in clearfelling treatments was sometimes low. However, regeneration in these low-quality forests often failed in drought years or when climatic extremes such as severe frosts occurred.

The silvicultural research conducted during the conditional forests project was an important input into the Native Forest Silviculture Technical Bulletins that covered dry forests (Forestry Commission 1991a, 1994a). Recommendations from the research included no logging of patches of grassy open forests with a dense grass understorey and low levels of advance growth, and retention of seed trees and/or advance growth, depending on site characteristics and existing forest structures.

The dry private forests project

A project began in 1989 to develop information on silvicultural methods for managing some of the forests that covered part of the private land owned by pastoralists and farmers. These forests were in small blocks, and usually had been frequently burnt, with a long history of grazing by domestic stock and with a fire regime appropriate for that use. The project was initiated by the Private Forestry Council and funded by the Rural Industries Research and Development Corporation, forestry companies, and private owners.

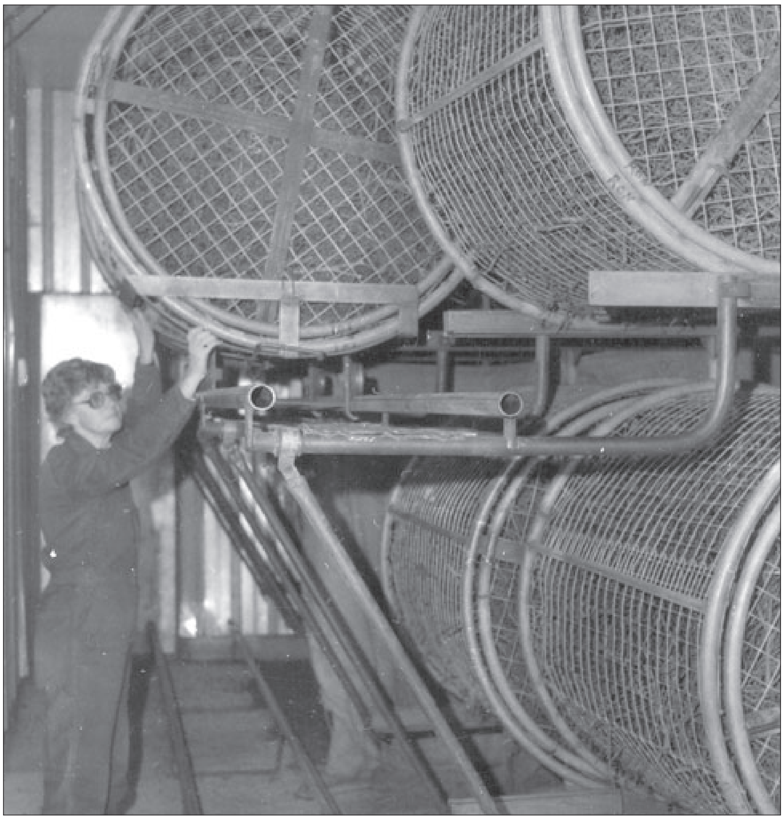
The project was conducted by Simon Orr, who established silvicultural demonstration trials of a range of techniques at Blessington in the north-east and Faddens Tier near Oatlands. Partial harvesting was integral to the trials, its feature of harvests at relatively short intervals producing frequent cash flows from a small area of forest. These trials successfully provided demonstrations of different harvesting and regeneration methods that could be used by private forestry owners. The project also resulted in the production of a booklet, *Managing Your Dry Forest*, which assists private landowners to manage their forested lands. The booklet included information on identification of eucalypt species, relevant Forest Practices Code requirements, harvesting and regeneration regimes, plantation site-selection principles, fire management and forestry economics (Orr 1991).

Later work by CSIRO researchers, supported by the Tasmanian Forest Research Council (see Chapter 7), evaluated different seedbed preparation techniques in dry forest, with particular reference to private forests. The studies concluded that a pre-harvest regeneration survey should be conducted to assess the stocking of advance growth present, species mix, and the amount of seed present on the trees. If advance growth stocking was adequate as determined by surveys, then the forest should regenerate from this advance growth, with new seedlings establishing on areas disturbed by the harvesting. If advance growth stocking before harvesting was less than 50%, then pre-harvest cultivation was recommended. Pre- or post-harvest burning in the forests was not recommended as a treatment to produce a seed-bed because burning only marginally increased regeneration levels compared with harvesting disturbance alone (Pennington *et al*. 2001a).

Seed Collection, Extraction and Storage

Considerable research into eucalypt seed collection, seed treatment and sowing methods was done when the clearfell, burn and sow technique was developed for the wet forests. The move to integrated harvesting of the dry forests in the 1970s required more work on seed and sowing due to the different species, species

An early 'trampoline-type' seed extractor at Hermons Road, Geeveston (now Huon) District, 1968.



Left: Extracting eucalypt seed from material in circular bins at the early seed kiln at Perth in 1981. (Freda Button pictured.)

Below: Loading seed into the modern rotary drum kiln at Perth in 1997. (Andrea Hutton, top, and Elaine Page.)

Inspecting capsules on eucalypt twigs before seed extraction. (From left: Andrea Hutton, Elaine Page and Neil McCormick.)

mixes and site factors encountered. The early work at the Triabunna Station included testing seed-crop assessment methods, investigating the seed-ripening process and seed-storage life, and rate of sowing trials.

In 1988–89, Eric Lockett reviewed the seed classification system and testing procedures for seed germination. New procedures were implemented for prescribing sowing mixes, and seed-testing procedures were amended. In the early 1990s, a Seed Advisory Group was formed and Eric Lockett and Michael Ross provided advice resulting in improved seed collection, extraction and storage. In 1993, the Tasmanian Seed Centre was established under the management of Neil McCormick. Its role was to manage the collection, extraction and storage of seed and to supply seed to external clients on a commercial basis.

Many improvements in the management of eucalypt seed were introduced by the Seed Centre. A formal seed-crop reporting system for the Districts began in the early 1990s, together with a measure to enable the infrequent crops of seed on *E. regnans* to be forecast using aerial spotting of its flowering. At Perth Nursery, new apparatus for testing the moisture content of incoming seed was developed by Eric Lockett, and later an electrical seed meter was introduced for testing moisture content of stored seed. A new kiln was installed at Perth in 1995–96, and eucalypt seed orchards were developed between 1996 and 2002 at Oigles Road in the south and Ben Nevis in the north-east to supply improved seed of *E. globulus* and *E. nitens* for the plantation program (see Chapter 5).

The Seed Zoning System

Early wet forest silviculture in Tasmania involved retaining some trees on the harvested coupe as a seed source for the new forest. This was seen as a safe, natural system in that local seed should produce regeneration well adapted to the site. Unfortunately, the retained trees often had no seed because of infrequent flowering. Collected seed therefore had to be applied. Where possible, it was collected from the local area, preferably from the coupe itself, and stored until needed. However, the advent of clearfell, burn and sow silviculture meant an expanding area needed to be sown each year. As seed was often not available in large enough quantities from felled tree crowns on all coupes, it sometimes had to be sourced from other areas. The proportions of each eucalypt species in the seed mix to be sown on each coupe were based on the proportions of mature stems in the unlogged stand obtained from assessment data. The Commission's policy was (and still is) that the first priority for sourcing seed is from the coupe itself and, if there is not enough available there, then seed must be taken from an area with an equivalent environment (Forestry Tasmania 2006).

A formal seed zoning system was developed by Eric Lockett in the late 1980s to replace an earlier

Measuring conductivity of cell electrolytes in a study of resistance to frost damage (Leigh Edwards pictured). This work formed part of investigations of genetic variation within *Eucalyptus obliqua*—a project that demonstrated the importance of using on-site seed wherever possible and led to improvements in seed collection and sowing practices.

Collecting seed from *Eucalyptus obliqua* in the early 1990s during the study of genetic variation within this species.

simpler system. The basic assumption was that the risk of regeneration failure is reduced and the chance of good growth enhanced by only using seed which comes from areas with similar environmental parameters to those of the area being regenerated. This zoning system, which is still in use, was based on the environmental attributes of elevation (altitude), dryness (annual rainfall) and coldness. The State was divided into several zones within each of these attributes (e.g. low, medium and high elevation). Seed to be sown on a coupe but sourced from outside the coupe must come from the zones which match the environmental attributes of the coupe to be sown (Lockett 1987).

The seed zoning system was an important step in matching seed to site, but studies in the early 1990s by Graham Wilkinson and Leigh Edwards clearly demonstrated the importance of using on-site seed wherever possible (Wilkinson 1995). These studies in *E. obliqua* forests at Forestier and Lune River showed there were genetic differences between populations of *E. obliqua* over relatively short distances of only a few hundred metres, a finding with important implications for conservation of genetic diversity and regeneration success at the individual coupe level.

Time of Sowing

There were many early time-of-sowing trials, often producing inconclusive results. From the research in wet eucalypt forests, the best time of sowing was considered to be autumn. This nearly matched the time of natural seedfall of the main wet forest eucalypts, which usually follows summer wildfire. While burning in summer would be more similar to the timing of natural seedfall from scorched tree crowns, the risk of wildfires escaping from regeneration establishment burns in this season greatly exceeds the risks to regeneration success of varying the time of sowing. As seedbeds in these wet forest sites remain receptive for only a short time due to rapid invasion by competing vegetation, sowing as soon as possible after burning is very important (Forestry Tasmania 1998a).

In the late 1980s, the prescriptions for time of sowing were reviewed and further developed by Michael Battaglia. This review was required because large-scale sowings were being conducted in high-altitude and dry forest types, which had different environmental conditions to the wet sites where the prescriptions were first developed. Work in Victoria in the 1960s had shown that seed of *E. delegatensis* being sown in high-altitude forests needed moist stratification to break primary dormancy (Grose 1963). Keith Orme tested stratified and unstratified seed in Tasmania in the 1970s and found that stratification was not so important for Tasmanian provenances of *E. delegatensis*.

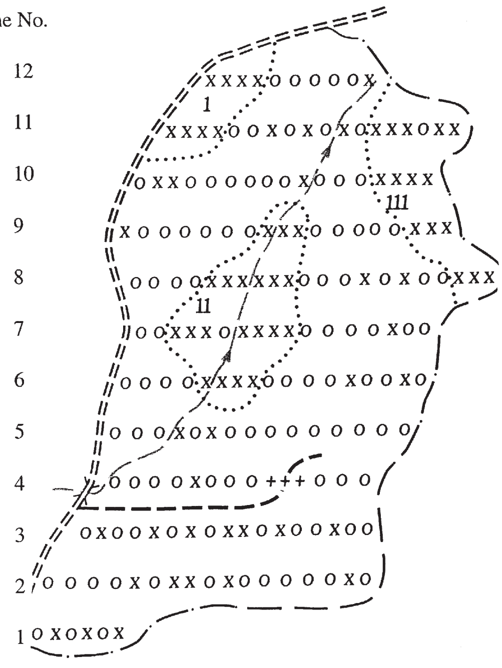
In trials conducted as part of the time-of-sowing review, seedlots of *E. delegatensis* and *E. amygdalina* were sown at 12 different dates at a high-altitude site at Mount Connection and a dry forest site at Bicheno. The main implications for management from this research were that autumn sowing as soon as possible after seedbed preparation was a less risky strategy than spring sowing; the emergence of seedlings from autumn sowing was split between autumn and the subsequent spring, whereas spring sowing resulted in one flush of emergence in spring (Battaglia 1994).

Developing Stocking Standards for Eucalypt Regeneration

In order to assess the effectiveness of regeneration treatments in eucalypt forests, a survey technique incorporating some measure of the amount of young regeneration established on the coupe was required. This measure not only had to provide an estimate of the total number of seedlings per unit area but, as clumpiness in eucalypt seedling distribution always occurs, this also had to be taken into account in any assessment method. Regeneration surveys were not used in Tasmania to any extent until the establishment of the Maydena Station in 1954. Even by the late 1950s, no standards for adequate stocking of eucalypt regeneration in Australia had been published (Cunningham 1960), although there were minimum standards available from North America based on the stocked quadrat concept introduced by Lowdermilk (1927). This concept involved assessing the percentage of small circular plots (quadrats), established on a systematic grid within a coupe, that contained at least one seedling and were therefore deemed to be 'stocked'. The unit used initially was one milacre (4.047 m^2), a convenient area to search. Where a eucalypt seedling was not found, a larger plot of double the radius was searched, its area being four milacres. Stocking assessments of eucalypt regeneration in Australia are now expressed as percentage stocking of 4 m^2 or 16 m^2 (roughly equivalent to one and four milacres respectively).

Obviously, it is not necessary for every milacre unit to contain a seedling for the stand to be satisfactorily stocked. The actual percentage milacre stocking considered to indicate a satisfactory regeneration standard is a matter of judgement influenced by several

Mapped results of seedling survey (o = stocked plot, x = unstocked plot, + = plot on road).



Line No.	Stocked section 16	Stocked section x	Stocked section Total	Understocked section 16	Understocked section x	Understocked section Total
12	5	1	6	0	4	4
11	6	2	8	1	9	10
10	10	3	13	0	4	4
9	11	1	12	0	6	6
8	10	2	12	0	9	9
7	8	1	9	1	7	8
6	11	2	13	0	4	4
5	13	2	15	0	0	0
4	10	1	11	0	0	0
3	10	7	17	0	0	0
2	12	5	17	0	0	0
1	3	3	6	0	0	0
Totals	109	30	139	2	43	45

Total number of plots = 139 + 45 = 184

A typical map of a eucalypt regeneration survey showing the location of stocked and unstocked plots, and understocked patches I, II and III. Once identified, the understocked patches could have further treatment to increase their stocking. (From Forestry Tasmania 2003a.)

factors, including the tree species and site characteristics. Five thousand seedlings per acre, representing over 80% milacre stocking, was suggested as an appropriate stocking level by Jacobs (1955). However, for *E. regnans*, Cunningham (1960) suggested that a standard of 30% milacre stocking, requiring 600–1000 established seedlings per acre, was a reasonable minimum requirement.

When Murray Cunningham returned to Tasmania from Melbourne after completing his Ph.D. on regeneration of *E. regnans*, one of the priorities he set for the Forestry Commission was to conduct research into an appropriate stocking standard for the regeneration of wet eucalypt forest. This research became the responsibility of Tony Mount, who developed a standard for wet eucalypt forests after clear-felling, using the stocked-quadrat technique. He also demonstrated the need to account for the clumpiness of seedling distributions and developed a new factor of heterogeneity ('h'), derived from a combination of frequency and density of seedlings on the coupe, rather than using a simple percentage stocking alone. The *Standing Instructions for Regeneration Surveys* became the standard for assessing the effectiveness of regeneration treatments in Tasmanian forests (Mount 1961). A mapping system for regeneration surveys was also developed, clearly showing where the stocked and unstocked sections of the coupe occurred, thus enabling easy targeting of any areas needing remedial treatments to raise stocking levels (Mount 1975). Tony also developed a system for assessing stocking in later-age regeneration. A technique for this purpose had little practical application for many years, it being clear that the dense stands of vigorous eucalypt regeneration, which were the norm, were at least adequately stocked. Techniques for assessing the stocking of regeneration in irregular forests (uneven-aged) were developed later, when silvicultural systems for such forests came to be commonly applied (see later in this section).

The early stocking standards were theoretically based, as no empirical data were available relating initial stocking to the structure and growth performance of stands at later ages. To provide such data, a trial was set up by Eric Lockett in 1978 in even-aged dry sclerophyll forest at Brockley Road in south-eastern Tasmania. Plots were hand sown at rates ranging from 0.1 kg to 1.0 kg/ha, and stocking, growth and development of the regeneration were monitored from regeneration establishment to age 16 years. The stocking of regeneration on the plots reached a peak at between two and five years after sowing and then declined only marginally. Height growth on all plots was fairly constant after age two years. These results provided evidence that contradicted the long-held view that there is significant loss of seedlings in the early years of the development of a stand of eucalypt regeneration. Such a loss may occur after a cool burn on wet sclerophyll sites, producing no significant ash-bed effect and much scrub regeneration, but not after a hot burn as occurred at the Brockley Road site.

The long-term nature of the trials provided data which enabled the production of a model of stand volume as a function of initial stocking. This model allows, for example, a forest owner to specify the initial stocking for stands to be managed under a particular silvicultural regime. The model showed that an initial 30% stocking of 4 m^2 plots (regarded as a marginal stocking in Tasmania) would be nearly ideal for growing sawlogs in an unthinned stand with an 80-year rotation (Lockett and Goodwin 1999).

The interpretation of the results obtained from the stocked plot system, based on assessing 4 m^2 quadrats and associated mapping, was refined by Eric Lockett and other staff of the Native Forests Branch, and the technique was in constant operational use by Forestry Tasmania until very recently. In 2003, after National and State reviews of regeneration stocking standards, Forestry Tasmania moved to a system which requires 65% of 16 m^2 quadrats on the coupe to be stocked to achieve a satisfactory stocking level (Forestry Tasmania 2003a). This new standard was adopted in part because, when tested against varying degrees of aggregation of seedling distributions, the 16 m^2 plots gave a relatively consistent indication of stocking, whereas 4 m^2 plots were very sensitive to the level of aggregation (Lutze 2001).

In addition to assessing the stocking of seedlings in clearfelled coupes, there was also a need to develop assessment methods for growing stock in forests managed with an irregular silvicultural system such as the variety of multi-aged stands encountered in some high-altitude and dry lowland forests. These stocking standards were developed by Eric Lockett and progressively refined by Graham Wilkinson, Leigh Edwards and Mark Neyland of the Native Forests Branch over the last two decades.

Prescriptions for stocking standards for both even- and uneven-aged eucalypt forests, based on some four decades of research and operational testing, are summarised for use by field staff in Native Forest Silviculture Technical Bulletin No. 6, *Regeneration Surveys and Stocking Standards* (Forestry Tasmania 2003a).

Remedial Treatments for Understocked Regeneration

Remedial treatments for understocked regeneration areas were an important topic of research relevant to the management of all commercial eucalypt forest types. When regeneration surveys showed that areas were understocked, spot sowing or planting was used to refill the gaps. However, there was mixed success from the early attempts at restocking, and research continued for many years to develop improved remedial treatments. The monitoring of coupes to detect impending understocking as soon as possible after sowing is critical to obtaining successful regeneration establishment at reasonable cost.

In 1975–76, a hand-sown 'indicator plot' was installed on each newly sown coupe so the progress of germination could be watched. Indicator plots became a standard operating procedure after further development and extension work by Leigh Edwards, Mark Neyland and other research staff. The design and use of these plots is detailed in Native Forest Silviculture Technical Bulletin No. 12, *Monitoring and Protecting Eucalypt Regeneration* (Forestry Tasmania 1999). The results of research into the causes of regeneration failures such as browsing damage (see Chapter 6) and remedial treatments, including spot sowings, were incorporated into Native Forest Silviculture Technical Bulletin No. 7, *Remedial Treatments* (Forestry Commission 1992a).

A technique used in Scandinavia to assist restocking, which showed early promise in Tasmanian forests, was the use of sheltered-spot sowing. This involved sowing a small amount of seed and then covering the sown area with a shelter to protect the new seedlings from climatic extremes. The initial Tasmanian trials in the mid 1970s at Borradaile, Camden, Mount Foster and Bicheno used plastic and waxed paper shelters. Fertiliser could be added to the spots. Fertilised spot sowings produced regeneration, although their stockings were often low. The initial good stockings of very young seedlings recorded in sheltered spots at some trial sites often declined with time and some spots suffered 100% mortality. In the early 1980s, a new type of shelter developed in Finland was tested over spot sowings at Tasmanian sites but was not durable enough to be effective. The overall conclusion from the work on sheltered-spot sowings was that they could have application as a rehabilitation method but at high cost.

A common problem with spot sowings was that when seedlings successfully established there were too many within the spot and they persisted for many years; in the worst cases, the bases of the trunks of the seedlings became fused. This overstocking often resulted from heavy applications of seed on a large spot. In the mid 1990s, Bernard Plumpton developed a new spot-sowing tool which delivered an

Bernard Plumpton with the Plumpton sower used to spot sow areas which are found to be understocked in regeneration surveys, c. 1996.

exact amount of seed to a smaller, cultivated spot. This method produced similar success rates to conventional spot sowings but used far less seed. Because the spot was smaller, it was expected that competition between seedlings would be greater and early domination by one or two seedlings should occur.

The Plumpton sowing tool was an important advance, but too many seedlings still persisted in some spots, leading to bad form and low growth. Bernard Plumpton and Joanne Dingle further refined the technique by determining the ideal weight of eucalypt seed to be sown per spot to achieve a balance between getting a high number of stocked spots and the proportion of plots stocked with one seedling. For *E. obliqua*, the ideal weight of Class A seed was found to be 0.08 grams per spot (Dingle and Plumpton 2003).

Thinning Eucalypt Regrowth for Added Value

Thinning forest stands reduces competition between trees and enables the production of sawlogs on retained trees at an earlier age or larger trees at the normal rotation age. Thinning of eucalypt stands has long been an important part of eucalypt silviculture in State forests. This is not surprising considering the vast areas of dense, young eucalypt regrowth arising after wildfires that followed early selective logging, and the more recent 'silvicultural regeneration' produced by the clearfell, burn and sow treatment. From the time the Department was formed in 1921, small trials of thinning in young eucalypt regrowth stands were reported and some sample plots were established.

> *The work of setting out sample plots for ascertaining rates of growth under various conditions regarding density, sylviculturally treated, untreated and thinned areas have been commenced and valuable data on girth and height, volume and increment will become available in a few years.* [Forestry Department 1925, p. 10]

Unfortunately, no record of the response to the thinning or the ultimate fate of the plots is available, although it can be safely assumed that the stands were burnt by wildfire. Some 3000 ha of eucalypt regrowth at Mawbanna in the north-west and Taranna in the south-east were thinned in the 1930s, with rates reaching over 700 ha/yr (Forestry Department 1938). However, most of these areas were burnt by wildfires in 1939 and 1940. One small area of *E. regnans*, *E. globulus* and *E. obliqua* on Balts Road at Taranna survived the 1940 fires on the Tasman Peninsula (Forestry Tasmania 1998b), including thinned and unthinned plots which had been established there by the Commonwealth Forestry and Timber Bureau in the 1940s. These were remeasured some 50 years later by Forestry Tasmania, providing data on response to thinning and recovery of sawn timber from what is probably the oldest surviving thinning trial in the State (Forestry Tasmania 1997b; Wardlaw *et al.* 2004).

In the late 1940s, the Forestry Commission reported the first detailed results from thinning trials. Data from experimental plots in *E. obliqua* regrowth showed growth rates for harvestable (usable) wood from age 46–51 years of 52 cubic feet per acre (3.7 m^3/ha) per year in an unthinned stand of 209 trees per acre (522/ha); and 190 cubic feet per acre (13.5 m^3/ha) per year in a thinned stand of 62 trees per acre (155/ha). The results prompted the comment:

> *These figures illustrate the typical intensity of the struggle for existence in dense forest stands. The Commission does not propose to initiate thinning as a silvicultural measure in the thousands of acres of pole regeneration, except to the extent that such thinning can be utilised economically, and that for the purposes of research to determine the great wood potential in Tasmanian forests. The silvicultural challenge to forest utilisation is accepted as a grave responsibility.* [Forestry Commission 1949, p. 11]

The 1949 comment on the need for economic utilisation of thinnings was, and still is, a key factor in the adoption of operational thinning programs. Over the next 40 years, no large-scale thinning programs were conducted on State forest, mainly because they were not economic, but also because of an enhanced risk of damaging wildfires in the thinning slash. However, a program of thinning of eucalypt regrowth was included in the Working Plan for the Australian Paper Manufacturers (APM) Concession in the Southern Forests in the early 1960s. After several years of thinning operations, the program was abandoned due to


The Dover–Hastings State Forest in the 1920s, showing an area of blue gum regrowth after first thinning.

problems with high levels of damage to retained trees, soil damage from machinery passes, and the high cost of wood from the thinnings.

Commission staff set up several thinning trials in different ages of eucalypt regrowth during the 1950s, but most of these trials, like those before them, were destroyed by fire. For example, plots thinned to various intensities were established in 1956 (in collaboration with the Commonwealth Forestry and Timber Bureau) in dense *E. obliqua* regrowth which arose from a

Sapling regrowth after cleaning and thinning by trainees at Taranna, late 1930s.

fire in the Esperance Valley in 1950; these plots were subsequently destroyed by fire in 1961 (Forestry Commission 1961). In 1963, the Eucalypt Thinning Yield Plots (ETYPs) were established in 50-year-old *E. obliqua* regrowth at Riawunna Spur in what is now the Huon District in a joint project with APM. The study aimed to determine regrowth response to thinning at a range of retention rates compared to that in an unthinned control. These plots were well laid out, using four replications of five treatments covering thinning intensities ranging

A thinned stand of *Eucalyptus obliqua* in the Florentine Valley. The stand was aged 49 years when photographed and had been thinned some years earlier. (Brett Warren pictured.)

from 60–180 stems/ha. They have provided valuable data on growth response to thinning high-quality older stands (Goodwin 1990; Brown 1997). Damage levels were also assessed after the thinning plots were established; 1% of retained stems were badly damaged, 2.5% moderately damaged and 8% slightly damaged (Forestry Commission 1964).

A large series of trials to test the effect of removing competing woody understorey on retained eucalypt overstorey was established in the early 1960s in the Florentine Valley in the south and Togari in the north-west. The competing understorey and eucalypt overstorey combinations examined were *Acacia dealbata* /*E. regnans*, *Pomaderris apetala*/*E. obliqua*, *Phebalium squameum* (now *Nematolepis squamea*)/*E. regnans* and *Pomaderris apetala*/ *E. delegatensis*. These trials were well known to Commission staff as the RP 115 series and they provided data on the detrimental effects of vigorous understoreys on eucalypt growth (Goodwin 1990). However, their usefulness was limited by the imposition of further treatments on the original trials, lack of control plots in some locations, and other difficulties (G. Brown 1996).

The Chesterman's Mill thinning trial was established in 1968 in 24-year-old *E. regnans* regrowth in the Plenty Valley in southern Tasmania. This is a well-replicated trial with three retention rates and a long measurement history (LaSala 2007). In the Southern Forests, the Edwards Road and Hartz Road plots were set up in 1976 in 10-year-old, high-quality eucalypt regrowth, thinned to obtain material for APM to test pulping qualities of young ash regrowth. These plots used retention rates of 250–440 stems/ha and an unthinned control. Between 1982 and 1984, Adrian Goodwin established five thinning experiments in 15–25-year-old eucalypt regrowth to test the effect on growth response of retention rates of 150–500 stems/ha compared with an unthinned control over a range of species and site qualities. These experiments were known as the Young Regrowth Thinning Series (YRTS).

The ETYPs, YRTS and the Southern Forests thinning trials all showed growth responses to the thinning treatments, with the trees on the ETYPs plots still responding 20 years after the thinning, and the response is expected to continue on the most heavily thinned plots. The smaller trees retained in thinning operations generally responded better than larger trees to all thinning intensities (Goodwin 1990). Adrian Goodwin extended the usual summary of growth response to thinning reported in these and previous trials; he produced density management diagrams which could be used to prescribe thinning treatments to suit different management objectives such as maximisation of wood production or minimisation of the time required to produce a certain number of sawlogs. Thus, thinning research was becoming more refined and being applied in a more sophisticated manner to the management of eucalypt regrowth.

A very significant research effort associated with thinning of eucalypts was the Young Eucalypt Program (YEP), a co-operative effort involving the Forestry Commission, Tasmania, the Victorian Department of Conservation and Environment, the Forest Industries Association of Tasmania, the Victorian Sawmillers Association, and CSIRO. The YEP ran for five years in the late 1980s and involved eight main projects, making it a landmark study because of its integration and depth. The main projects addressed:

- Area of eucalypt regrowth available and suitable for thinning;
- Prediction of growth response from thinning;
- Evaluation of spacing and thinning technologies;
- Damage to retained trees caused by thinning operations;

- Methods for debarking;
- Methods for drying sawn timber from young, small trees;
- Kraft pulping;
- Economic analyses of alternative management regimes.

The results from the YEP were very encouraging for the future treatment of young regrowth stands. The program identified some 100 000 ha of fast-growing eucalypt regrowth in Tasmania and Victoria as suitable for thinning. It was concluded that there were no major theoretical obstacles to the implementation of a range of management options involving thinning and that all the thinning treatments would yield more commercially usable wood per hectare per year than unthinned stands (Kerruish and Rawlins 1991).

Inspecting retained trees for stem damage from a thinning operation, mid 1990s. (John Cunningham pictured.)

The increased emphasis on more intensive management of native forests and plantations by the Forestry Commission in the late 1980s and early 1990s resulted in an expansion of investigations into utilising different thinning strategies to maximise sawlog production from a given area in a given time. These investigations included trials of pre-commercial thinning (PCT), also known as early-age or mid-age spacing, to prepare the stand for a commercial thinning and to enable this operation to be conducted earlier in the life of the stand than would otherwise be possible.

In 1985–86, David Minifie continued the thinning research, including trials of PCT using stem injection with herbicide to kill competing stems in young eucalypt regrowth stands, a project conducted in co-operation with Deloraine District. A second trial in Geeveston District determined the minimum effective dose for killing competing eucalypt and wattle stems, and this work formed the basis of early prescriptions for chemical thinning.

Thinning research in Tasmanian forests received another major boost in 1990. Under the Intensive Forest Management Program (see Chapter 5), a Research Officer, Gary Brown, was appointed to a five-year project to quantify the growth response to thinning regrowth eucalypts of different ages and to develop strategies involving both PCT and commercial thinning. Several new thinning trials were established and results were collated from many of the older existing trials. Key findings from this project are summarised below (from G. Brown 1996):

- Growth response of retained trees after thinning is positive and linear and can continue for at least 25 years after thinning.
- Younger stands respond the most, with older stands having a lower but more protracted response.
- Growth response is positively correlated with initial stem diameter.

A cable-thinned stand of 29-year-old *Eucalyptus regnans* in the Florentine Valley. Logs harvested in the thinning operation are pulled laterally from the forest into the outrow (centre of photo) and then hauled along it to the road edge.

- There is a positive relationship between clear bole length and stocking density in *E. obliqua*. The increase in length of the clear bole is reduced by thinning. A dense understorey encourages the development of a clear bole and its removal results in reduced clear-bole length.
- Overall stand basal area increment in response to thinning is only reduced when more than half of the original stand basal area is removed.
- Thinning markedly increases the potential sawlog to pulpwood ratio.

A general conclusion from these studies, which assisted policy development in Forestry Tasmania on intensive forest management, was that rotation lengths in eucalypt regrowth could be reduced by 10–20 years using thinning strategies tailored to stand age and site (Brown 1997).

A most significant part of the thinning research conducted under the IFM program was the development of operational techniques and monitoring systems co-ordinated by John Cunningham. This work evaluated PCT and commercial thinning for cost and productivity,

Spreading fertiliser in a pre-commercial thinning and fertiliser trial in 21-year-old *Eucalyptus obliqua* regrowth in eastern Tasmania. (Ann LaSala, left, and Neil McCormick.)

and developed monitoring systems for safety procedures and for residual damage to retained stems. The program resulted in the design and implementation of an effective cable-thinning operation using a purpose-built cable-harvesting machine new to the State. This work demonstrated the commercial potential of cable thinning in eucalypt regrowth stands, with the added benefits of minimal soil disturbance and low visual impacts compared with ground-based thinning operations (Cunningham 1997).

The thinning research conducted under the IFM program enabled the production of operational prescriptions for PCT and commercial thinning for use in the expanded thinning program on which Forestry Tasmania had embarked (Forestry Tasmania 1998b). Further work in the late 1990s by Anne LaSala, Jo Dingle and John Cunningham quantified the response of young regrowth stands to PCT and enabled the development of recommendations on the best time to apply stem injection treatments and monitor their effects (LaSala 2000; LaSala and Dingle 2000).

Now that good information was available on growth response to thinning, techniques for PCT and commercial operations, and monitoring systems for contractor performance, the major need for Forestry Tasmania was to determine the best thinning regimes for larger scale operational use in young high-quality eucalypt regrowth stands. Various simulated thinning regimes were evaluated by Anne LaSala in terms of maximising sawlog volumes and economic performance. This modelling, using data from assessments of regrowth stands, evaluated various combinations of PCT and commercial thinnings, and compared them with an unthinned regime. The highest sawlog yield at age 65 years was produced by a thinning regime of PCT plus one commercial thinning. The highest financial returns (in terms of Net Present Value) were produced by a regime with one commercial thinning. In practice, management objectives such as total sawlog yield or production of a certain product at a particular age will determine the choice of thinning regime (LaSala *et al*. 2004). Further research on the use of PCT and fertiliser (N and P) application in eucalypt regrowth aged 16–21 years has confirmed that these are both useful tools in preparing such stands for later commercial thinning (LaSala 2007).

Eucalypt Silviculture: Then and Now

Eighty-five years of research and development in the eucalypt forests of Tasmania has brought great changes in the way they are managed. In the 1920s, the only silvicultural treatments were a few opportunistic thinning operations conducted without any data on the level of tree retention appropriate to the type and structure of the forest. Today, after the decades of research and operations described in this chapter, specific harvesting and regeneration techniques are available for each major forest type, and these are applied based on the nature of the forest at the individual harvesting unit level. For example, partial harvesting systems are appropriate for many dry forests but the presence and distribution of potential sawlogs or advance growth on individual coupes before harvesting will determine the type of partial harvesting regime to be applied.

Central to the development of these silvicultural methods for eucalypt forests has been the ecological research conducted in the different types. Understanding the ecology of wet eucalypt forest, particularly the role of fire, laid the basis for the clearfell, burn and sow technique which has successfully regenerated several hundred thousand hectares of this forest type. Similarly, the research into the environmental factors operating in the high-altitude forests and studies of the ecology of the highly variable, multi-aged dry forests were an essential basis for the development of appropriate silviculture for these types.

Thinning is now a very important part of eucalypt silvicultural practice and there is detailed information on growth response in different forest types after varying thinning intensities. Better selection of retained trees that do not have internal defect (see Chapter 6) is now possible, and monitoring systems are used to keep track of damage to retained trees so that damage levels can be kept low during operations. A range of sophisticated harvesting equipment is also available for different types of thinning operations. Most importantly, the economics are known for a range of thinning regimes designed to produce particular products at certain ages.

Silvicultural methods will need to change as management objectives evolve. In the future, there will be an increased emphasis on tailoring silvicultural methods to produce wood products for specific markets. In addition to the developments relating to productivity and economics in eucalypt forestry, environmental factors and social perceptions are now a major influence on forest management methods used by Forestry Tasmania and other forest managers. The increased awareness of maintaining biodiversity, water quality, aesthetics and other natural values of managed forests in the landscape has led to the development of variable retention systems for tall oldgrowth forests. This concept could also potentially be applied to thinning prescriptions for eucalypt regrowth, where some part of a coupe could be deliberately left unthinned to provide a greater range of structural and understorey types within thinned coupes (J. Hickey, pers. comm.).

Chapter 3

Fire Management

Introduction

Fire is a fundamental part of the ecology of Tasmanian forests and has a major influence on the composition and distribution of vegetation types. Tasmania's extensive forests and flammable vegetation types periodically provide ideal conditions for wildfires to spread rapidly, particularly during extended dry spells. Fire was widely used by the Tasmanian Aborigines as often noted by early European explorers; the influences of Aboriginal fires on the State's vegetation are discussed in *Vegetation of Tasmania* (Reid *et al.* 1999).

Much of Tasmania's mature and oldgrowth eucalypt forest originated following wildfires that occurred before European settlement. Since that event, there has been a well-documented history of large wildfires (e.g. in 1851, 1880, 1898, 1914, 1918, 1934, 1961, 1966, 1967, 1982) that damaged life and property but, importantly, were also the origin of fine eucalypt regrowth forests. The history of fire management in the State is one of establishing a legislative policy framework and developing and changing techniques to reduce the occurrence of damaging fires. In more recent years, fire has been used beneficially for reduction of fuel accumulations and for forest regeneration.

The first legislation introduced by the State to address the bushfire problem was the *Bush Fires Act 1854,* its main purpose being to protect fences and other rural private property. The Act prescribed penalties for 'wilfully or negligently lighting a fire or occasioning a fire to be lighted during the months of December, January, February and March on land of which he is not the owner'. In 1894, a regulation under the *Crown Lands Act 1890* prohibited the lighting of fires on unoccupied Crown land except with the permission of the Commissioner for Crown Lands, with a penalty not exceeding £5 ($10). Apart from the *Bush Fires Act 1854,* this regulation was the only legislative attempt to that date to control bushfires. In February 1896, a further regulation prohibited lighting of fires on sawmilling licence areas between 1 October and 31 March unless a space of 12 feet (3.7 m) was cleared in every direction around such a fire. The same regulation prohibited the 'firing' of scrub or forest on such sawmilling licence areas under pain of cancellation of the licence. It is doubtful if this regulation was ever enforced as the practice of burning the bush after selective logging was still very widespread in the 1920s (Steane 1947).

One of the worst fire seasons ever recorded in Tasmania occurred in the 1897–98 summer, only some twenty years before the Forestry Department was created.

Steane (1947) noted the initial mild response to the 1897–98 fires that reflected the tolerant attitude at the time towards bushfire control:

> *Consequent on the great destruction to property by bush fires throughout the country during last summer, which, in many cases, rendered poor people homeless, and even in some instances unfortunately resulted in the loss of human lives, it was considered desirable to reprint and issue copies of 'The Bush Fires Act'. Special notices were also circulated cautioning persons against lighting any bush fires, except as within the conditions prescribed by law.* [Steane 1947, p. 10]

However, a report by Mr Counsel, Secretary of the Lands and Surveys Department, to the Minister in 1898 entitled *The Timber Industry of Tasmania* contained several recommendations for improving forest policy and management in the State, including 'stringent measures for preventing the lighting of bush fires on unoccupied Crown lands'. In response to Counsel's report, the Government obtained a report from Mr George Perrin, the former Conservator of Forests for Tasmania who was, by then, the Conservator of State Forests, Victoria. In his report, Perrin states:

> *… the condition of the Tasmanian forests is infinitely worse today than at the date of my report in 1886–87. Another decade of waste, of private monopoly, of fierce bush fires, of neglect by the Government to check the damage to public property, must ultimately result in disaster to the industries and to thousands of people dependent upon the timber resources of the Colony.* [Steane 1947, p. 13]

In 1915, Counsel again commented on the bush-fire problem, including a pointed remark on a perceived lack of responsibility by forest users:

> *It is futile to talk of preventing bush fires in Tasmania, from the very fact that the lands in our agricultural settlements are covered with a dense scrub that can only be disposed of by being cut down, and when sufficiently exposed to the sun and air burnt by a fierce fire, which frequently extends far into the virgin forest, and sometimes travels for many miles, sweeping all before it, as in the case of the devastating fires which occurred last year in the north coast settlements, or some years before in the vicinity of Mt Wellington and the Huon districts, when the homes of some poor people were utterly demolished, and in some cases human lives were actually sacrificed. It is a significant fact, worthy of note, that the agitation for preventing bush fires, and the consequent destruction of valuable timbers, never comes from those who have devoted their lives to and made a success of sawmilling or farming industries.* [Lands and Surveys Department 1915a, p. 5]

BUSH FIRES

IN

WESTERN AND SOUTHERN TASMANIA

WHOLE DISTRICTS DEVASTATED

COLONISTS BURNT TO DEATH, AND HOMES DESTROYED.

The Tasmanian Mail
January 8, 1898

Headlines in the local newspaper, 8 January 1898.

Just prior to the formation of the Forestry Department, the Conservator, Llewellyn Irby (appointed in December 1919), emphasised the overriding need to control fires if viable forestry were to be practised in the State:

> *... natural reafforestation will eventually prove abortive unless steps are taken to protect areas of regrowth from fire. Excellent crops of seedling eucalyptus were observed in most parts of the State, but from numerous object-lessons to be seen after last summer, they stand badly in need of fire protection.* [Lands and Surveys Department 1920, p. 18]

In the first Annual Report of the new Forestry Department, the Conservator addressed the

Wildfire in Tasmanian eucalypt forest in 1984.

problem of forest fires and set out measures for fire management (Forestry Department 1921, p. 8):

Owing to a larger and more even rainfall than the mainland, Tasmania is not usually confronted with the menace of severe bush fires recurring annually, and, as a general thing, it is only once in several years that the fire risk becomes alarming.

On the other hand, this very immunity from fire during several years of good rainfall becomes in itself an added source of danger to the forests in that the accumulation of debris becomes proportionately heavier than in a locality where the fires are more frequent.

As a consequence, when the real fire day arrives, and the fire comes sweeping through this accumulated debris of years, with a strong wind behind it, 'all the King's horses and all the King's men' would be helpless to combat it. Fire breaks are crossed as though they did not exist, and burning pieces of bark may be carried a quarter of a mile or more ahead of the conflagration.

Fire protection measures in the future must therefore take the course of:

(a) Endeavouring by every means possible to check the indiscriminate lighting of fires when likely to get out of control, which includes the severe punishment of offenders when traced.

(b) Constant patrol of valuable young forests during the fire season, in order that when a fire has started it may be attacked in the earliest stages. This necessitates the formation of tracks and breaks, in order that transit from one part to another by the fire-fighters may be rapid and effective.

An old Beattie photo entitled 'Forest devastation: swamp gum forest near Tyenna', taken after the bad fires of 1934 in southern Tasmania.

An important initial contribution by Llewellyn Irby towards getting some organisation into forest management in the State, including controlling fires, was the establishment of Forest Districts.

> *By way of starting on the tightening up of bush control and decentralising the work generally, Irby organised the Department's forest jurisdiction into five Forest Districts.* [Steane 1947, p. 20]

The damage from severe bushfires was highlighted in many subsequent Annual Reports of the Department. Some thousands of acres of 'young native regrowth' were burnt in 1932–33, 'the worst fire season since the Department started'. In the huge fires of 1934, there was great loss of life and property, and large areas of native forest and some plantations were burnt in southern and western Tasmania, particularly in the Tyenna Valley and at Uxbridge and Moogara. The *Bushfires Act 1854* was amended in 1935 after these devastating fires, with more restrictions on fire use and with most of the power for administration of the Act vested in the Conservator of Forests (Carron 1985).

The worst bushfire disaster in Tasmania's history occurred on 7 February 1967, inflicting heavy loss of life and property in the south-east, with 62 lives lost and over 653 000 acres (261 000 ha) of land being burnt (Chambers and Brettingham-Moore 1967).

Dense, natural regeneration of *Eucalyptus regnans* under a stand killed by fire in February 1967 at Fern Tree, Mount Wellington. The photo was taken in September 1969.

On the positive side, some of today's best eucalypt regrowth stands originated from these fires.

Much of the improvement in the management and use of fire by Forestry Tasmania, particularly fire-control techniques, is the result of incremental changes gained from operational experience. This has come from managing wildfires and conducting high-intensity burns to regenerate forests and fuel reduction burning to reduce fire hazard. This ongoing operational development has been supported by research activities in such areas as fuel characterisation and the effects of fire on flora and fauna, topics which are more suited to traditional research trials involving experimentation and extensive data collection and analysis.

Some aspects of fire management research and development relating to regeneration of eucalypt forests were mentioned in Chapter 2. The present chapter provides an account of the history of fire research and development by the Forestry Department and its successors, beginning with the early years of fire detection and fire-control equipment and techniques, and progressing through to today's sophisticated fire-behaviour prediction methods, regeneration establishment and fuel reduction burning techniques and the management of the ecological effects of fire.

Fire Detection

Systematic study of fires by the Department really began with gaining basic but essential knowledge such as identifying the origin of fires. An early observation on the source of damaging fires was transmitted from Mr R. Garrett, the District Forest Officer for the North-Western District, to the Conservator of Forests:

> *I wish to bring under your notice, Sir, that it is the habit of men employed on many grazing leases, whether acting under instructions from the lessees I know not, to ride about during summer months dropping lighted matches, firing the plains and open forests, which often results in great damage to standing timber and young regrowth.* [Forestry Department 1927, p. 9]

Some of the causes of fires in those early years are very familiar to today's foresters while others are more a product of a bygone era. For example, 57 fires caused by steam locomotives in 1935–36 were extinguished by the Marrawah Patrol in north-western Tasmania along the local railway line (Forestry Department 1936). An analysis of 239 fires reported in 1939–40 show that 130 were caused by burning-off by 'graziers and settlers', 40 from locomotives, seven from 'campers and picnic parties', two from burning-off by Government employees, and 60 were untraced (Forestry Department 1940). Only some 20 years later, reports on the extensive 1960–61 fires show that, while private land-owners were still the major identified source of wildfires, trains were no longer a factor. A total of 480 fires were reported: major sources were farmers and graziers (107), hunters and fisher-men (60), incendiarists (41), timber getters (19), miners and prospectors (10), Government employees (8), trains (0), all others (46), origin unknown (189) (Forestry Commission 1961).

Some of the 'unknown' causes of fires could be attributed to lightning. This ignition source was considered much less frequent than in mainland States (*The Mercury* 1961), but lightning fires were recorded in the 1961–62 fire season:

> *An interesting feature of the 1961–62 fire season was that for the first time lightning became a significant source of forest fires in Tasmania. Five fires resulted from lightning.* [Forestry Commission 1962, p. 7]

The deliberate lighting of fires by timber getters to remove scrub before logging, and slash after logging, and by landowners to protect their assets and help clear forest was a major source of wildfires for many years before this activity was controlled. Measures to contain these fires within predetermined boundaries were (probably) rarely taken, and fires sometimes burnt large areas of forest. In the case of cut-over eucalypt forest, especially wet forest types, extensive areas of regrowth forest often resulted.

Procedures for managing wildfires developed slowly. Early detection of fires was a first priority but, even when fires were detected, it often took a long time to report their locations to fire-fighting crews. It was not until the 1940s when the first fire towers were constructed (Cubit 1996) that fires could be detected at considerable distances and information on their locations telephoned through to the District Offices, thus enabling a more rapid response. During the war years, volunteers from local communities assisted with operating the fire towers. Another innovation was staffing two of the towers with women (Forestry Department 1943). The valuable contribution of the fire towers to overall fire-control operations was noted:

> *The second feature* [of fire control operations] *was the successful co-ordination of detection of outbreaks from look-out towers, with two-way radio communication to despatch fire-fighting crews to the fires and rapid transport over roads constructed for that purpose. Only by these means was the damage to valuable timber areas kept to a minimum in the Gould's Country forest. In the Urana forest where these facilities have not yet been provided, the task of controlling fires was more difficult and called for much greater expenditure of money and effort.* [Forestry Commission 1952, p. 5]

Detection was further improved by the use of aircraft, pioneered by Wes Beckett in the 1950s in the Circular Head area (Cubit 1996), and this technique soon became a standard part of the Forestry Commission's fire management procedures. It was not only a vast improvement on sole reliance on fire towers, but also led to a reduction in the number of illegal fires because of the fear by arsonists and those lighting irresponsible burn-offs that they would be quickly spotted. The use of aerial detection was refined by combining information on past fire records with fire weather prediction data in the form of the McArthur Fire Danger Index (McArthur 1967). Thus, it was then possible to time aerial detection with periods of greatest known fire risk (Cubit 1996).

The progressive improvement in communication technology since the first telephone links with

Monitoring fire occurrences from Doodys Hill fire tower near Geeveston. (Tim Geard pictured.)

An early fire tower at Walduck Hill, south of Scottsdale in north-eastern Tasmania, 1950.

A modern fire tower at Mount Hobbs near Buckland. Note the telecommunications equipment.

the fire towers in the 1940s was a key element in the development of better fire detection and reduced response times. Radio communication evolved from the early high-frequency sets introduced in the 1950s, through to VHF radios and a Statewide radio communication network, strongly encouraged and developed by Jim Hickman, the Fire Protection Officer, following the disastrous fires of 1967 in consultation with other Government Departments (Cubit 1996). Constantly advancing technology has significantly benefited fire management through the use of airborne global positioning systems (GPS) carried in helicopters to pinpoint fire locations and mark fire boundaries, portable repeaters for managing communications at fires or in remote areas, and digital mobile phones.

As well as visible fires in the landscape, damaging fires can start from 'invisible' ignition sources; for example, smouldering bark and peat fires. These fires can remain alight for many months, even through long wet periods, and have started several serious bushfires when fuels dry out in spring and summer. Reliable detection of sub-surface fire was eventually achieved by the use of an infra-red detector brought to Tasmania by a Canadian forester, Stuart Hagell. Thermal imaging cameras are now routinely used to detect heat from smouldering fires in bark heaps at log landings and elsewhere under the ground.

Fire-Control Equipment and Techniques

Early fire control relied on hand tools and hard labour to establish firebreaks to stop, or at least delay, the progress of wildfires. Even basic fire-control equipment such as pumps was not available to forestry fire crews. In this context, there was considerable anxiety expressed in the early Annual Reports of the Forestry Department regarding fire-protection capabilities, strong words sometimes being used to describe a perceived lack of support from certain quarters:

> *No support was forthcoming from the apathetic public nor from the equally apathetic Municipal Councils. In 1933–34 lack of funds prevented*

Using a thermal imaging camera from a helicopter. These cameras are used to detect 'invisible' fires in places such as windrows and smouldering edges of wildfires. Nowdays, this type of equipment is mounted in helicopters rather than being hand-held. (Rod McNeil pictured.)

any patrolling and also stopped all work on the tracks and firelines already embarked on. Out of its very meagre funds the department managed to buy half a dozen knapsack pumps, for which it was immediately ridiculed in the House of Assembly for its futile waste of public money; the main argument being that when the pumps were taken to a fire there would probably be no water and so they would be useless. [Steane 1947, pp. 21–22]

However, the summer of 1933–34 brought the worst fire season Tasmania had experienced since 1897–98, and the knapsack pumps proved invaluable. In a blunt rebuttal of the high-level criticism of the acquisition of some of the first fire-fighting technology used by the Department, the Conservator, Sam Steane remarked:

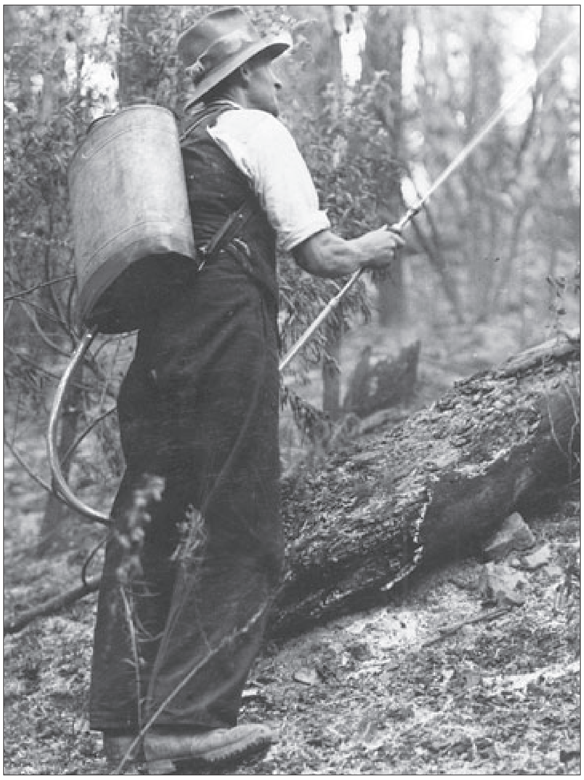
> *It is worth recording that the knapsack pumps purchased in the previous season which had been so severely condemned and ridiculed by at least one Member in the House of Assembly, proved invaluable, and regrets were expressed everywhere that we had not enough of them.* [Forestry Department 1935, p. 6]

The wisdom of these initial purchases was again emphasised in the following year:

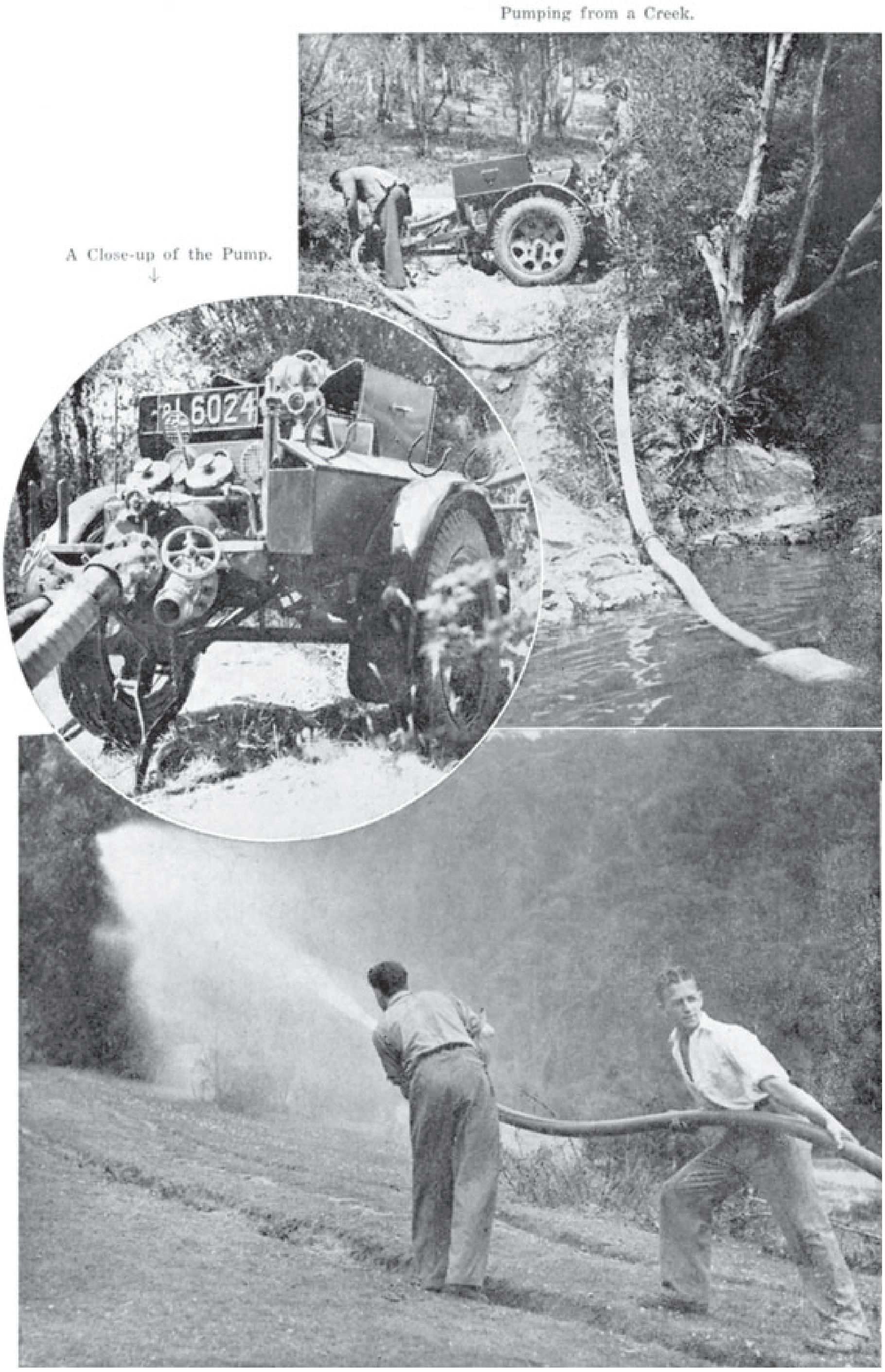
> *The portable fire-fighting motor pumps purchased in 1934 proved very effective ... Both the Wajax motor pumps and the Knapsack pumps have created a very favourable impression and enquiries have been received from various public bodies as well as sawmillers, landowners and others.* [Forestry Department 1936, p. 5]

By then, with the severe impacts of the 1934 fires, Cabinet was much more aware of the need for better fire-protection equipment and organisation of fire-control procedures. Consequently, the Conservator was instructed to consider what equipment should be purchased on the understanding that funds would somehow be made available. Unfortunately, by the time decisions had been made and quotations obtained, Cabinet had come to the conclusion that the necessary funds would not be forthcoming. However, in 1935, a new and much improved *Bush Fires Act* was passed to replace the long-out-of-date Act of 1854 (Steane 1947).

Training of teams for deploying the portable fire-fighting motor pumps continued through 1936–37, and 1689 chains (34 km) of fire lines were cut that year. By the following year, it was reported that every forest division had at least one motor fire pump and that volunteer fire-fighting crews had been trained in the use of Dennis trailer pumps. The equipment and training were sorely needed because the impact of fires in the 1930s was severe. The 1938–39 fire season, at least in the north, was one of the worst in 40 years, but not as bad as the 1934 season in the south. Losses from the 1934 fire were estimated at about 40 million super feet (94 340 m^3), representing (incredibly) a bit less than half the annual cut for the whole State (Forestry Department 1935).



A firefighter using an early hand water (or knapsack) pump to extinguish burning logs and tree trunks in a fire on Mount Wellington (date unknown but possibly 1930s). Notes on the original photo mention that 'the scrub and undergrowth has been completely burnt out'.



Details of the Dennis Pump taken from the Forestry Department's 1938–39 Annual Report. The collection of photos is entitled 'A Dennis Fire pump in action', with the caption for the bottom photo given as 'The hose in action, throwing a jet of approximately 100 feet'.

During the early 1940s, the Department's fire-protection system was re-organised. Colonel Denis Lane, who had been Working Plans Officer, was put in charge of the newly created Fire Protection Branch in September 1940 and held that charge till February 1945. By then, fire plans had been prepared for the various Fire Districts and a system of fire look-outs was being developed, supplementing and, to a large extent, gradually replacing the patrolling system; the fire-break and patrol-track network was also being developed. Whereas in 1934 the Department had six knapsack pumps, by 1947 it had 33 power pumps and hundreds of knapsack pumps, and manual fire-fighting equipment to match (Steane 1947). A most important development in improving the effectiveness of fire control in Tasmania at this time was the setting up of the Rural Fires Board in 1950 under the *Rural Fires Act 1950*. This was an initiative of Alec Crane, the first Chief Commissioner of the Forestry Commission, who also became the first Chairman of the Rural Fires Board.

In the early 1960s, the Commission's fire-control equipment was significantly expanded. Seven new two-way radios and nine small, highly portable FM radios were purchased and one experimental slip-on tanker unit was designed and constructed. Four one-ton 4WD vehicles were purchased for fire-fighting and four 200 gallon (909 litre capacity) slip-on tankers provided for use with 30 cwt (1525 kg) 4WD Jeeps. For difficult terrain, a Bombadier Muskeg tractor was purchased, fitted with a front-mounted blade and tanks for carrying 360 gallons (1637 litre capacity) of water. A major initiative of the decade of the 1960s was the construction of over 800 km of firebreaks and 560 km of light duty roads (Cunningham 1989), which greatly improved the fire protection and control capabilities of the Commission.

The devastating fires of Black Tuesday, 7 February 1967, severely tested the available equipment. One finding of the subsequent inquiry into these fires (Chambers and Brettingham-Moore 1967)

The aftermath of the devastating Black Tuesday fires of 7 February 1967. The photo, taken in January 1968, shows severely burnt *Eucalyptus obliqua* regrowth on Snug Tiers.

was that there was a great diversity of fire-fighting pumps and a lack of standardisation and compatibility between the equipment of the different fire-fighting organisations, particularly in relation to such basic matters as fire-hose diameters and couplings. Incompatibility of radio communications facilities between organisations was found to be another significant failing. Following the 1967 fires and the subsequent inquiry, there were sweeping changes in legislation, with the *Rural Fires Act 1967* being passed, and in responsibilities for rural fire control (Cunningham 1989). Jim Hickman was responsible for introducing modern light-weight, high-performance Tohatsu pumps from Japan (P. Bennett, pers. comm.). These were robust centrifugal pumps that were simple to operate and relatively 'foolproof'. They were to be the mainstay of forest fire-fighting by the Forestry Commission and the volunteer rural fire brigade system for the next twenty years.

Above: A heavy tanker used by the Forestry Commission. The tanks, pump and crew haven are an integrated module which can be removed in the off-season and the truck can then be used for other purposes.

Left: A Class 4 fire tanker with an aluminium tank and a single fire pump.

Fire tankers designed for the Forestry Commission were utilitarian and multi-purpose because they were for a forestry organisation rather than a fire service. Most had slip-on tanks so the truck unit could be used in winter for carting gravel and other general tasks. This philosophy of tanker design, encouraged by the first Chief Commissioner, Alec Crane, differed from that in many other organisations. However, with the exception of ten purpose-built heavy duty 4 x 4 fire-fighting units constructed in the early 1970s, most of these tankers were heavy 6 x 4 and 6 x 2 tipper trucks, with large slip-on tank units and without standardisation of plumbing. Thus, although they were multi-purpose vehicles, they had several limitations, including poor off-road performance, inadequate crew protection, diminished carrying capacity (because of the tipper body) and, overall, represented an inefficient use of capital (Geard and Bennett 1991). To overcome these limitations, Forestry Tasmania's Fire Management Branch, in conjunction with Plant Workshop staff and private engineering companies, designed a replacement tanker system. The basis was a five tonne, 4WD cab chassis which could carry interchangeable modules—a heavy duty forest fire tanker, a tipper, or a tray which could be attached when a tanker was not required (Geard and Bennett 1991). These units were backed up by the development of smaller slip-on tankers designed to be carried on 1.5 tonne, 4 x 4 gang work vehicles and 1.0 tonne staff vehicles.

Tanker equipment was further refined in 1994 with the development of a pump-testing system by Gary Kennedy (Plant Workshop) and Peter Bennett (Fire Management Branch). This system enabled rapid assessment of pumps using a new application for a venturi flow meter to determine flow rates, lift capacity and pressure (Kennedy and Bennett 1994).

The concept of using aircraft in forest fire-fighting in Tasmania was first explored in the 1970s by Brian Hodgson, a Tasmanian forester who had spent some time working in Canada where there was extensive use of water bombing with specialised aircraft. A scarcity of suitable aircraft and prohibitive costs prevented any serious development of water bombing in Tasmania for some years. However, from the 1970s, twin-engined, fixed-wing aircraft had been used extensively for aerial prescribed burning, dropping incendiary capsules in grid patterns over large areas of dry sclerophyll forest and remote buttongrass plains. During the 1980s, three crews of fit young employees were trained and equipped for remote area fire-fighting using small helicopters for deployment.

In 1988, there was a large fire in the Jubilee Range in south-western Tasmania, an area with no ground access for equipment and where considerable damage would occur if

A Squirrel AS40B helicopter dropping a water/foam mixture from a collapsible bambi bucket during trials near Craigebourne Dam, south-eastern Tasmania.

Helitack training, 1985. Helitack is a helicopter-based operation developed in the 1970s to provide an effective means of fighting fires in remote areas by rapidly transporting crews and equipment to positions where they are best placed to attend the fire.

the fire spread. This fire focussed attention on the need for an aerial fire-fighting capability. Coincidentally at this time, the Victorian Division of the National Safety Council of Australia deployed two Bell 205H medium helicopters with water-bombing capability to Tasmania. Forestry staff learnt the art of aerial fire-fighting and resources deployment on the job in an extended campaign involving strategic burnouts of large areas of buttongrass, remote area camping, night fire-fighting and water bombing.

Peter Bennett was then Deputy Fire Management Officer and responsible for the engagement of Rod McNeil as a dedicated Air Operations Officer. Rod oversaw the development of the Helitack crews; this system involves the use of helicopters to rapidly deploy staff and equipment to fight fires in remote areas inaccessible by more conventional means. This period also saw the improved use of aircraft in other areas of forest management such as aerial fertilising of plantations, and the further development of aerial fire-management systems. These included the use of foam injection into the buckets used for water bombing, and high-altitude, infra-red line scanning of active fires, first used on the Lune River fire in 1988.

The capability and range of current fire-fighting equipment now used by Forestry Tasmania contrasts greatly with those first knapsack spray pumps purchased in 1934 with associated criticism. Current equipment, much of which has been modified by forestry staff to suit particular operations, comprises heavy fire tanker units with a water-carrying capacity of 3800 litre, slip-on units (630 litre capacity) and mini slip-ons (480 litre capacity). These tankers are backed up by a large range of pumps of varying pressures, hoses, nozzles, water-storage units, backpacks and hand tools. Other specialised equipment such as bladders and buckets suitable for transport by helicopter to remote locations, and portable automatic weather stations to provide weather information via a radio link, are also used (Forestry Tasmania 2002a).

Management of Fire-Fighting

In addition to the acquisition and development of sophisticated fire-fighting equipment and associated staff training, the organisational methods for tackling large wildfires have also had to change to enable effective fire management. Although not strictly research as such, improvements and re-organisation of administrative structures, systems and responsibilities are so critical when dealing with large wildfires that they are included as part of this account of fire research and development. Developments along these lines commenced with the introduction of the *Fire Service Act 1979* that saw the amalgamation of the urban and rural fire services under one authority and greatly simplified the chain of command in the sector. This subject is particularly important in Tasmania because Forestry Tasmania is not the only large forest manager in the State and good co-operation with others is essential for effective fire prevention and control.

The three major agencies in Tasmania that have responsibility for fire-control operations are the Tasmania Fire Service, Parks and Wildlife Service, and Forestry Tasmania. Under their separate Acts of Parliament, each of these bodies has different systems and priorities and, for many years, although there was some degree of co-operation, it was not as effective as it could have been. A major driver for better co-operation between these agencies was agreement by all three to use the Incident Control System (ICS) for managing large fires.

The ICS is a part of the Australian Inter-service Incident Management System (AIIMS). It originated in the United States of America and has been adopted by most fire-fighting agencies in Australia since the late 1980s. The ICS provides a consistent approach to incident management, and covers the specific and defined areas of control, planning, operations and logistics. It uses procedures familiar to each of the agencies, while still allowing them to retain their own command structures at levels below the four-person incident management team, which takes responsibility for managing large fires when working in joint operations. Forestry Tasmania Fire Management Officers Peter Bennett, and subsequently Dick Chuter, played key roles in introducing and developing this highly successful system which has significantly improved the quality and efficiency of organisation seen in managing large fires.

In 2000, following a large fire in southern Tasmania and the experience gained by Tasmanian firefighters assisting in the control operations for the huge fires of that year in the United States of America, a Multi-Agency Co-ordinating Group (MAC) was formed to strengthen centralised co-ordination between the three Tasmanian fire-fighting agencies. The group developed policies, performance standards and associated training needs for all the functional areas of the ICS. Incident Management Teams were appointed by the MAC to tackle large fires as they occurred. The value of this multi-agency team approach was clearly demonstrated by the very effective management of subsequent large fires in 2001 and 2002.

In 1994, the three agencies developed an Inter-Agency Fire Management Protocol designed to ensure that management of fires in vegetation, including fire-suppression operations, would be based on co-operation and mutual respect. This protocol has resulted in resource sharing, development of compatible training and fire-suppression methods, joint research through a Fire Research Fund (see below), common planning and methods for prescribed burning, shared aerial and fixed detection, a common system for wildfire investigation and the sharing of specialist functions such as infra-red detection, aerial incendiary machine operators and aerial mapping of fires.

The Fire Research Fund was established in 1995 as a co-operative funding effort by Forestry Tasmania, Parks and Wildlife Service, and the Tasmania Fire Service. The aim of the fund is to promote an interest in University students to study fire research and fire matters relevant to the practical fire-management needs of the three funding agencies. Examples of projects supported by the fund are: the effects of bush-fires on stream hydrology (Mounster 1995), fire-retardant garden plants for use in urban fringe and rural areas (Chladil and Sheridan 1997) and burning in buttongrass moorlands (Marsden-Smedley *et al*. 1998).

Predicting Fire Behaviour

Weather conditions

Current weather conditions—temperature, wind speed and humidity—are the key factors used to predict the behaviour of a fire. Fuel quantities, sizes and arrangement are important, as are the moisture contents of each of the components of the fuel; developments relating to these factors are discussed below.

The first fire-behaviour prediction measures introduced by the Forestry Department were reported in the mid 1930s:

> *A fire danger station was installed at Mawbanna during the year with a view to correlating observable conditions with approaching fire danger conditions. Two or three other similar stations are being installed for the coming season.* [Forestry Department 1936, p. 5]

The location of this station in the far north-west may have been chosen because periods of severe fire weather (high temperatures, strong winds and low relative humidity) preceding the development of a low pressure system are typically first experienced in the north-west and then spread to the east and south, thus affording an opportunity to alert forest districts down-wind.

That early beginning recognised the importance of current weather in making fires spread. The weather parameters that govern rate of spread can be easily and precisely measured and, over the decades, meteorologists have learnt to accurately predict weather conditions, including those that indicate extreme fire danger, some days ahead. The McArthur Fire Danger Index was produced by Alan McArthur in Canberra in the 1960s as a way of integrating measured weather parameters to indicate likely rates of fire spread. The first version of the Index incorporated a simple assessor of drought conditions which was refined in Tasmania by Tony Mount after he had developed the Soil Dryness Index (see below).

Fuel moisture

The moisture content of fuels has a huge impact on the fierceness with which they will burn. Fuel moisture (or hazard) sticks are used as an index of the moisture content of fine fuels and therefore of potential fire behaviour. The use of fuel moisture sticks originated in the USA in the 1920s. They were first used in Tasmania by the Forestry Commission in the late 1940s and their contribution to forecasting fire danger was immediately recognised:

> *The Commission has continued its reading of fire-hazard indicator sticks in each division. This data is transmitted directly each day in summer to the Commonwealth Meteorological Bureau. The fire-hazard stick gives a measure of the degree of inflammability of the undergrowth and litter on the forest floor. The Meteorologist combines this data with weather data with the objective of forecasting the fire danger for the following day. A continuous study is made of the effect of weather conditions on the moisture content of forest fuels. For the last summer it is reported that the accuracy of the forecast of fire danger rating was 86.1 per cent.* [Forestry Commission 1949, p. 9]

Later on, hazard sticks began to be an essential component of deciding when to burn logging slash for both high-intensity burning and low-intensity burns under young eucalypt regrowth. Unpublished studies by Ken Felton of moisture contents of logging slash fuels (see Chapter 2) showed that the moisture content of twigs fully exposed to the sun, of similar cross-sectional area to hazard sticks, were very similar to those of the sticks having the same exposure. The moisture content of the sticks was therefore a good indicator of the ease of ignition and spread of the fire within a fuel pile.

Sets of three radiata pine sticks with a cross-section of 10 mm x 10 mm and an oven-dry weight of 100 g are placed on stands some 200 mm above soil level and their weight after periods of exposure is compared with their oven-dry weight to determine moisture content. They are mainly used when planning regeneration establishment burns to determine the differential moisture content between the slash in logged areas and that of the surrounding unlogged forest.

The relationship between stick readings and the moisture content of the actual fuels was studied in detail in a research project conducted by Zati Eron in the early 1990s (Eron 1991). The moisture content of sets of fuel moisture sticks exposed at different heights in logged and unlogged areas was compared with fuel samples collected near the stick sets. From these data, stick-drying curves and the relationship between stick readings and fuel moisture content were derived, thus providing a better basis for forest managers to predict if and when the logging slash is suitable for burning and the surrounding forest is safe from escapes.

Pine hazard sticks in place for determining the moisture content of fine forest fuels.

The moisture content of dead fuels is currently being investigated in a project initiated by Alen Slijepcevic when working in the Fire Management Branch. The trials are located in a range of forest types on the lower foothills of Mount Wellington. The aim is to develop models for predicting the moisture content of dead fuels to assist operational fire management. Many meteorological and site factors are being recorded as inputs into the models. These include Soil Dryness Index, Drought Factor, relative humidity, dew-point temperature, rainfall, wind speed, cloud cover, time of year, vegetation cover and type, slope and aspect.

Weight and composition of fuels

Forestry Tasmania and other agencies assisted studies funded by the Tasmanian Forest Research Council (see Chapter 7) which developed methods for rapidly estimating the weight of fuels in dry forests in south-eastern Tasmania. Fuel-accumulation curves were produced from fuel and environmental data obtained from 59 sites in this forest type. These accumulation curves enabled assessment of fuel weight over time at any site using one of four environmental categories: canopy type, geology, rainfall and tree density (Bresnehan 1998).

The characteristics of fuel in wet *E. obliqua* forests and the effects of low-intensity burning were studied at the Warra LTER Site (see Chapter 7) in southern Tasmania (Marsden-Smedley and Slijepcevic 2001). Fuel loads were measured before and after burning in wet sclerophyll (mixed regrowth and oldgrowth) and mixed forest types with different understoreys. The effects of different logging regimes (clearfell, burn and sow; patchfall and burn; dispersed retention) on the characteristics of the fuel (types and composition of litter, and near-surface, elevated and canopy fuels) were examined, and changes in these characteristics at different stages of the harvesting and regeneration process (before logging, before burning, after burning) noted. These studies assisted in evaluating the utility of low-intensity burning in coupes logged by dispersed retention silviculture.

The Soil Dryness Index

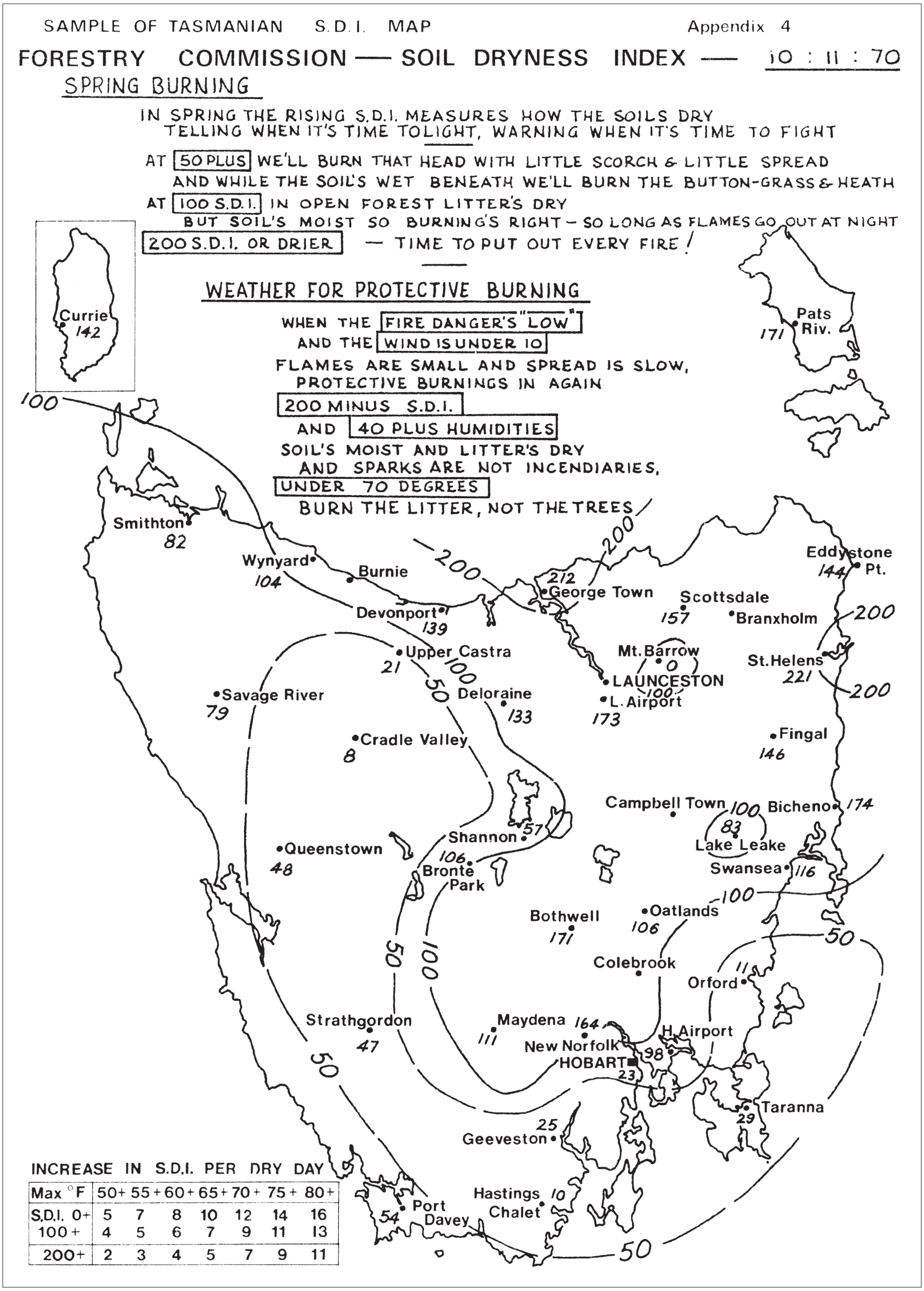
The moisture in fine fuels has a great influence on the rate of spread of a fire, and this changes rapidly with changes in weather conditions. Moisture in fuels with larger cross-sectional areas has a small influence on the rate of spread but a significant effect on fire intensity.

The Byram-Keetch Drought Index (Keetch and Byram 1968) was developed by the United States Forest Service for forest fire control, introduced to Australia by Alan McArthur, and used in the late 1960s and early 1970s by several Australian States. It was first applied in Tasmania in the 1965–66 summer on a trial basis by Ken Felton, then working on regeneration establishment burning at Maydena. The Byram-Keetch Index was constructed to be an estimator of long-term drying of coarse fuels, one of three indices for fine, intermediate and coarse fuels.

Experience in Tasmania showed that an index which better represented the dryness of intermediate fuels would be more useful in predicting fire behaviour. Using the equations from Keetch and Byram as a base, with some modifications, Tony Mount developed a new index which he termed the Soil Dryness Index (SDI), obtaining data from Tasmanian and New South Wales catchments on daily rainfall, temperature, interception losses, run-off and evapotranspiration (Mount 1972). The SDI is a numerical index which estimates the rainfall needed to bring the soil back to field capacity. It gives a good indication of how fuels are drying, and has replaced the Byram-Keetch Drought Index in the McArthur Fire Danger Index.

The Byram-Keetch Drought Index was a very useful tool for fire managers, but there were aspects of the model where refinements were needed for it to give a more accurate picture of soil dryness. For example, it used only daily maximum temperatures to estimate evapotranspiration for a given stage of drying and did not take account of seasonal variations in radiation, dewpoint or wind. Also, the drought index used a uniform rainfall interception-loss formula and did not account for flash run-off. Tony Mount's studies compared observed run-off with the values estimated from the Byram-Keetch Drought Index and the Soil Dryness Index. The values for Byram-Keetch were usually higher than the observed values, therefore overestimating the dryness of the soils. The values estimated by the Soil Dryness Index gave a more accurate estimation of the true values.

Development of the SDI by Tony Mount is an excellent example of operations-oriented research in that only daily maximum temperatures and rainfall are needed to calculate the index, and the relationship between SDI values and likely burning conditions are clearly explained. The SDI was first used throughout Tasmania in the 1970–71 fire season. Because of its simplicity of calculation and its proven accuracy for estimation of fire behaviour, the index has been a key tool for those conducting regeneration establishment and protective burning for over thirty years in Tasmania and other Australian States. It has also been used by the Melbourne Metropolitan Board of Works to determine soil water yield and effects of forest treatments, and by the Tasmanian Mines Department to determine ground water yield. The SDI map for Tasmania featured on page 131, from Tony's original Bulletin (Mount 1972), is an example of the maps that are produced daily by the Bureau of Meteorology and widely used by fire and land managing agencies and individuals. Note the poetic notes accompanying the map: these were also a regular feature of the technology transfer and undoubtedly added to the keen acceptance of the tool! Today's computerised technology unfortunately omits the whimsy of the Mount era.



A map of Soil Dryness Index showing values for locations across Tasmania, together with helpful hints on when to burn. (From Mount 1972.)

Participation in national fire-behaviour research projects

Fire-behaviour research has been conducted at the national level for many years, and Forestry Tasmania has been involved in the major national projects, Project Aquarius and Project Vesta. Project Aquarius was initiated by CSIRO and was an all-embracing program, encompassing fire behaviour and control measures. Forestry Tasmania participated in this project in the 1980s, and the joint research resulted in improvements in fire-management practices in the State.

Project Vesta was established to investigate the behaviour of very high intensity fires in order to develop better predictions of the spread of major bushfires. It is the most comprehensive investigation into the behaviour and spread of high-intensity forest fires conducted in Australia (Project Vesta website: www.bbm.csiro.au/vesta). Trials in this project were conducted jointly by CSIRO and the Department of Conservation and Land Management in Western Australia. Historically, prediction of fire spread in eucalypt forests has been based on the McArthur Fire Danger Rating System and/or the Western Australian Forest Fire Behaviour Tables. However, these were derived mainly from trials with low-intensity burns and they have been extrapolated for use in high-intensity fires. Project Vesta has shown that the assumed relationships between fuel loads and the rate of fire spread do not always hold in these high-intensity fires and that, in some situations, rate of spread can be far higher than previously assumed for certain fuel loads. This obviously has far-reaching consequences for the safety of firefighters and the management of bushfires generally.

Forestry Tasmania sponsored Ben Merritt from the Fire Management Branch to participate in Project Vesta in Western Australia in 1998. As a result of this secondment, fire management practices in Tasmania have been modified by reinforcing the use of the Incident Control System as a method for managing large fire suppression operations and improving safety procedures when fire behaviour and fire weather are extreme. As well as providing national fire-fighting organisations and the Tasmanian Inter-Agency Group (Forestry Tasmania, Tasmania Fire Service, Parks and Wildlife Service) with a better overall understanding of fire behaviour, Project Vesta has also greatly expanded knowledge of specific items such as in-forest winds and the rate of fire spread under specific conditions.

Regeneration Establishment Burning

The problem of burning the large amounts of slash left after harvesting to prepare a seedbed in forests with dense understoreys was discussed briefly in Chapter 2. In this section, more detail is provided on the history of developing techniques for large-scale burning of logging slash with high-intensity fires for establishing eucalypt regeneration or plantations.

Even by the mid 1960s, little was known about methods for carrying out slash burning with fires that consumed the logging debris and produced an ash bed while remaining within chosen boundaries and being safe for those conducting the burn (P. Bennett, pers. comm.). It was usual to first light the fuel on the exterior edge of an area to be burnt and either wait for the fire to spread unaided through the slash or send in gangs with hand torches to start spot fires away from the edges, a practice which was obviously very risky. Days were selected for burning which had little wind and were relatively mild, so that any escapes across exterior fire lines would be easy to contain. In summary, a passive approach was the norm, born from experience of fighting wildfires, with escapes being expected. This approach resulted in too many fires that were of low intensity and did not produce a satisfactory ash bed.

Systematic work on how to achieve hot fires that did not escape and were safe began in

Using a drip-torch to light logging slash in a regeneration establishment burn.

mid 1965 when Ken Felton was sent to the Maydena Station (see Chapter 2), where he and Eric Lockett began investigating the problem. Studies of the practical side of the operation—what happens on the day chosen for ignition—awaited the autumn and the slash-burning season, but measurements and observations on fuel arrays were made and the literature examined. Reports of practices in the USA indicated the benefits of an active approach to slash burning. The energy of combustion was used to create a microclimate in the area of the burn, producing a fire that was very intense, consumed fuel, gave an ash bed, created inflow winds, sucked air across the external fire lines and lifted fire brands high into the air up the well-developed convection column so that they had time to burn out before falling to the ground.

These features of stationary fires were clearly suited to successful regeneration establishment burning, but safe, reliable techniques for igniting and managing the fires had to be developed. It took a couple of decades before the art of regeneration establishment burning was well-established. Knowledge from research trials and operational experience provided inputs to analyses of the burning problem, practitioners and specialist researchers working together. Forest planners had a key role in eucalypt forests, where boundaries of potential logging coupes were located on landscape features which maximised the chances of success. Guiding principles gradually emerged:

- The highest priority in planning and execution of burning has to be given to the safety of operational personnel and the public.
- Logging boundaries have to be chosen that will facilitate safe burning, with the fires being contained within the pre-determined boundaries which must not be breached—the surrounding forest must be safe from fire.
- The area of seedbed must be maximised so as to obtain vigorous, well-stocked eucalypt regeneration.
- The time the burns are active should be minimised so that the chances of escapes on days following ignition are reduced.
- A day for ignition should be selected without appreciable wind, during a time when the surrounding forest is moister than the slash on the burn.
- The final burn-out stage of the fire, after the convection column has collapsed, was recognised as the time of greatest risk of fire escapes. The risk can be reduced by timing initial ignition so that burn-out occurs late in the day, with a rising relative humidity.

Detailed information on these principles and the conduct of burns was made available in a series of guidelines which led to a manual on high-intensity burning in the late 1990s. The current manual dates from 2005 and is a nationally recognised training aid (Forestry Tasmania 2005b).

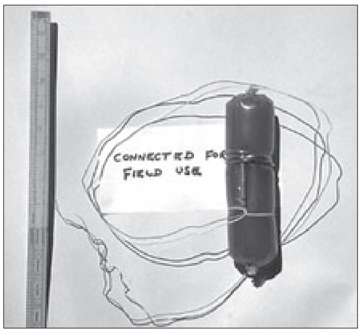
Developing remote ignition devices

A key need was a safe system for lighting the interior of a coupe. The first useful technique came in the late 1960s, when Dick Chuter was at the Maydena Station. Pre-set, remotely operated ignition devices were developed which could be employed within a coupe to establish a central fire. A system using electrical ignition of a series of gel blivets was tested in wet forest slash in the Australian Newsprint Mills Concession, on Bruny Island, and in the Picton Valley (Chuter and Felton 1970). The blivets comprised jellied fuel contained within polyvinylidine chloride plastic tubes, adapted from an American system, and the electrical circuits and gear used for ignition were developed for large blasts in quarries. The tests gave good results, and the circuits and blivets could be put in place at any time. But they did not allow flexibility in ignition patterns, and the wires of the circuits were liable to be broken by animals, necessitating early morning checks of electrical conductivity and hasty repairing of any breaks after they had been found, not an easy task in the midst of a large pile of slash.

To supplement this remote ignition system, DAIDs (Delayed Action Incendiary Devices) taped to blivets were found to be useful for throwing into patches of dense and hard-to-access slash. At the same time, firing of incendiary cartridges from 12-gauge shotguns and large matches from adapted .22 calibre rifles were investigated, but both these methods lacked practicability and cost efficiency.

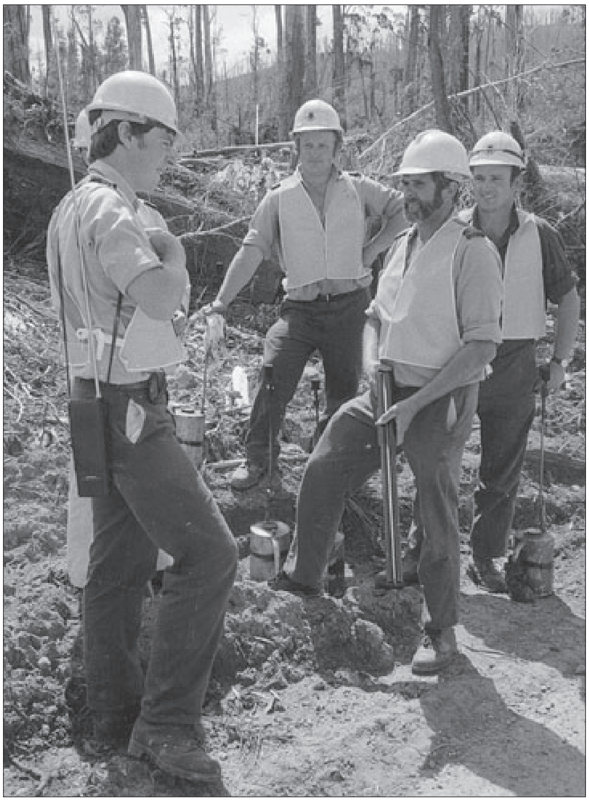
A gel blivet used in trials of remote ignition at Maydena in the late 1960s. This was an early prototype exploding package, containing petrol gel with a small cordtex fuse and a detonator wrapped around with plastic igniter cord.

The diesel gel blivet in place on a bed of dry myrtle leaves.



A later version of a gel blivet. These were tubes of polyvinylidine chloride which were impervious to fuel oil. A plastic igniter cord was wrapped around the sausage of diesel gel. Diesel was substituted for petrol as it was less volatile and safer to use.

This research into different methods of ignition was difficult and potentially dangerous because of the unstable nature of substances such as jellied petrol used as ignition sources, not to mention various types of explosives designed to spread the lighted materials. Some bizarre experiments were attempted including the use of a small mortar, courtesy of the Fire Management Officer, Jim Hickman. The danger was demonstrated in spectacular fashion at the Maydena laboratory in 1969. Dick Chuter had carefully placed bags of jellied petrol in the refrigerator to keep them at a cool, stable temperature while he went to lunch. During his absence (fortunately), a spark from the refrigerator thermostat caused the petrol vapour to ignite in the confined space, the subsequent explosion scorching the laboratory. Diesel replaced petrol (even though the Army, which supplied the gelling agent, said it would not work on diesel) thus reducing risk. But, after the accident at Maydena, a visit to the Defence Standards Laboratories at Maribynong in Victoria was arranged by Murray Cunningham, where the intricacies of ordnance development were explained and all further experimentation with explosives was discontinued.



Briefing a lighting party prior to a regeneration establishment burn at Arve Loop, Geeveston, in March 1980. The shotgun was used to fire incendiary cartridges into the dry slash. (From left: Richard Shoobridge, Terry Ware, Ron Nicholls, Brian Strong.)

Overall, the remote ignition system was a major step forward in the slash-burning technique because the central ignition created inflow winds as a convection column developed. Most importantly, it made slash burning much safer by requiring manual lighting only around the boundary of the coupe rather than in the dense slash.

While studies of remote ignition by pre-set devices were being conducted, operational trials of methods for lighting up green fuels were made. The fuel on some coupes was invaded by scrub due to delayed burning, became covered in a green sward and was difficult to ignite using hand-held drip-torches. In the late 1960s, trials were conducted of aerial and ground spraying of green slash with the herbicide 2,4,5-T to remove the sward and to prepare new dry fuel which assisted lighting up. With the same objective, diesel was sprayed from ground tankers on the edges of coupes. Neither the use of 2,4,5-T nor diesel had any real effect on making ignition easier. However, the phenomenon of interaction between fires was explained at slash-burning schools to field staff who were encouraged to use it when lighting up fuels that did not readily ignite. The increased fire intensity in junction zones is well known; two converging fires radiate energy to the fuel which dries on its surface and becomes easier to ignite, burns more fiercely, producing small-scale fire winds, which further increase the rate of combustion; in short, a self-reinforcing process is established.

Ken Felton visited Tumut in New South Wales in the 1960s to study methods used there to burn large areas of slash produced during conversion of eucalypt forest to pine plantations.

An internal ignition was made and a convection column created. Advantage was taken of its inflow winds to draw smoke and firebrands into the column, which was gradually moved over the area, one fire taking several hours to ignite. The technique was successfully used in Tasmania, notably by Rodney Rich, District Forester at Triabunna in the 1970s, in burning areas of up to 400 ha (P. Bennett, pers. comm.).

Though these techniques improved the effectiveness of slash burning, the biggest achievement of the early high-intensity burning program was in influencing the location of boundaries for logging coupes and compartment boundaries for plantations. A guiding principle became to locate boundaries in places that resulted in burning units with natural boundaries conducive to easier fire management, and on features that made it difficult for fires to escape, such as wet gullies.

Flame throwers and lasers

Work continued on the development of methods for remote ignition because many people were needed (up to 40 on a single coupe) on the ground to light the slash with hand-held drip-torches. This inevitably increased the risks to those workers and posed all manner of difficulties in controlling the burning process in both space and time.

There were some initial trials with a flame thrower mounted on the back of a truck and a specially constructed tank to fit behind a log skidder. However, as can be imagined, the difficulties of traversing rough terrain around the coupes and the limited lighting distance, not to mention the inherent danger from such a technique, soon saw these trials discontinued.

A more advanced investigation of the lighting problem was pursued when laser technology became available in the 1970s. It was based on weapons research in the United States of America and the theory was that if the development of lasers for ignition of forest coupes was successful then they could ignite the harvesting slash from up to 4–5 km away using an elevated vantage point overlooking the coupe. Thus, the need for labour would be markedly reduced and the operation would be far safer.

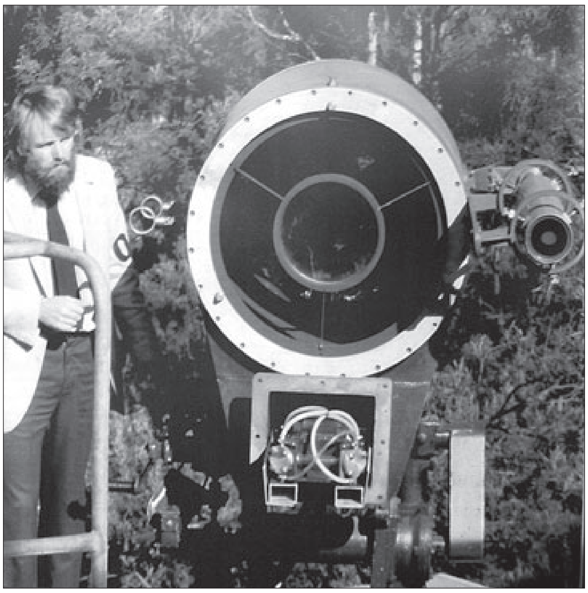
Testing a flame thrower mounted on a tractor, 1971. The tank contained a petrol/diesel mixture which was ignited by being pumped past a pilot flame in a wick. (At rear of tractor, Gary Siely, left, and Mark Whitney; others unidentified.)

Jim Hickman, the Fire Management Officer, first suggested the idea of using lasers to ignite logging slash in the late 1960s, and the idea was promoted further by Phil Shepherd in a series of reports in 1973. Then, in 1975, a joint research project was established between the Forestry Commission and the Physics Department at the University of Tasmania under the guidance of Dr Mike Waterworth, with Phil Gourlay (University of Tasmania) as the co-ordinator of the project. In 1977, Evan Rolley took over as the co-ordinator of the research and development of the laser ignition device (Gellie 1983).

The device consisted of laser elements mounted on the support structures for a Bofors gun and it took some two years to get clearance from the Navy to release this weapon to a Government agency. The propagation mirrors for the laser were gold-plated and required very skilful polishing and aligning to be effective. Unfortunately, during the trials, the expert who carried out these tasks moved from Hobart to Brisbane and Evan Rolley had to take numerous trips to Brisbane to get this work done.

Field trials of the laser were undertaken between 1979 and 1981, with varied success obtained in igniting canvas targets at distances between 200 m and 500 m. By 1982, testing had still not proved that the laser ignition device could ignite eucalypt leaves at distances over 750 m. There were several problems in getting the laser to be operationally effective. It required a very stable platform, the mirrors had to be precisely aligned to concentrate sufficient power at one point to light the slash from a considerable distance, many native forest coupes did not have suitable topography, and the costs of developing the unit for operational use were very high. These

Test-firing the flame thrower in dry logging slash on the east coast.



The laser ignition device trialled in the early 1980s, with the project co-ordinator, Evan Rolley.

problems were never sufficiently overcome for the unit to be operational and, following further testing by Nick Gellie, the laser project was discontinued (Gellie 1983).

Aerial ignition—the current method

The need for ground-based remote ignition devices for high-intensity burning became redundant with the introduction to Tasmania of the aerial drip-torch in 1987. The drip-torch, or helitorch as it is commonly known, was originally developed in the United States of America and later refined in New Zealand by the then New Zealand Forest Service. The Forestry Commission imported a helitorch from New Zealand and it was further refined, mainly by Peter Bennett and workshop foreman John Triffett, to improve its effectiveness and meet the stringent safety conditions required by civil aviation authorities.

The helitorch consists of a 200 litre container of jellied petrol carried as a sling load beneath a helicopter. The operation is controlled by a bombardier sitting beside and directing the pilot. The device can very precisely release the petrogel onto the area targeted for ignition, thereby increasing the safety of the operation as no lighting crews are needed except on some occasions at the boundaries of the coupe. Originally, stearic and palmitic acid were used to gel the petrol but gelling is now achieved with synthetics, which cause the burning fuel to stick better to the slash. Subsequent refinement of the design, construction, and ignition and control systems by Rod McNeill and Martin Piesse resulted in a reduction in the mass of the system and increased versatility of operation.

The helitorch has revolutionised high-intensity burning in Tasmania. The speed, safety and enhanced control of the process compared with ground-based methods allow up to about 40 coupes to be burnt in one day. This is enormously important given the often brief period of suitable conditions for burning in Tasmanian forests. The length of this period has also been increased because, in marginal conditions, larger quantities of petrogel can be dropped to get the fire started. The Tasmanian equipment is used in the Northern Territory for prescribed burning and was contracted to the ACT for burning pine debris from salvage logging which followed the extensive bushfires of 2003.

Fuel Reduction Burning

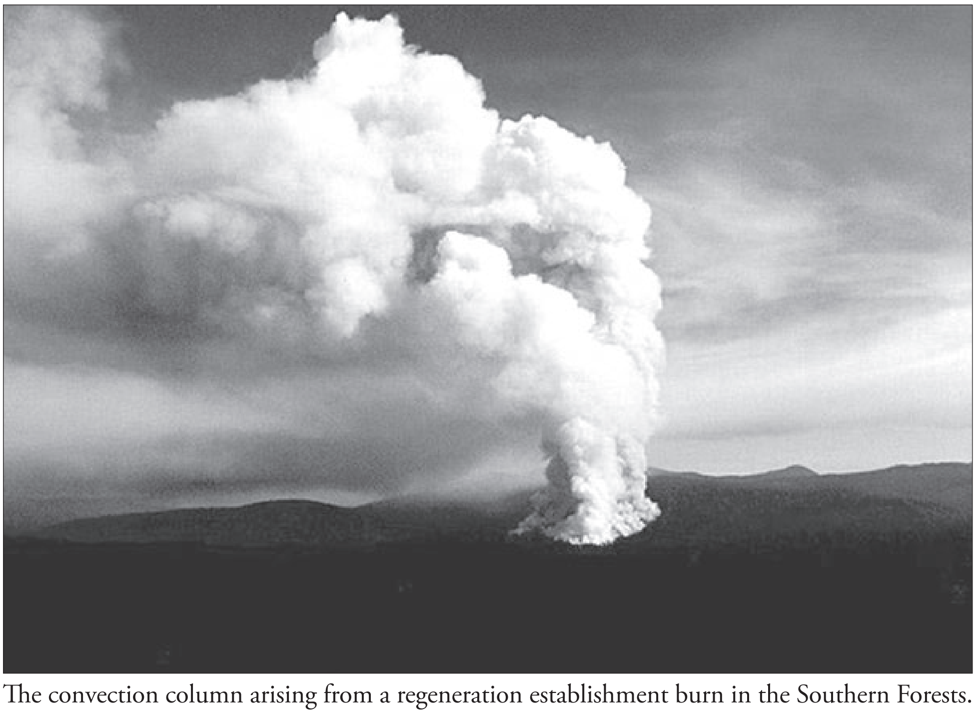
The aim of fuel reduction burning is to protect life, property and forest values by reducing fuels before a wildfire occurs, thereby broadening the weather conditions within which fires will not sustain themselves or effective fire suppression can be performed. Fuel reduction burning acts to change the fuel characteristics present at a site so that the ratio of dead to live fuel, bulk density, fuel continuity, fuel height and total fuel load are all reduced. This in turn reduces the rate of spread and intensity of any subsequent wildfires (Cheney 1996).

The need for fuel reduction programs has been a common recommendation of inquiries into

The first helitorch used in Tasmania. It was based on a Western Australian design, comprising a welded steel pressure vessel with a propane gas lighting system to ignite the petrol gel.


The current helitorch. This is known as the 'Firefly' and is based on a New Zealand design. It is lighter and uses an electrode to provide a continuous spark which ignites the gel as it passes. (Rod McNeill, Aerial Operations Officer in the 1980s and 1990s.)


Lighting up slash with the current helitorch in a regeneration establishment burn on Tasman Peninsula.


The convection column arising from a regeneration establishment burn in the Southern Forests.

fires in Tasmania and elsewhere. For example, the report of the 1993 review of vegetation-based fire in Tasmania stated:

> *A major fire at Bronte ... burnt 40 000 ha of 'cut-over' forest carrying slash fuels, destroyed pulpwood valued at $6 million and caused severe damage to the standing forest. The Committee believes it is not being too alarmist in predicting more similar events in Tasmania if something positive is not done to reduce the accumulation of slash fuels created by forest harvesting.* [Tasmanian Fire Review Committee 1994, p. 20]

The Tasmanian inter-agency group has a stated aim for fuel reduction burning of reducing 70% of the fuels from vegetation (i.e. litter and shrubs) over 70% of the treatment site (Forestry Tasmania, Parks and Wildlife Service, Tasmania Fire Service 1996).

Early selective logging in Tasmanian forests created large amounts of slash scattered through the forest and when fires started accidentally or deliberately ('to clear the scrub') considerable damage often resulted, although these fires also produced large areas of vigorous regeneration. Many old photos of logging operations and sawmills show the burnt, standing forest adjacent. When the Huon Timber Company was logging in the Southern Forests, it recognised the dangers from selective logging and tried to reduce fuels. A major driver for better fire management was the desire to protect the tramways which gave access to the forest and enabled the logs to be extracted.

The earliest fuel reduction burning was conducted in buttongrass plains in the 1930s (see later). In the 1950s and 1960s, there were some scattered fuel reduction activities directed at flash fuels (fine, highly inflammable fuels) but their extent was not reported. Some fuel reduction burning was done opportunistically by field staff in the late 1960s and 1970s. In higher rainfall areas with forests with dense woody understoreys, scrub was burnt in openings in the forest when it was considered practicable to conduct the burns without damaging the

Hazard reduction burning in dry eucalypt forest near Triabunna in the 1980s. The fire tanker is on hand to keep the fire to the planned area.

surrounding forest. In forests with an open understorey—dry sclerophyll forests—some burning was done under the standing trees. These operations were really a continuation of the traditional practice of 'burning off', commonly used by landowners since European settlement. Systematic studies of prescribed burning under standing trees were pioneered by Tony Mount in the 1960s and early 1970s in *E. delegatensis* regrowth at Mount Dromedary in the south, Mount Foster in the north-east, and Mentmore Road in the Central Highlands. These early trials showed that it was possible to conduct fuel reduction burns safely and with minimal damage to the trees in these regrowth forests provided weather and stand conditions were suitable. Successful fuel reduction burning under *E. delegatensis* was also conducted by Bob Ellis in the 1970s on the Camden Plateau in the north-east as part of research on high-altitude dieback (Chapter 6).

Planned fuel reduction burning on a large scale was not practised until the late 1960s and early 1970s. As in the case of high-intensity burning, the initial lighting method for fuel reduction burns was by hand-held drip-torch. The Forestry Commission then experimented with aerial ignition using a variety of methods. Ignited giant matches, or DAIDs (Delayed Action Incendiary Devices), were dropped from a helicopter onto the target area. This method almost resulted in disaster on one occasion. The match head flew off a lighted DAID and fell into an open box of DAIDs inside the aircraft, causing them to ignite and fill the cabin of the helicopter with so much smoke that the pilot had to land very quickly while there was still just enough visibility in the cockpit. The DAID method was discontinued following an unexplained three-person fatality in Victoria when a helicopter crashed while conducting lighting operations using this technique.

Subsequent methods of aerial ignition used devices which were primed in the aircraft and actually ignited after being thrown out. An early device was a plastic vial containing potassium permanganate, which was injected with ethylene glycol through the plastic cap just before being thrown from the aircraft. Once in contact, the potassium permanganate oxidised the ethylene glycol, releasing heat which, after a time delay which varied with ambient temperature, raised the temperature of the capsule to a point at which the plastic ignited. A soda water syphon was carried in the aircraft as a fire extinguisher. Later, 25 mm plastic-cased balls containing 20 g of potassium permanganate were injected by hand in the aircraft with 3 ml of glycol and then thrown from the plane. These primed balls ignited after they hit the ground and stayed alight for up to three seconds. This method originated in New South Wales and was known as the 'ping-pong ball' technique. Later, an Aerial Incendiary Machine (AIM) was developed which automated the priming and then launched the balls from the aircraft at predetermined intervals, spacing the spot fires more accurately. Paul Leitch from the Fire Management Branch, in co-operation with Les Curry, a tool and die maker in Bellerive,

An early version of the aerial incendiary machine. The ping-pong balls were fed from the hopper into a gate where they were injected with glycol; they then dropped from a chute and were alight before hitting the ground.

refined the engineering of this 'ping-pong ball machine' (P. Bennett, pers. comm.). The AIM was commonly used for fuel reduction burning and was successful in regeneration establishment burning in very flashy fuels. When the helitorch came on stream, it was used for regeneration burning and the AIM was used only for lighting fuel reduction burns.

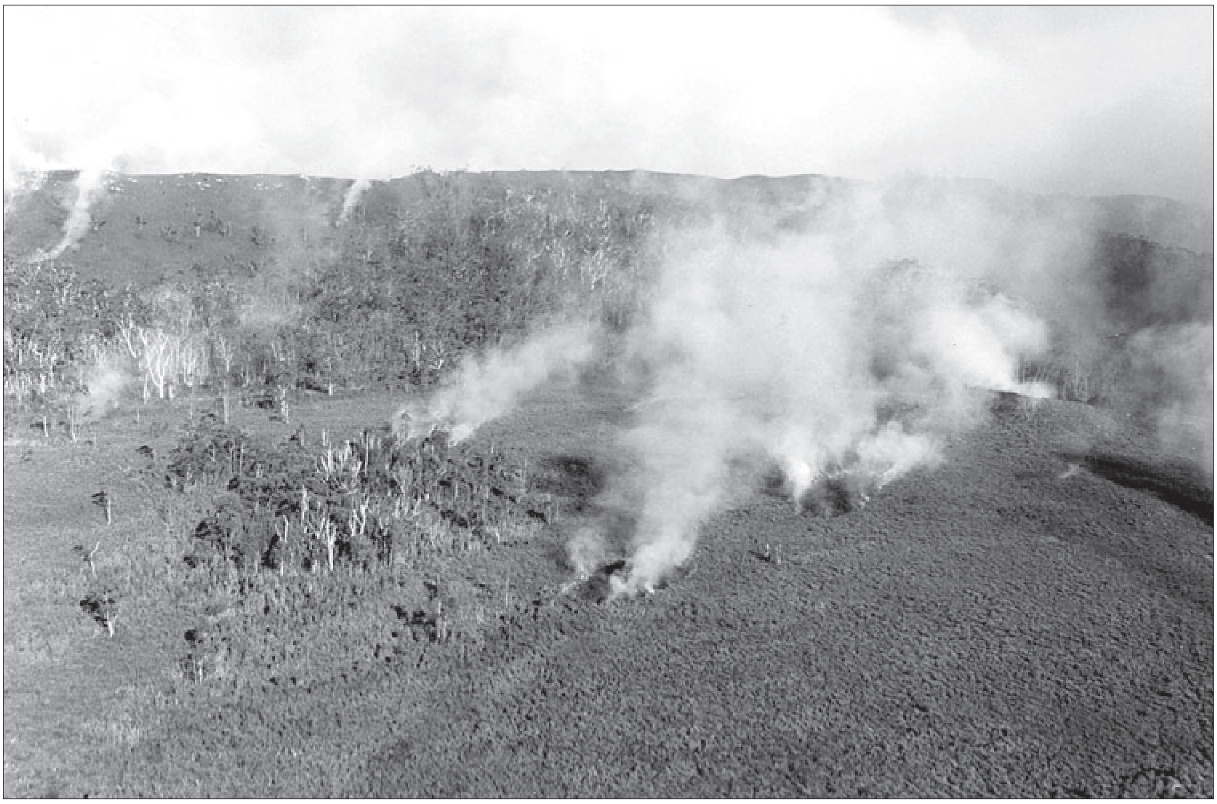
One of the problems encountered when planning fuel reduction burns across areas of forest with several landowners or tenures was achieving agreement between landowners on the need for burning and the timing and methods to be used. Often there would be 15–20 landowners who needed to be consulted when planning to burn 2000–3000 ha of forest and this task often prevented the burning being considered by field officers. To overcome these difficulties, Evan Rolley and Tony Mount developed a co-operative aerial-burning procedure in which landowners were briefed through public meetings, local publicity and direct liaison between participants on the vegetation types to be burnt and the techniques to be used. Once agreement with landowners was reached, Government land management agencies then organised the hire of aircraft for the burning, the landowners' responsibility being to protect their fences and other assets. The use of aerial ignition reduced the importance of ownership differences, and fire containment was assisted by using natural boundaries formed by sharp changes in fuel type and quantities (Rolley and Mount 1980).

Mark Chladil and Tim Rudman conducted trials in the early 1980s to develop prescriptions for safe fuel reduction burning next to and under dry forest types. Tim also investigated fuel reduction burning in radiata pine plantations as fuel accumulation from litter and from pruning and thinning slash can be significant. His initial trials showed that, provided the Soil Dryness Index was low, safe fuel reduction burning could be achieved, with minimal effects on the retained trees and low carry-over of fires into the following day (CSIRO 1989).

In the 1990s, Zati Eron and other fire management staff studied the characteristics and accumulation rates of fuel under dry eucalypt regrowth forest in eastern Tasmania. The aim of these studies was to determine if fuel reduction burning under eucalypt regrowth was necessary and feasible. This work showed that, on the basis of fuel characteristics alone, fuel reduction burning was unlikely to be a viable option due to the very rapid re-establishment of high litter and dead fuel loads. It would be required on a four-to-six year rotation, a rate which could result in significant nutrient losses from the system and other undesirable ecological effects. The level of damage that would be suffered by the regrowth trees was also a critical risk factor.

Wilkinson *et al.* (1995) compared the effectiveness of using conventional hand-held drip-torches and the aerial drip-torch to conduct top-disposal burning of logging slash in partially logged, dry forest in eastern Tasmania. Although both methods produced similar levels of fuel reduction, the aerial drip-torch gave more flexibility for achieving burning programmes in the often limited time-frames available for safe and effective burns, and it is now commonly used.

Buttongrass moorlands in Tasmania have been a priority target for systematic research on fuel reduction burning because of their flammability from fuel build-up and their rapid return to a flammable condition following rain. There has been a long history of spread of wildfire from the moorlands into adjoining forests, and fuel reduction burning in buttongrass areas to reduce accumulated fuels and limit danger from summer wildfires has been a common activity for both Forestry Tasmania and the Parks and Wildlife Service. Research on fuel reduction burning in these vegetation types has concentrated on developing methods that reduce costs, improve effectiveness and reduce unintended consequences. The Forestry Commission began fuel reduction burning in buttongrass in 1939 using ground-based


Fuel reduction burning using aerial ignition in buttongrass plains on the West Coast.

lighting and started aerial ignition in 1969, with an annual program reaching 10 000 ha by 1975 (Gellie 1980). The fire behaviour and management research associated with fuel reduction in buttongrass moorlands has been reviewed by Marsden-Smedley *et al.* (1999), who developed prediction tables and equations for estimating fuel characteristics, rates of spread, flame heights and fire danger ratings.

Ecological Effects of Fire

Understandably, most of the publicity surrounding fires in Tasmania has centred on the impact of disastrous bushfires, such as those of 1934 and 1967, on life and property. Fire, of course, can also have significant impacts (some desired, some not desired) on the flora, fauna, soils and other natural values managed by forest management entities. The ecological effects of both high-intensity burning for establishing regeneration and repeated low-intensity fuel reduction burning have been the subject of considerable direct and collaborative research by several agencies, including the Parks and Wildlife Service, Tasmania Fire Service, the University of Tasmania, CSIRO and Forestry Tasmania. These agencies have produced several landmark studies of the relationship between fire regimes and vegetation, particularly the distribution of vegetation types and plant species composition (e.g. Jackson 1968; Brown and Podger 1982). Duncan (1985) and Taylor (1991a) have reviewed some of the research dealing with the effects of fire on flora and fauna respectively.

Containing managed fires to the target areas during regeneration establishment and fuel reduction burns, so preventing adverse broad-scale ecological effects, is a fundamental task for fire managers. In the past, escaped burns from a variety of sources, and fires deliberately lit to destroy forest and aid access, and those lit to

Fire-killed stems of King Billy pine on the slopes of Mount Algonkian in south-western Tasmania, 1990.

promote grazing, have had very serious impacts on sensitive flora, particularly in alpine areas where species such as King Billy pine (*Athrotaxis selaginoides*) and pencil pine (*A. cupressoides*) have been severely affected (Brown 1983). This section discusses some of the main research and development projects on the ecological effects of fire relevant to operational forestry in Tasmania. Improvement of burning techniques and control measures discussed earlier in this chapter are also relevant.

Leatherwood regenerating from coppice shoots after the Savage River wildfire of 1982.

Wildfires

As part of the Tasmanian component of the National Rainforest Conservation Program which ran from 1988 to 1996 (see Chapter 7), the successional stages of rainforest re-vegetation following the 1982 Savage River and Waratah wildfires and the response of rainforest species to different fire intensities were investigated.

Eight years after the fires, most of the vascular plant species found in the unburnt sites were also found in the burnt sites although sclerophyllous species such as bracken, tea tree and cutting grass were more abundant than true rainforest species in the burnt sites. The abundance of these sclerophyllous species in the regenerating rainforest also make the forest more likely to burn again for a period than if the forest were pure rainforest. The type of rainforest and the intensity of the fire were the variables which had most influence on the floristics of the regeneration (Barker 1991). The presence of viable seed on surviving trees in the fire area, in surrounding forest or in the ground, can also significantly influence the species composition of the regenerating forest after fire.

Though protection of eucalypt regeneration from wildfire is a high priority, significant areas have been burnt. Although eucalypts have mechanisms to recover from fire (epicormic buds, lignotubers), tree form and timber quality are affected to a greater or lesser degree depending on fire intensity, area and species burnt, and other factors. Information on the impacts of wildfire on eucalypt regeneration assists the decision-making by forest managers as to whether the burnt forest should be cleared and regenerated again, remedial treatments applied, or the stand left to recover naturally.

Recovery of young *E. obliqua* regeneration after a major wildfire in north-western Tasmania was investigated by Wilkinson and Jennings (1993). Their studies showed that the degree of recovery was strongly related to the age of the trees. Very young seedlings (1.5 years) were killed when the foliage was totally scorched, whereas older regeneration (7.5 years) could

Open *Eucalyptus delegatensis* forest on the Camden Plateau, 1963, showing the effects of different fire frequencies. The dense shrub layer in the background is in a part of the forest which has not been burnt for over 60 years; the foreground area has been frequently burnt.

survive scorching of the foliage but high mortality occurred if the foliage, branches and upper stem were burnt. The oldest regeneration studied (9.5 years) mostly survived total crown burning. Surviving trees responded with crown and stem epicormic shoots but the overall form of these trees was poor, with multiple leaders and stem malformations. The authors concluded that affected areas required resowing where survival was poor but no treatment was probably justified where survival was adequate. They considered that the wood quality of the burnt stands was likely to be reduced and that this should be reflected in yield estimates.

Regeneration establishment burns

For many years there has been much debate on the ecological effects of regeneration establishment burning compared to wildfire, particularly in relation to the botanical composition of the regenerating forest arising from both types of fires. To address this question, John Hickey studied the vascular plant floristics of 20–30-year-old regeneration resulting from clearfell, burn and sow (silvicultural regeneration) and from wildfire (Hickey 1994). This landmark study showed that most vascular species common in oldgrowth forest were represented in similar frequencies in both types of regeneration, except that there was a much lower frequency of epiphytic fern species in the silvicultural regeneration and a higher frequency of cutting grass (*Gahnia grandis*), often associated with disturbed areas. After a single logging and regeneration treatment, the floristics of the regeneration were sufficiently similar to those of the wildfire regeneration to deduce that both would become mature mixed forest and eventually rainforest if there were no further disturbances. It is not known whether repeated harvesting at 80–100 year intervals will allow retention of sufficient rainforest elements to enable progression to the original mixed forest composition.

Following this study, similar comparisons have been made for other biodiversity components in silvicultural and wildfire regeneration. Assemblages of litter-inhabiting beetles in logging and wildfire treatments could not be distinguished although there were some small differences in beetle populations (Baker *et al.* 2004). Studies of macrofungi in wet eucalypt forest showed some indications of differential effects of sivicultural regeneration establishment burns and wildfire on this component of the flora (Packham *et al.* 2002). Bryophytes occurring in different age classes and on a range of substrates were sampled by Turner and Pharo (2005) in 105 mixed forest sites, including 69 of the same sites sampled by Hickey (1994); they discussed the importance of maintaining substrate diversity for conservation of bryophytes in production forests currently being managed on an 80–100 year rotation. All the above studies have provided information that is guiding the development of silvicultural methods (including frequency and pattern of burning) which will assist biodiversity conservation in managed forests.

In a longer term approach, a series of fire reference sites have recently been established at the Warra LTER Site (see Chapter 7), which have been burnt by either wildfire or clearfell, burn and sow silviculture. These sites represent a wildfire chronosequence (a series of forest areas ranging in age since they were burnt) and will be used to investigate biodiversity, physical responses and ecosystem processes following wildfire, and to compare these to responses and processes in the years following harvesting and regeneration establishment burning. The project will assist in optimising forestry and conservation management practices to better cater for fire-dependent biodiversity (Turner *et al.* 2005).

Forestry Tasmania has made significant contributions to the debate on the effects of regeneration establishment burning on nutrient status in Tasmanian forests, both through co-operative research and through contributions to research bodies such as the Tasmanian Forest Research Council. In a high-intensity fire used to regenerate mixed forest in the Florentine Valley, University of Tasmania scientists recorded losses of about 18% of total phosphorus, 17% of potassium, 12% of calcium and 29% magnesium (Harwood and Jackson 1975). However, there are considerable methodological problems in determining even reasonably accurate estimates of changes in nutrient status following slash burning (Neilsen 1976). Soil nutrients were sampled by CSIRO scientists in clearfelled coupes before and after burning, and in an uncut coupe in southern Tasmania. They concluded that for wet mixed forests on dolerite soils a single regeneration establishment burn probably improves the nutritional status of the soil and that the quantity of nutrients lost from the site in particulate ash would be replaced in rainfall within 15–20 years (Ellis and Grayley 1983). These and other studies on the effect of burning on nutrient cycling in Tasmanian forests were summarised by Bill Neilsen and Gordon Davis as part of the information supplied for the Environmental Impact Statement on Tasmanian Woodchip Exports (Neilsen and Davis 1985a). Their general conclusion was that long-term deleterious effects of slash burning on reasonable forest soils had yet to be demonstrated, but they pointed to the need for continuing study of the effects of burning on different soil types, particularly the effects on different elements.

A major study on nutrient cycling in Tasmanian forests was conducted in the mid 1980s in a range of wet and dry eucalypt forests in northern and north-eastern Tasmania (Adams and Attiwill 1988). This work was published as the first report from the Tasmanian Forest Research Council (see Chapter 7). The studies showed that fire initially increased concentrations of NH_4^+, potentially mineralizable N and extractable inorganic P, and increased rates of mineralization. Concentrations of N and P decreased continually to background levels within 18 months, and mineralization rates also decreased, although more slowly. Felling and burning increased the rate of mineralization of N. However, there was no increase in nitrification, no leaching of NO_3^- or NH_4^+ and immobilisation and uptake of inorganic N. Fire produced little change in the organic P pools but increased inorganic P pools several-fold.

The effects of burning on soils have been an important part of the research conducted at the Warra LTER Site (see Chapter 7). In a co-operative study between Forestry Tasmania and the CRC for Sustainable Production Forestry, Pennington *et al.* (2001b) assessed the long-term impacts of forest harvesting and high-intensity broadcast burning on soil properties at Warra. They found that the combined effects of these practices nine months after the regeneration establishment burn were most pronounced in the top 50 mm of soil; bulk density increased, there were losses of C and N, but levels of total P increased. Changes were progressively smaller at increasing soil depths. These results are generally consistent with those of Ellis and Graley (1983) discussed earlier. Pennington *et al.* (2001b) pointed out that changes in soil bulk density resulting from harvesting and burning should be expressed on a kilogram per hectare basis rather than a total amount to more accurately reflect the significance of the changes. In another study of the effect of regeneration establishment burning at Warra, 58–63% of the total weight of organic fuel and its carbon content was lost to the atmosphere during burning, with the majority of carbon loss coming from slash with a diameter greater than 7.0 cm (Slijepcevic 2001). With increasing discussion of human-induced climate change, further studies can be expected of the contribution to the carbon cycle of wildfire, burning for regeneration establishment and fuel reduction, and forest decay.

Fuel reduction burns

Concern over the ecological effects of large fuel-reduction programs has prompted considerable

Sampling wet eucalypt forest to determine weight and composition of forest fuels prior to regeneration establishment burning at Warra, 2000. Sampling after the burn then provides data on the effects of the burn on fuel.

research into the effects of these fires on the vegetation of buttongrass moorlands and their associated fauna, particularly ground-dwelling birds and small mammals. Of particular concern in the 1970s was the possible harmful effect of these repeated fires on several rare endemic species. The fire ecology of buttongrass moorlands was studied by Nick Gellie of the Forestry Commission in the late 1970s and early 1980s (Gellie 1980). This work outlined the fire behaviour characteristics of buttongrass moorlands, growth and recovery of buttongrass itself and of other plant species, the potential impacts on small mammals and birds and the relative merits of spring and autumn burning in relation to these possible effects. These studies provided recommendations on the intensity and frequency of fuel reduction burning and the need to avoid the main breeding season for birds in these areas, and proposals for future research into nutrient status and other aspects.

The Forestry Commission, through the Tasmanian Forest Research Council, assisted another major study of buttongrass moorlands in the mid 1980s. This study included discussion of fire ecology in buttongrass vegetation and the need to ensure that fuel reduction burning practices did not lead to degradation of the buttongrass moorland ecosystem (Jarman *et al.* 1988a, b). The studies of Jonathan Marsden-Smedley and Kristen Williams in burning buttongrass moorland (Marsden-Smedley and Williams 1993) have provided valuable information for the development of prescriptions for fuel reduction burning in this vegetation type. These prescriptions aim to provide high levels of asset protection and habitat use while minimising the impacts on other values. Variable fire regimes and strategic, rather than broadscale, burning can help overcome the ecological damage associated with inappropriate fire frequencies.

On the poorer forest soils, frequent hazard reduction burning may result in impoverishment of the nutrient status and lower productivity, but this risk needs to be balanced against the advantages of reduced risk from wildfires (Neilsen and Davis 1985a). Obviously, conservation of nutrients in production forests can be assisted by measures such as retention of slash (which contains most of the nutrients) on-site (Grant *et al.* 1995).

The appropriate frequency of prescribed burning in different forest types has long been a priority topic for investigation by Tasmanian land management agencies. In dry sclerophyll forests, which get burnt naturally at approximately 5–25-year intervals, simplification of the understorey and lower species diversity can occur with too frequent fires in some types; for example, *Eucalyptus sieberi* forest burnt repeatedly at seven-year intervals (Neyland and Askey-Doran 1996). However, too long an interval can cause vegetation change in species which require high light levels, have short life cycles and/or require a fire trigger to germinate. The main conclusion arising from the studies of repeated fuel reduction burning on vegetation is that it is essential to get the balance right between the frequency of burning to reduce fuels and that which is appropriate to sustain the natural values of particular forest types (e.g. some high-altitude *E. delegatensis* forests: see Chapter 6).

Alen Slijepcevic, a former Fire Management Officer at Forestry Tasmania, proposed a classification of vegetation communities on the basis of fire characteristics. Adrian Pyrke and Jonathan Marsden-Smedley (Department of Primary Industries, Water and Environment) recently derived three major fire themes from the TASVEG vegetation community classification: fire attributes categories, fire sensitivity and flammability. These themes will aid fire suppression and fire management planning by providing extra mapping layers for a geographic information system (GIS), thus assisting decision-making by fire managers (Pyrke and Marsden-Smedley 2005).

Summary

The control and use of fire has been a major topic from the earliest reports of the Forestry Department, and fire remains a dominant influence on forest management in Tasmania. Some of the main achievements produced by years of research and experience in managing fire are listed below:

- Sophisticated incident management procedures, particularly in the areas of organisation, detection, communication and control methods;
- Significant contributions to the high level of co-operation on fire management between land management agencies;
- Very high technical competence in fire control, recent evidence of this being the high praise for Forestry Tasmania staff received from authorities in the United States of America, New South Wales and Victoria after assistance was provided to combat major fires there;
- Development of reliable tools for predicting fire behaviour, the best example being the Soil Dryness Index now used nationally;
- Development of safe and effective methods for using fire for regeneration establishment and fuel reduction;
- A better understanding of the ecological effects of fire across a range of vegetation types and in relation to other natural values.

Chapter 4

Special Timber Species

Introduction

One reason for the settlement of Tasmania by the British in 1803 was 'to secure another place for procuring timber' (King 1803) for the British navy which was busily engaged defending Britain from Napoleon at the time. The native conifers, Huon pine and celery-top pine, provided timbers for boat construction. The outstanding qualities of Huon pine, including resistance to 'the worm' (presumably the teredo worm, a mollusc which bores in piles and other timber structures immersed in water), were praised by the Surveyor General, John Oxley, in 1809 (Kerr and McDermott 1999). Huon pine quickly became one of Australia's most sought-after boat-building and cabinet timbers and is present among other timbers in the earliest piece of signed and dated (1815) furniture made in Australia (Bell 2004).

Apart from the main special species (Box 6), many other non-eucalypt species that occur as smaller trees and in limited quantities are also highly prized by specialised craft and furniture makers. Examples of these species are horizontal (*Anodopetalum biglandulosum*), musk (*Olearia argophylla*), goldey-wood (*Monotoca glauca*),

> ***Box 6***
>
> *Special timber species.*
>
> The collective term **special timber species** is used to describe the native, non-eucalypt tree species in Tasmania that are prized for their high quality and high value as furniture timbers, veneer and craftwood. Most of these species occur in rainforest or as a component of the understorey in mixed forest. The main special species are blackwood (*Acacia melanoxylon*), celery-top pine (*Phyllocladus aspleniifolius*), Huon pine (*Lagarostrobos franklinii*), King Billy pine (*Athrotaxis selaginoides*), leatherwood (*Eucryphia lucida*), myrtle (*Nothofagus cunninghamii*) and sassafras (*Atherosperma moschatum*).
>
> Some timber cut from special species has particular characteristics that are highly sought after in the furniture and craft industry: for example, 'birdseye' Huon pine and King Billy pine, 'black-heart' sassafras, 'fiddleback' blackwood and 'tiger' myrtle.

Large myrtle trees in a fine callidendrous rainforest in western Tasmania. (Max Gilbert pictured.)

Port Arthur plum (*Cenarrhenes nitida*), native laurel (*Anopterus glandulosus*) and dorrel (*Notelaea ligustrina*).

By 1873, a regulation issued under the *Waste Lands Act 1870* prescribed licence fees to fell and split native pines and blackwood which were twice those for 'ordinary timber'. In perhaps the first reference to 'special' timbers, Steane (1947, p. 3) comments on this regulation:

> *Evidently blackwood and the 'native pines' were beginning to be recognised as timbers of special value. The 'ordinary timber' referred to in the above regulation would, of course, be the eucalypts.*

Blackwood, in particular, was recognised early on as a very valuable timber species for cabinet-making and barrel staves, and production boomed from about 1920, particularly in the Circular Head region (Mesibov 1980). When the Forestry Department started in 1921, it began to make the case for the retention of the blackwood-rich, north-west swamps as forests rather than being cleared for farming. Competition between agricultural and forestry interests intensified. In 1926, Mr R. Garrett, the District Forester in the north-west, recommended that large areas of blackwood forest in Circular Head be dedicated as State forest. However, Conservator Irby reduced the request to 4000 acres (1600 ha) in the North Arthur, which was gazetted that same year. At the same time, sawmillers were agitating for access to blackwood forests in the South Arthur, and eventually some 130 000 acres (52 000 ha) were granted for this purpose in 1927, under the *Timber Industries Encouragement Act 1927* (Mesibov 1980). However, over the next few decades, several areas of prime blackwood forest were cleared for agriculture, some State forest was revoked and new dedications of State forest were opposed by the agricultural sector.

It was not until the 1970s that blackwood production was placed on a more secure footing following the dedication as State forest of some 6000 ha of swampland. This allowed the creation of the Swamp Working Circle for management of the blackwood resource in Circular Head (Forestry Commission 1982b).

A large musk (*Olearia argophylla*) on the boundary between wet sclerophyll forest and rainforest in the Florentine Valley in the 1960s. Musk was a highly prized cabinet timber, particularly in the mid to late nineteenth century. (Tony Mount pictured.)

Black wattle (*Acacia mearnsii,* formerly referred to as *A. mollissima*) and silver wattle (*A. dealbata*) were important special species during the late nineteenth and early twentieth centuries. They were highly prized for the tanning properties of their bark. There are frequent references in Tasmanian Government reports to the potential for expanding the wattle-bark industry based on these acacias in eastern Tasmania. A small wattle-bark industry operated between 1885 and 1960 on the east coast, its heritage now displayed at the Swansea Bark Mill tourist centre. The mill's resource was bark stripped from local black wattle, a species which yields high levels of tannic acid from its bark and is still planted in some countries (e.g. China) for its tanning properties. An 1898 report by the first Conservator of Forests in Tasmania, George Perrin, commissioned by the Government after he had become Conservator of Forests in Victoria (also see

A blackwood swamp forest near Smithton in north-western Tasmania.

A typical woodland of black wattle, *Acacia mearnsii*, near Swansea in eastern Tasmania. These dry forests were the source of bark for the wattle-bark industry that operated in the area between 1885 and 1960.

Chapter 1), included a recommendation that wattle districts should be closed for three to five years to give time for recuperation, and then 'let by tender royalty for stripping trees of or over 4 inches diameter' (Steane 1947). By the time the Forestry Department began operations, the wattle-bark industry was in decline, due mainly to over-exploitation of the wattle forests, the frequent burning by lessees of Crown Lands to produce feed for grazing, and increasing imports of wattle bark into Australia from South Africa. It is ironic that the seed for cultivation of black wattle in South Africa was originally collected in Tasmania.

This chapter examines the history of silvicultural research on the main special species which led to the implementation of specific silvicultural regimes for individual species. Conservation of flora, including special species, is also a key management responsibility for Forestry Tasmania, and is dealt with in Chapter 7 as part of the history of development of conservation measures for all species.

Early Research

Some of the silvicultural requirements of special species had been documented by the early twentieth century. Llewellyn Irby described the known distribution of the main Tasmanian special species, including Huon pine, King Billy pine, celery-top pine, blackwood, myrtle and silver wattle. Commenting on the silviculture of Tasmania's forests, he made a clear distinction between native trees that regenerate after fire and those that do not. Of the special species dealt with in this chapter, he included the acacias (blackwood, silver wattle, black wattle) in the former group and Huon pine, King Billy pine, celery-top pine and myrtle in the second. He noted:

> *Good regrowth of young Huon pine, King Billy pine and celery-top may often be met with in natural glades, on rotten logs, and wherever sufficient light and heat have been allowed to penetrate by the fall of some forest giant. Where the clearing has been the result of fire, however, it is doubtful if a crop of seedlings ever come.*
>
> *It would appear therefore, that the reafforestation of our pines must be by taking advantage of natural clearings as far as possible, and by endeavouring to bring about suitable conditions generally, to permit of the free entrance of light and heat to the soil without the agency of fire. In other words, by methods diametrically opposed to those resorted to for the eucalypts and acacias.* [Forestry Department 1921, p. 9]

Various silvicultural treatments were tried in order to increase the productivity of some species. Early thinning of blackwood at Teepookana, Oceana and Corinna was conducted in 1922–23

A photo from the Forestry Department's 1922–23 Annual Report entitled 'Area of blackwood treated at Teepookana. (West Coast, Tasmania.)'.

and, in the same year, five acres (2 ha) of King Billy pine carrying 200–300 trees per acre were 'cleared of undergrowth and undesirable species' at Mount Dundas. Irby noted that the King Billy pine regeneration 'clearly indicates that this is essentially a light-loving species and that regeneration is unlikely to occur freely under a dense undergrowth'.

Commenting on the blackwood stands at Corinna, Irby noted:

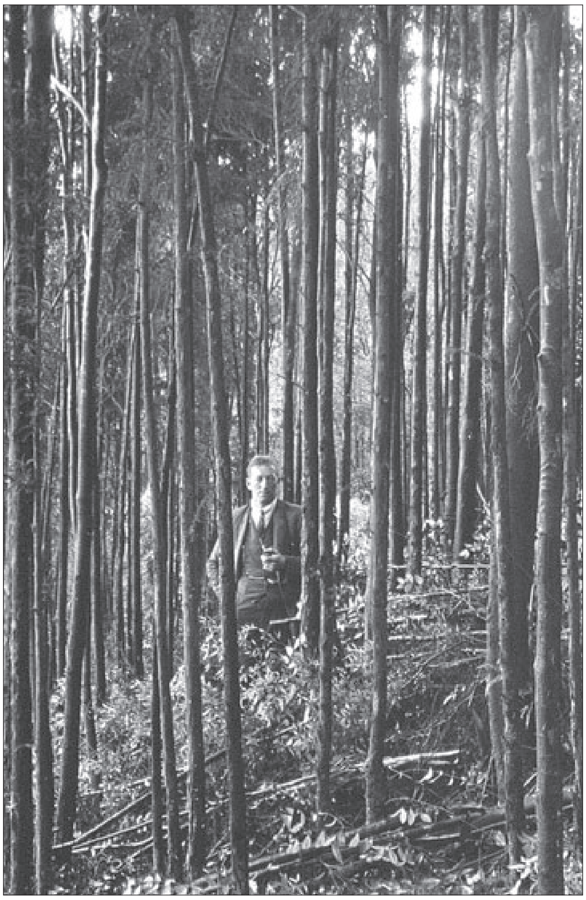
> *It is reasonably anticipated that the cutting out of the existing forests along the Pieman River, followed by silvicultural treatment of same, will result, some 40 years after treatment, in almost pure forests of blackwood, which can be cut out in a face and periodically reafforested, proving an asset of enormous value to the State.* [Forestry Department 1923, p. 8]

As early as 1925, an area of 500 acres was dedicated as State forest for the permanent production of blackwood and the capacity of the species to regenerate noted:

> *… the regeneration power of blackwood (*acacia melanoxylon*) is very pronounced and almost equals that of the eucalypts. A blackwood bearing area having beech (*fagus cunninghamii*) as the predominating type, and with blackwood only occurring in patches or as isolated trees, and showing under the dense overwood little or no regeneration, has, after removal of valuable species, only to be fired to produce, in most cases, a magnificent crop of seedlings of this invaluable timber tree. As the beech does not regenerate to any extent after a heavy fire, blackwood becomes, in turn, the predominating type. The value of this tendency to the whole question of future blackwood supplies cannot be overestimated.* [Forestry Department 1925, p. 14]

One year later, a cut-over blackwood area on the Spence River (a tributary of the Gordon River) was treated by opening up without using fire and, by the following year, the treated area was carrying dense regeneration of both blackwood and myrtle seedlings. However, in 1930, the Conservator, Sam Steane, while noting the success of the regeneration treatment, commented that the cost of £9 per acre ($45/ha) was high and that a cheaper method needed to be devised.

Rates of growth of some special species were investigated in the early 1920s by District Forestry Officers, A.H. Warren and Edward Julius in the Western and North-Western Districts respectively. In 1923, it was recorded that, at 15–20 years of age, some of the blackwood at Corinna were 60 feet (18 m) high, with a diameter of 12 inches (30 cm). In the North-Western District, stump analyses showed that, at 60 years, blackwood could be



A photo from the Forestry Department's 1922–23 Annual Report entitled 'King William pine regrowth after primary sylvicultural treatment. (Mt. Dundas, West Coast, Tasmana.)'. (The person pictured is possibly Arthur Warren, District Forester in the Western District.)

30 inches in diameter, while celery-top pine of the same diameter was 300 years old (Forestry Department 1930). The rate of growth of blackwood was also investigated in the late 1920s by analysing sections taken from five trees in the Arthur River swamp. This analysis showed that useful timber could be grown in 70–90 years. Many comments continued to be made in the Departmental reports of the 1920s and 1930s about the enormous potential for blackwood in terms of value to the State.

In these early years, the potential of other non-eucalypt species was investigated opportunistically. In 1923–24, assessments were made of 60 acres (24 ha) of almost pure sassafras at Ellendale and 3000 acres (1200 ha) of celery-top pine, myrtle and sassafras in the Parish of Loongana in the North-Western District. The sassafras stands in south-central Tasmania subsequently became the resource for the manufacture of clothes pegs in a factory at New Norfolk, which was in production from 1926 to the mid 1970s. Sassafras production from Crown Lands reached a peak in 1940–41, when 2 902 257 super feet (6845 m^3) were produced compared with myrtle and blackwood for the same year of 1 596 333 super feet (3765 m^3) and 742 098 super feet (1750 m^3) respectively (Forestry Department 1941).

In the early 1930s, Mr C.W. Fidler, the District Forester on the West Coast, measured growth rates and diameters of whitey-wood, *Acradenia frankliniae*, when interest was shown in using the wood for axe handles by a Mr Salter of Melbourne. The wood was tested by CSIR (Council for Scientific and Industrial Research, the forerunner of CSIRO) and early tests showed that it was remarkably tough. The species coppiced readily from cut stems and cuttings were easily established (Anon. 1983). In 1933–34, lancewood, locally known as tallow wood (*Nematolepis squamea*/*Phebalium squameum*), was retained in a 'cleaned area' (an area where some undergrowth and competing stems were removed) near Brickmakers Beach in the north-west because its lasting qualities in the ground made it suitable for use as telephone poles and posts.

Poles of *Nematolepis squamea* (formerly *Phebalium squameum*). High rot resistance made this species popular for fence posts, racks for drying kelp and other specialised uses. (Bill Holmes pictured.)

The non-wood products from special species timbers were also investigated. In the mid 1920s, samples of sawdust of leatherwood, celery-top pine and King Billy pine were sent by the Forestry Department to the Forest Products laboratory in Perth, Western Australia, for investigation of tannin values. Leaves of various species were sent to the Technological Museum in Sydney for testing for essential oils; stinkwood, *Zieria smithii* (now *Z. arborescens*), was a promising species in this regard. However, the best known non-wood product was Huon pine oil (methyl eugenol), which was distilled from sawdust and waste timber. The properties of this oil had been known for many years. It was used as an insecticide, for cosmetics, soap, and for an amazing range of medical afflictions, including 'treatment of ulcers, abscesses, pyorrhoea, puerperal fever and syphilitic cavities' (Kerr and McDermott 1999). By 1928, three plants for the distillation of Huon pine oil had been erected at King River and Strahan, including the Pine Oil factory owned by the company Megenol, which closed in the mid 1930s (Kerr and McDermott 1999). These plants achieved about 4% oil recovery but costs of production were too high for pine oil to compete with synthetic methyl eugenol.

Mixed forest (*Eucalyptus obliqua* and *E. delegatensis* over a rainforest understorey) in the Florentine Valley.

In the 1920s and 1930s, seed production by special species was of great interest to the foresters at the time because forest renewal after harvesting relied on natural regeneration. For example, in 1931, the Department's Annual Report notes that, in the Western District, leatherwood and sassafras had seeded well but otherwise it was a bad seed year, while in the following year, no Huon pine seed was found in that District. The importance of monitoring seed production generally was emphasised:

> *As regeneration operations will largely be conditioned by the seed years, these must be carefully watched for and the seeding habits of the various species observed.* [Forestry Department 1932, p. 4]

It was not until the late 1950s that detailed information on the ecology and regeneration of special species was recorded during studies in mixed eucalypt–rainforest in the Florentine Valley by Max Gilbert (Gilbert 1958, 1959) and later by researchers at the Maydena

Station (see Chapter 2). During the 1970s and 1980s, considerable unpublished data on the occurrence of rainforest species after logging of mixed forest in the Southern Forests, Florentine Valley and the north-west were obtained by various researchers and summarised by Hickey and Savva (1992).

Important general conclusions from these studies were that, although some rainforest regeneration occurred after clearfelling and burning areas of mixed forest, stocking of rainforest species was negatively affected by increasing fire intensity, and that regeneration was more common where remnant seed sources were present.

The Smithton Rainforest Research Station

By the 1970s, apart from the limited amount of information referred to above, the silvicultural requirements for successful management of rainforest species and blackwood swamps (which are not considered to be rainforest) had not been formally investigated. This lack of attention to rainforest and swamp silviculture was due mainly to the emphasis placed for many decades on eucalypt forestry, which supplied the great majority of the State's timber production. Exploitation of rainforests had consisted mainly of salvage logging of deep red myrtle from stands being converted to agriculture, particularly on the fertile soils of the north-west, and selective logging of the most valuable species, principally Huon pine (Kerr and McDermott 1999) and King Billy pine (Blakers and Robertson 1983). The generally low sawlog yields and often difficult access had restricted further forestry activity in rainforest areas (Hickey and Felton 1991). Though the blackwood swamps gave high yields and were close to roads, their soils gave fertile agricultural land when the forest was cleared. They were a wasting asset for forestry until the 1970s, as already indicated.

Leatherwood seedlings being grown in a glasshouse at the Smithton Research Station in the early 1980s as part of the research into rainforest silviculture. (John Hickey pictured.)

In the 1970s, the Forestry Commission directed some of its research effort to a better understanding of rainforest silviculture with a view to developing management regimes which could be applied to sustainable production of some special species timbers. In January 1975, the Smithton Rainforest Research Station was established, with the major objectives of:

- Investigating the natural regeneration processes in rainforests and blackwood swamps;
- Developing practical methods for their regeneration after logging.

The location of this new research station in the District Office at Smithton enabled easy access to study sites in three of the four identified major sources of special species timbers: tall myrtle forests on fertile sites, short forests rich in celery-top pine on infertile sites, and the blackwood swamps.

The appointment in 1975 of the first Rainforest Research Officer, Charmian Shepherd, marked the start of what became a very successful research station in the Smithton (now Murchison) District. Over the next three decades, the research staff who worked at the Station (Andrew Blakesley, Mike Castley, Leigh Edwards, Neil McCormick, Bob 'Spider'

A large old King Billy pine in rainforest in western Tasmania.

Mesibov, John Hickey, Sue Jennings and John Kelly) gathered valuable information on the ecology of rainforest species. John Hickey and Sue Jennings, building on the work of other research and District staff, finalised the development and implementation of the silvicultural regimes for rainforests and blackwood now used by Forestry Tasmania. Major reasons for the success of the Station were the well-defined focus of the work, proximity to the forests under study and the enthusiasm of the staff for rainforest research.

The approach was firstly to gain a better understanding of the natural processes occurring in rainforests and then, as in the earlier studies of the ecology of eucalypt forests, apply this knowledge to the development of management prescriptions. The initial investigations included ring-count analysis to gain a basic understanding of the age-size relationships for the major rainforest species: myrtle, sassafras and leatherwood. The age structure of the rainforest types, particularly the higher productivity tall myrtle forests, was investigated. Studies of the regeneration mechanisms of the major species were also initiated, including post-graduate studies at the University of Tasmania by Satwant Calais on regeneration of King Billy pine, celery-top pine and myrtle after rainforest logging in the Dundas area. Regeneration of these species was inversely correlated with post-logging burning and positively correlated with soil disturbance.

Studies of rainforest ecology in the north-west were also conducted by Greg Rowberry (late 1970s) and Jenny Read (early 1980s), post-graduate students at the University of Tasmania. In 1980, a plant survey instigated by the Forestry Commission was conducted by Jean Jarman and Gintaras Kantvilas in the Sumac forests where the major rainforest trial was established (see next section). This work provided the incentive for a detailed study of rainforest lichen ecology undertaken subsequently by Gintaras in the Sumac forests. The problem of mammal browsing of seedling rainforest species was recognised early on and the first trials to determine the effect of browsing on seedling growth and survival were set up by Station staff using fenced plots, under the direction of Helen Fletcher.

Rainforest Silviculture

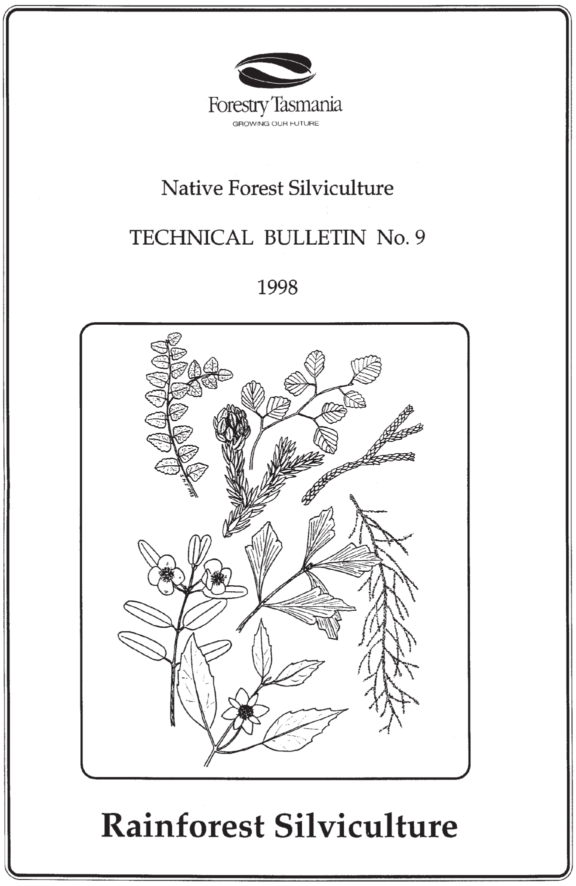
The current ecological classification of cool temperate rainforest in Tasmania divides the low to mid-altitude vegetation into three major groups, based on floristics and vegetation structure: callidendrous, thamnic and implicate forest (Jarman *et al.* 1984). However, for wood production purposes, rainforest can be conveniently classified into two broad but distinct types known by their photo-interpretation classifications, M+ and M- (see Chapter 1). M+ forests are mainly the taller, more productive forests on more fertile soils (callidendrous and taller thamnic types); M- are the lower yielding, principally thamnic and implicate forests on less fertile sites. The research program at the Smithton Station, supplemented by studies in rainforest areas in the north-east and the south, was aimed at understanding the ecology of the M+ and M- forests, and developing silvicultural regimes for them.

Twenty years of silvicultural research in rainforests enabled the production in 1998 of Native Forest Technical Bulletin No. 9, *Rainforest Silviculture* (Forestry Tasmania 1998). This publication contains silvicultural prescriptions for managing rainforest and a wealth of ecological information on the special species within this forest type. The information summarised in the Bulletin also laid the basis for management of Special Timber Management Units, areas specifically designated and managed for the sustainable production of special species timber.

The following sections discuss the history of research in M+ and M- rainforest, particularly the development of silvicultural prescriptions for individual rainforest species.

Logging and regenerating M+ rainforest

In 1976, the Sumac logging and regeneration trial was established in the South Arthur rainforests by Andrew Blakesley, who succeeded Charmian Shepherd as the Rainforest Research Officer at Smithton. This landmark trial was a very significant step forward in special species silvicultural research, the results providing a major input into the silvicultural regimes now used in the management of rainforest species.



Rainforest Silviculture, published in 1998, includes ecological information and descriptions of Tasmanian rainforest, and silvicultural prescriptions for its management.

The trial covered some 80 ha in lowland rainforests dominated by myrtle, and compared the following five logging and regeneration treatments to an unlogged control area (Blakesley 1980):

- Selective sawlogging, retaining about 80% of the canopy;
- Stripfelling;
- Shelterwood, retaining about 60% of the canopy;
- Clearfelling and slashburning with retained cull trees;
- Clearfelling and slashburning, with all culls felled to waste.

All areas were allowed to regenerate naturally, and seedlings of several rainforest species

A four-year-old King Billy pine planted in a small arboretum established in 1979 near the Sumac logging and regeneration trial. (Neil McCormick pictured.)

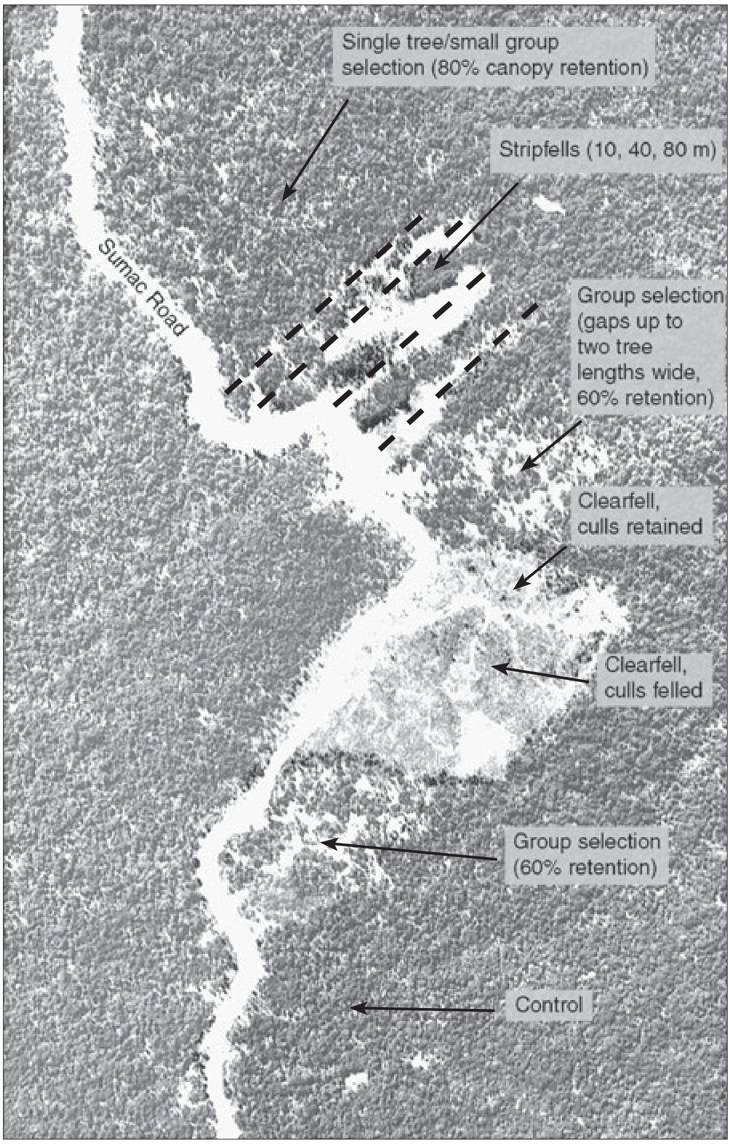
were also planted in small arboreta in the two clearfelled areas to investigate planting as a regeneration treatment. The results of this trial have been reported by Hickey and Wilkinson (1999) and are summarised below.

Areas treated with selective logging, stripfelling and shelterwood systems were densely regenerated, with the regeneration being dominated by myrtle, although other rainforest species were represented. These treatments had all maintained a seed source from retained mature trees within 40 m (i.e. maximum tree height) of the treated areas and there were several years of very high seed production (mast years) in the 20 years following trial establishment. The selective logging treatment comes closest to the natural system in these forests, with regeneration occurring in gaps created by fallen trees or death of myrtles from myrtle wilt disease (see Chapter 6). A major difference, however, between the treatment and the natural system is that damage to retained trees during selective logging increases the level of myrtle wilt, creating larger gaps which will only regenerate from advance growth or if seed falls on exposed seedbeds. Consequently, regeneration may be patchy (Forestry Tasmania 1998c).

The clearfelling with cull retention produced regeneration but, in the clearfelled area where culls were felled prior to burning, virtually no regeneration occurred greater than 100 m from a forest edge. Once established, myrtle seedlings grew best in more open conditions, averaging 40 cm height growth per year over 18 years. Growth rates were reduced in treatment areas that were more shaded.

A shelterwood treatment, involving an initial partial harvest and then a subsequent removal of the retained trees once seedlings are well established, was considered to produce the highest yields over a rotation. However, because saleable pulpwood and sawlog yields from these rainforests are unlikely to justify the costs of the shelterwood removal treatment, the current prescriptions for rainforest in Special Timber Management Units (STMUs) are to use selective sawlogging and overstorey retention treatments. These are used in preference to more intensive treatments such as seed-tree systems because they are more likely to maintain the natural uneven-aged structure of the rainforest, based on very long intervals between harvests.

The Sumac trial showed that establishment of myrtle regeneration is dependent on provision of an adequate seed source, mechanical disturbance of the topsoil and provision of shelter during the early years of establishment. Myrtle wilt disease provides a gap regeneration mechanism in rainforests (see Chapter 6) but can be a serious problem in disturbed rainforest stands. To monitor the progress of myrtle wilt, transects were established in the treatments in the Sumac trial that included retained trees. Health assessments of trees on these transects showed that in the selectively sawlogged area (> 80% canopy retained) the percentage mortality of myrtle trees rose from 24% immediately following the logging in 1978 to 51% in 2004. However, the unlogged control area showed a similar increase in myrtle mortality (8% to 33%) over the same period (1980–2004). Despite these high mortality levels, the rainforest at both Sumac trial sites is still multi-aged and structurally diverse, with little current sign of disturbance from the logging (Elliott *et al.* 2005).



An aerial view of the Sumac logging and regeneration trial established in 1976–78, showing the arrangement of treatments.

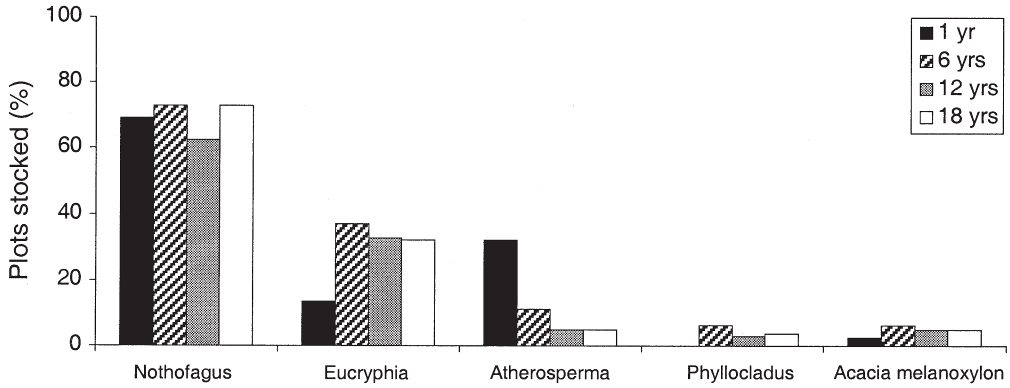
The Sumac trial also showed that regeneration success can be significantly affected by the level of browsing by native mammals. The main animal species causing damage are the pademelon (*Thylogale billardierii*) and, to a lesser extent, Bennett's wallaby (*Macropus rufogriseus*). Considerable variation was found in the susceptibility of special species to browsing. Blackwood and sassafras are the most susceptible, then leatherwood and myrtle. Celery-top pine has low susceptibility (Forestry Tasmania 1998c).

To further test logging and regeneration methods over a range of sites, conditions and treatments, several further trials were established in the 1970s and 1980s in the north-west rainforests, particularly the more productive sites on basalt soils. A range of logging methods, including seed-tree systems, shelterwoods and selective logging, and seedbed preparation (e.g. snig track extension, topsoil scarification and fern dozing), were tested in these additional trials.

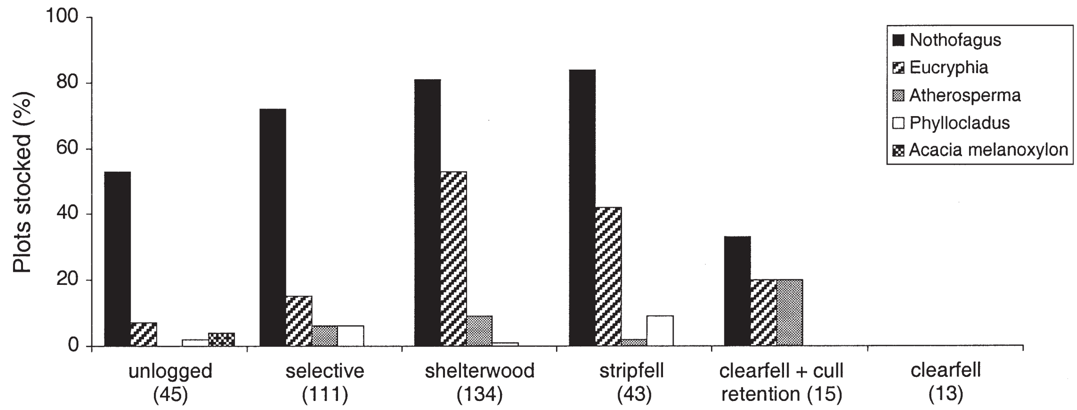
In 1981, a logging and regeneration trial to test a seed-tree regeneration system in M+ rainforest was established at Pruana Road. Myrtle trees were retained as a seed source during the harvesting at an approximate stocking of 16 trees/ha and the site was scarified to increase available seedbed.

The selectively logged area in the Sumac logging and regeneration trial, six months after logging. Note the high canopy retention giving a relatively undisturbed appearance.

Clearfelled, culls-retained area, one year after a low-intensity burn in rainforest in the Sumac trial.



The percentage of research plots which were stocked with regeneration of rainforest species and blackwood at one, six, twelve and eighteen years after logging. A stocked plot was one containing at least one seedling of the species being monitored. (From Hickey and Wilkinson 1999.)



The percentage of research plots which were stocked with regeneration at ten years after logging in each of the logging and regeneration treatments, and in the unlogged control area. (From Hickey and Wilkinson 1999.)

Although retained trees suffered windthrow and myrtle wilt, a sufficient number survived to produce seed, resulting in prolific regeneration. After 19 years, the area was fully stocked with vigorous myrtle regrowth up to 9 m tall. The seed-tree system may be appropriate in STMUs if the objective is to harvest most of the wood, obtain dense regeneration and maximise growth, and where there is little requirement to maintain a semblance of the original forest structure. However, as already stated in the discussion of the shelterwood trial at Sumac, treatments such as selective sawlogging or overstorey retention, which maintain some of the original stand structure, are preferred for STMUs (Jennings and Hickey 2003).

The information gained from the Sumac and other logging and regeneration trials formed the basis for development of prescriptions for management of STMUs. Two silvicultural prescriptions are recommended for M+ rainforest depending on the level of utilisation planned (from Forestry Tasmania 1998c):

1. Overstorey retention where there is a pulpwood market for rainforest timber products. Seed and shelter trees that do not contain significant merchantable volumes are retained at 30 trees/ha. At least half of these trees must be evenly spaced myrtles, with the remainder being other species such as leatherwood and sassafras. Damage to retained stems must be minimised to reduce the spread of myrtle wilt.

Measuring the height of myrtle saplings in a seed-tree retention trial at Pruana in north-western Tasmania. The dense myrtle regeneration in this trial averaged 7 m in height 20 years after the logging and regeneration treatment.

2. Selective sawlogging is recommended where there is no pulpwood market for rainforest products and tree selection is primarily for sawlogs, veneer or craftwood, or in areas where there is a strong desire to keep or create an uneven-aged forest structure. Only selected sawlog stems are removed, avoiding disturbance to areas containing non-sawlog stems and avoiding canopy gaps greater than 30 m in diameter. All unmerchantable stems are kept to provide seed and shelter, with myrtle seed trees retained at 15–20 m spacing. The uneven-aged structure of the forest is maintained and the visual impact is low.

In addition to providing information on appropriate silvicultural practices in rainforest, all the logging and regeneration trials provided valuable data on the volumes of pulpwood and sawlog that could be recovered. This information on likely yields greatly assisted management planning and economic assessments of rainforest harvesting. The data were particularly helpful when a review of the deep red myrtle resource, as required by the Regional Forest Agreement (RFA 1997), was conducted (Mesibov 2002). This review assumed selective logging regimes developed from the rainforest silvicultural research would be applied to the available resource, thus enabling derivation of yield estimates over the remainder of the RFA period.

Sassafras studies

Research into the silviculture and ecology of sassafras, *Atherosperma moschatum*, was part of the work of the Rainforest Research Station at Smithton, particularly during the logging and regeneration trials in M+ rainforest. The results of these studies were included in Native Forest Silviculture Technical Bulletin No. 9, *Rainforest Silviculture* (Forestry Tasmania 1998c).

A separate study on induction of black-heart in sassafras trees is included here as an example of ambitious research aimed at developing a technique which had the potential to rapidly produce a product for a small but high-value market. The dark-stained, multi-coloured black heartwood found in some sassafras trees is keenly sought by furniture makers, woodturners and other craftspeople.

In the late 1980s, Tim Wardlaw and Murray Jessup, in co-operation with Martin Line at the University of Tasmania, conducted inoculation trials to see if black-heart could be artificially induced in a short period in live sassafras trees. Four fungal species were isolated from naturally occurring black-heart, cultured in the laboratory and inoculated into living trees by drilling and injection.


Drilling holes into a stem prior to injecting a fungal suspension to induce black-heart rot, the fungus that produces the highly prized coloration in sassafras wood. (Tim Wardlaw pictured.)

After a year, the wood from inoculated trees had a similar, although paler, coloration to natural black-heart and it seasoned and turned well (Forestry Commission 1990c). Thus, the technique was successful but has not been used commercially to date, principally because there are still adequate supplies of natural black-heart timber to supply the market.

Logging and regenerating M- rainforest

The research effort into rainforest silviculture was understandably focussed mainly on the M+ (or higher productivity) rainforest types. These types have higher growth rates, provide more scope for silvicultural manipulations and are an important source of special timbers for industry. However, studies were also conducted by the research staff at Smithton of some of the lower productivity M- rainforests.

Celery-top pine silviculture

Most of the soil nutrients in M- forest are held in the organic peat layer that often overlies infertile gravels. Inappropriate harvesting can remove much of the peat layer, and it is critical that post-logging burning is not used. Logging of these forests can sometimes be justified where celery-top pine, a sought-after species for panelling, boat building and poles for building construction, is abundant, particularly if roading expenses can be spread by harvesting nearby stands of eucalypts or M+ forest. It should be noted that some 400 years are needed to produce celery-top pine sawlogs 60 cm in diameter (Hickey and Felton 1991).

To investigate the silvicultural options for managing celery-top pine stands, four logging and regeneration trials were established between 1978 and 1986 (Hickey and Felton 1991). Two of these trials were harvested for sawlogs only and two were logged for sawlog and pulpwood. One of the trials logged for sawlog and pulpwood yielded 26 m^3/ha of sawlog and 73 m^3 /ha of pulpwood. As celery-top pine seedlings arise from ground-stored or bird-dispersed seed, retention of trees as a seed source is not required. Seedlings of this species occur in the greatest numbers on poor soils which often have a thick peat layer (Hickey 1983). The trial showed that there was good germination if the peat layer was lightly disturbed and good survival if some shelter was provided by retaining stems during logging.


Measuring a twelve-year-old celery-top pine seedling after selective logging in an M- logging and regeneration trial in north-western Tasmania.

It was concluded from the celery-top pine logging trials that any harvesting of these forests should be primarily for sawlogs, while retaining myrtle and leatherwood stems for shelter and a leatherwood nectar resource. Increased levels of disturbance of the peat layer on these fragile sites through additional pulpwood logging are likely to result in soil erosion and general site degradation (Forestry Tasmania 1998c).

Huon pine silviculture

Huon pine (*Lagarostrobos franklinii*) is the best known native softwood species in Tasmania and occurs mainly in riverine environments in thamnic and implicate rainforest communities in western and south-western Tasmania (Peterson 1990). Understandably, there has been little formal silvicultural research into Huon pine because of the limited areas available for harvesting and the very slow growth rates characteristic of this icon species. In the mid 1980s, the Forestry Commission decided that, although there was little likelihood of implementing Huon pine silviculture on an operational scale, it was important at least to determine which harvesting treatment could adequately regenerate the forest.

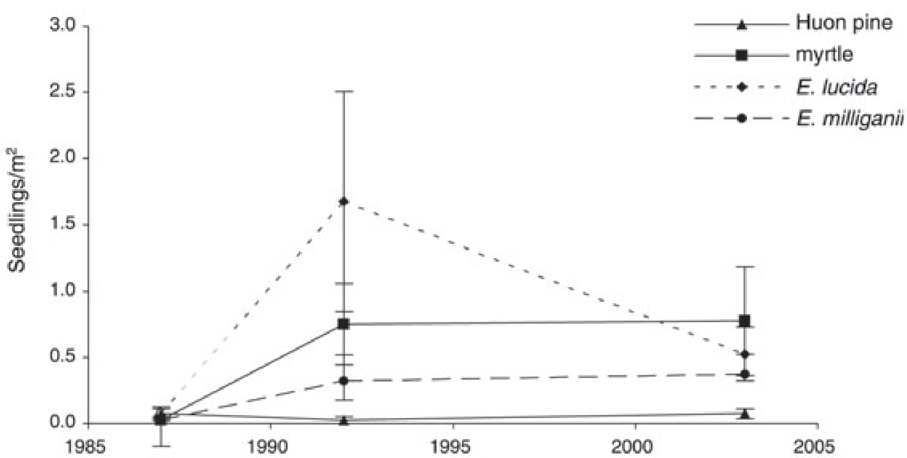
Thus, in 1987, a Huon pine logging and regeneration trial was established at Traveller Creek, 10 km south of Queenstown. In 1935 at this site, Cliff Bradshaw (father of Bern, current owner of Bradshaw's Mill) set up a steam-driven spot mill which operated until World War Two (Kerr and McDermott 1999); the stumps from this old operation are still visible near the trial site. Following selective logging in 1987 of some standing trees and removal of downers, three regeneration mechanisms were studied in the trial. The natural regeneration from retained seed trees was monitored using 4 m^2 plots, and groups of rooted cuttings (raised at Perth Nursery) and instant cuttings (taken from trees on the site) were established.

In 2003, sixteen years after the selective logging, 39% of the 4 m^2 plots within 50 m of live Huon pine trees were stocked with natural regeneration. As expected, these seedlings had grown very slowly, averaging only 2 cm in height growth per year. Some 63% of the rooted cuttings had survived and their height growth averaged a respectable 8 cm/yr over the last 11 years. The instant cuttings mostly failed to establish and the few survivors had very low growth rates (Jennings *et al.* 2005).

The results from the Traveller Creek trial, combined with data on genetics and seed production obtained by Alison Shapcott during

A naturally regenerated Huon pine seedling at the Traveller Creek trial. This seedling was 15 cm high 16 years after the forest was harvested.

Left: A particularly good example of a mature Huon pine, Junction Creek, 2004. More typically, Huon pine occurs as a tree with poor form, multi-stemmed and leaning, growing along river banks in western Tasmania. (Dick Chuter pictured.)



Natural regeneration (seedling density) of the four most common rainforest species recorded in logged Huon pine forest at Traveller Creek near Queenstown. Neither celery-top pine nor sassafras had established on the plots. (From Jennings *et al.* 2005.)

her studies under the National Rainforest Conservation Program (see Chapter 7), have enabled the formulation of silvicultural prescriptions for logging and regenerating Huon pine. These include monitoring of mast seed years, retention of at least 10 seed trees per hectare to obtain natural regeneration, harvesting of all saleable pine (standing and on-ground), retention of advance growth seedlings, and planting of understocked, disturbed areas after logging with rooted cuttings grown in a nursery from material collected on-site (Forestry Tasmania 1998c).

Leatherwood silviculture

Leatherwood is another species which is more abundant in the M- forests and, although it is used for timber production, its main use is as a source of the famous leatherwood honey (Ettershank and Ettershank 1993; see also Chapter 7). Since the 1970s, there has been concern expressed over the possible reduction in the leatherwood resource for apiculture through the logging of mixed forest and subsequent regeneration to predominately eucalypt forest to be managed on 80–90 year rotations. To address this concern, Ken Felton initially worked with bee-keepers in the 1970s to gain knowledge of the management of the apiary resource and then conducted preliminary trials of artificial seeding. Keith Orme showed that cuttings of leatherwood rooted readily, and he established a small sowing trial near the Arve River in 1975. Further sowing trials were established by Graeme Clark and Leigh Edwards in the Arve and Hastings areas in the late 1970s, but few leatherwood seedlings resulted.

Measuring the height growth of leatherwood regeneration at the Sumac logging and regeneration trial. (Leigh Edwards pictured.)

The Sumac rainforest trial was the source of new data on leatherwood silviculture. Like myrtle, leatherwood germinated in autumn after seedfalls, and the subsequent regeneration was highest on areas disturbed by logging and lower on burnt areas. Leatherwood growth was highest in the more open conditions, again similar to myrtle, and its stocking levels increased markedly after age one year and remained constant from age six years to at least 18 years after logging. Leatherwood seedling densities were highest in the shelterwood and stripfelling treatments at Sumac and lowest in the clearfelled treatments, following a similar pattern to myrtle, although its height growth at age 18 years was approximately half that of myrtle (Hickey and Wilkinson 1999).

Results from the sowing trials at different locations using a range of rates, seed sources and methods showed that very few leatherwood seedlings successfully established. This poor establishment from the sowings was attributed to several factors, including heavy browsing from native animals, generally low sowing rates, low field germination rates of stored leatherwood seed and competition from other species (Neyland and Hickey 1990).

The overall conclusions from the studies of leatherwood silviculture were that leatherwood regenerates well after logging of rainforest in the presence of a seed source and if there is no subsequent burn. However, in logged mixed forests regenerated to eucalypts, competition and shading from fast-growing eucalypts limit the value of leatherwood regeneration for apiculture. Good potential leatherwood nectar sources are provided by formal reserves of rainforest and mixed forest, mixed forest reserved by management prescriptions (e.g. streamside reserves) and unlogged rainforest outside reserves (Neyland and Hickey 1990). Where leatherwood-rich patches occur in mixed forest, there are also opportunities to retain these as clumps on sites where aggregated retention silviculture can be practised.

Myrtle thinning

Research plots established between 1981 and 1984 in even-aged M+ rainforest across a range of ages indicated that at least 200 years were needed to produce 60 cm diameter sawlogs (Hickey and Felton 1991). If these rotations in tall myrtle forest could be shortened by more intensive silvicultural treatments such as thinning, then the economics of growing myrtle could be improved, provided the costs of thinning were kept low.

Some dense, even-aged stands of myrtle occur in rainforest areas as a result of spot fires or earlier logging, and thinning of these stands was studied to gain information on the potential for reducing the long rotation time for myrtle. To investigate this potential, small areas of even-aged myrtle regrowth aged 15 (Sumac), 40 (Rabalga), 50 (West Takone) and 70 years (Blackwater) were thinned. These trials showed a good response of young myrtle to thinning, with diameter growth rates up to 1 cm/yr compared with less than 0.5 cm/yr for unthinned control plots. However, thinning of the 70-year-old stand resulted in severe mortality from myrtle wilt and windthrow. The early conclusion from these trials was that thinning of stands up to the age of 40 years was feasible in terms of getting a reasonable growth response without incurring unacceptable damage from myrtle wilt, but at high cost.

To obtain data on myrtle thinning over a longer period, the growth response of even-aged myrtle regeneration in the Sumac area thinned in 1981 at age 15 was measured after 15 years. Comparison of the growth in thinned and unthinned plots suggested that reduced rotation

Measuring diameter growth of a thinned myrtle stand in north-western Tasmania. This stand of dense myrtle regrowth resulted from a small fire some 40 years previously. (Sue Jennings pictured.)

lengths of about 100 years were possible in thinned stands, although at considerable cost (Forestry Tasmania 1998c). The treatment could potentially be applied to any areas of even-aged myrtle produced by silviculture or wildfires.

Seedfall of special species

Occasional observations of good and poor seed years for some special species in Tasmania were made informally over the years, and myrtle seedfall was monitored by the Forestry Commission in the Florentine Valley from 1962 to 1971. Apart from this, there was little information on the seedfall of special species in Tasmania until studies were conducted at the Smithton Research Station.

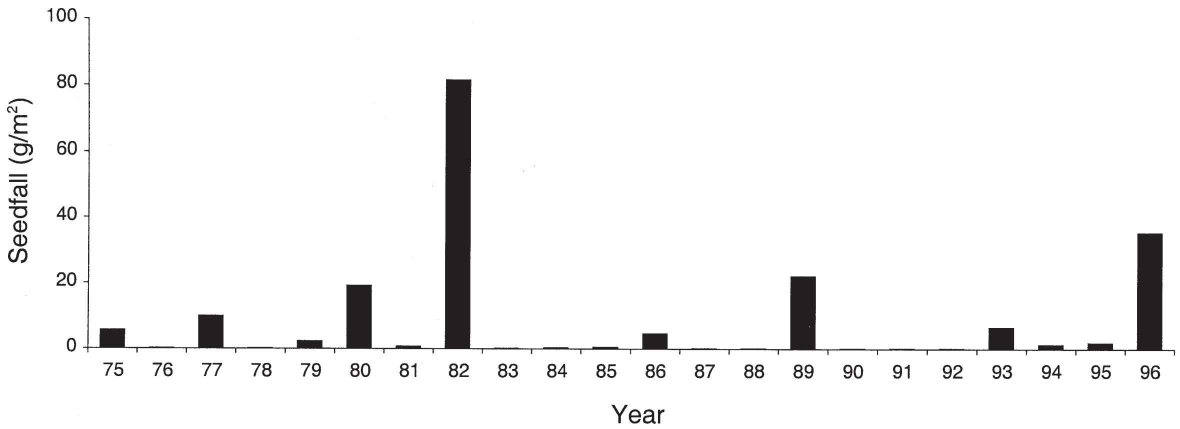
A seed trap at the Sumac logging and regeneration trial, where myrtle seedfall was monitored for 21 years.

The Smithton studies involved monitoring of seedfall of myrtle, sassafras and leatherwood using seed traps at the Sumac and Pipeline Road sites. Leigh Edwards and Neil McCormick spent many hours sorting these trap catches. These studies quantified the seedfall from the three species and showed that the quantities of myrtle seed varied greatly from year to year, whereas seed production for sassafras and leatherwood was more consistent (Hickey *et al.* 1982). Germination capacity of myrtle seed was greatest in high seedfall years and low in light seedfall years and also decreased with seed collected at higher altitudes. Sassafras had low germinative capacity from year to year but germination was consistent for leatherwood.

The studies provided information on the timing of seed shed for each species and, importantly, the distances from seed-bearing trees that viable seed falls. For myrtle and leatherwood, most viable seed fell within 40 m from source trees, but sassafras seed was found to travel longer distances. This information was directly applicable to the design of logging and regeneration treatments which involved retention of some trees on the logged areas. To provide for a good stocking of regeneration after logging, it was recommended that retained myrtle and leatherwood trees should be spaced at intervals of less than 40 m and, at higher altitudes, more myrtle trees should be retained per hectare.

Maintaining special species in managed mixed forests

Special species occur in pure stands of rainforest and also as an understorey in eucalypt forest (mixed forest). Although it had been observed that special species were still present in the regeneration after clearfelling, burning and sowing of mixed forests (e.g. Jordan *et al.*



Annual seedfall of *Nothofagus cunninghamii* from 1975 to 1996 at the Sumac trial. (From Hickey and Wilkinson 1999.)

1992), concerns were raised by special timbers users, apiarists, environmentalists and scientists over the effects of using 80–90-year rotations (as planned in eucalypt forest) on the special species components of those forests (Hickey and Savva 1992).

In a study of the special species components in mixed forest regenerated by wildfire and in silvicultural regeneration, no marked difference was found in the presence of myrtle between sites regenerated by stand-replacing wildfire, by artificially sowing eucalypt seed, or by using seedfall from retained eucalypt trees. The floristics of 20–30-year-old regeneration arising from wildfire and from silvicultural treatment were compared with those of oldgrowth mixed forest, and the results showed that the frequency of occurrence of most rainforest species was greatest in oldgrowth mixed forest and lowest in silvicultural regeneration. Most species common in oldgrowth forests were present in similar frequencies in both categories of regeneration, although there was a lower mean frequency of epiphytic fern species in silvicultural regeneration. The floristics were sufficiently similar to assume that after one clearfelling and burning treatment, without further logging or fires, the silvicultural regeneration could become mixed forest and eventually rainforest (Hickey and Savva 1992; Hickey 1994).

Regeneration of mixed forest (eucalypts with a rainforest understorey). (Mark Neyland is beside the eucalypt.)

A recent study on the colonisation of clearfelled, burnt and sown mixed forest coupes by seed from rainforest species in adjacent mixed forest showed that densities of total rainforest species were greater than 1000 stems/ha in the regeneration at all distances from the edge of coupes between 0 and 200 m. However, the abundance of all rainforest species declined with increasing distance from coupe edges. From the results, it was assumed that without further disturbance, mixed forest, including all rainforest species previously present, would re-form on the clearfelled coupe within the lifetime of the dominant eucalypts, albeit with probable changes in relative abundance (Tabor 2004).

Alternative silvicultural methods and longer rotations needed to be considered for the treatment of mixed forest used for wood production if a significant yield of special timber was to be sustained from this type of forest. These requirements have been incorporated into the management prescriptions for STMUs containing mixed forest.

Blackwood Silviculture

Because blackwood (*Acacia melanoxylon*) was recognised early in Tasmania's forestry history as a valuable timber species, some basic information on its regeneration, rates of growth and response to thinning was already available when more detailed research into special species began in the 1970s. Blackwood research at the Smithton Research Station followed similar lines to that of the rainforest research. The main emphasis was on investigations of blackwood ecology, the development of logging and regeneration regimes for the different blackwood forest types, response to thinning and protection from browsing. The research effort on blackwood silviculture was boosted in 1977 by the appointment of Bob ('Spider') Mesibov, who made significant contributions to the myrtle-dominated research but was primarily involved with blackwood silviculture.

In recent years, Sue Jennings has led the further development of silvicultural regimes for the different types of blackwood stands.

Blackwood occurs in four distinct associations (Forestry Commission 1991c):

- An understorey species in wet eucalypt forest;
- A canopy species in swamps, with teatree and some other species;
- A component of riverine rainforest;
- An understorey species in dry eucalypt forests.

The first three types are all sources of commercial quantities of blackwood sawlogs.

The Smithton Research Station was very well placed to conduct blackwood research as the three commercially viable forest types occur in the Circular Head forests, including most of the remaining blackwood-rich swamp forest in Tasmania. The swamps have been the major source of blackwood timber in Australia for over a century (Forestry Commission 1989b). In addition to studies of blackwood in native forests, there has also been research into growing blackwood in plantations (see Chapter 5).

Each of the first three blackwood forest types mentioned above required a different regime for achieving a commercial harvest and establishing regeneration. However, the early research showed that there are at least three vitally important factors that influence the success of blackwood silviculture in all these forest types: seed source, light conditions, and protection from browsing.

Blackwood seed

One common feature in all blackwood forests is the presence of ground-stored seed that has accumulated from many decades (at least) of seedfall. The phenomenon of prolific regeneration of blackwood from ground-stored seed following disturbance had been recognised for many years but, in the late 1970s, more precise investigations were undertaken into the distribution and viability of ground-stored seed. Preliminary results indicated that 1–2 million viable seeds per hectare could be present in the top 10 cm of soil. Surveys of ground-stored seed in 1984 in the Dismal and Montagu Swamps showed there were 9–38 million seeds per hectare in the top 15 cm of soil (Jennings 1998). Later studies in the early 1990s showed that ground-stored blackwood seeds at Salmon River in the North Arthur forests reached levels of 20 000/m^2 (200 million per hectare); viable blackwood seeds were distributed through the soil to a depth of at least one metre, with 50% of them within the upper 10 cm (Wilkinson and Jennings 1994).

A photo from the Forestry Department's 1924–25 Annual Report entitled 'Ida Bay State Forest, Southern District. Re-growth of eucalypt and blackwood. Area has been thinned.'

The identification of the best sources of blackwood seed for use in enrichment treatments and other plantings was also a priority. The Kanunnah blackwood stand adjacent to the Arthur River was identified as a very good local provenance, and seed from this stand was used for many years for raising seedlings at Perth Nursery and at a small nursery at Smithton for use in the enrichment planting discussed later in this chapter. However, Kanunnah blackwood performed badly in provenance trials on harsher sites such as Meunna, south of Wynyard, and was costly to collect so seed from other provenances was used to grow seedlings for later plantings.

Tall, straight blackwoods in the Kanunnah forest near the Arthur River in north-western Tasmana. This stand was the source of seed for some early blackwood plantings.

Given the enormous quantities of ground-stored blackwood seed, it is not surprising that seedling densities following disturbances such as fire, logging or windthrow can reach extraordinarily high levels. Assessments of plots in swamp forests in 1987 showed that blackwood stocking at age three years was over 100 000 seedlings per hectare (Jennings 1998), and 70 000 seedlings per hectare have been recorded in mixed eucalypt/blackwood forests (Forestry Commission 1991c). In spite of the enormous germination potential from the reservoir of ground-stored seed, the subsequent stocking of blackwood seedlings was variable, commonly being very much reduced by browsing of the highly palatable seedlings, usually by native mammals.

Light conditions

Observations by rainforest research staff, particularly Bob Mesibov, of blackwood in Circular Head growing in the swamps, in wet eucalypt coupes and in rainforest have shown that seedlings require very specific light conditions in order to achieve optimal growth and form. Adequate top lighting is needed to promote height growth but, when too much side light is present, the plants develop an open-grown form with heavy branching.

Suitable conditions of top and side lighting occur to varying degrees in the swamps and wet eucalypt forests when seedlings are accompanied by nurse crops of teatree and dogwood, respectively. However, blackwood does not self-thin very well and growth can slow or even cease in dense stands when light availability is too low. In rainforest situations, the best growth and form are achieved when seedlings grow in light wells in the forest formed by gaps in the canopy of myrtles and/or other rainforest species (Forestry Commission 1991b).

Much of the silvicultural research discussed later in this section has been directed at obtaining the best combination of top- and side-light conditions, using release thinning techniques. Obtaining the appropriate light conditions has also been a critical aspect of blackwood plantation silviculture (see Chapter 5).

Protecting seedlings from browsing

Browsing of newly germinated blackwood was soon identified as a major problem by researchers at the Smithton Rainforest Research Station. Seedlings were found to be particularly vulnerable when less than 0.5 m high and, without protection, 90–100% were almost invariably browsed. In 1977, when 1000 blackwoods were planted on a freshly burnt coupe, 950 were browsed on the first night (L. Edwards, cited in Statham 1983).

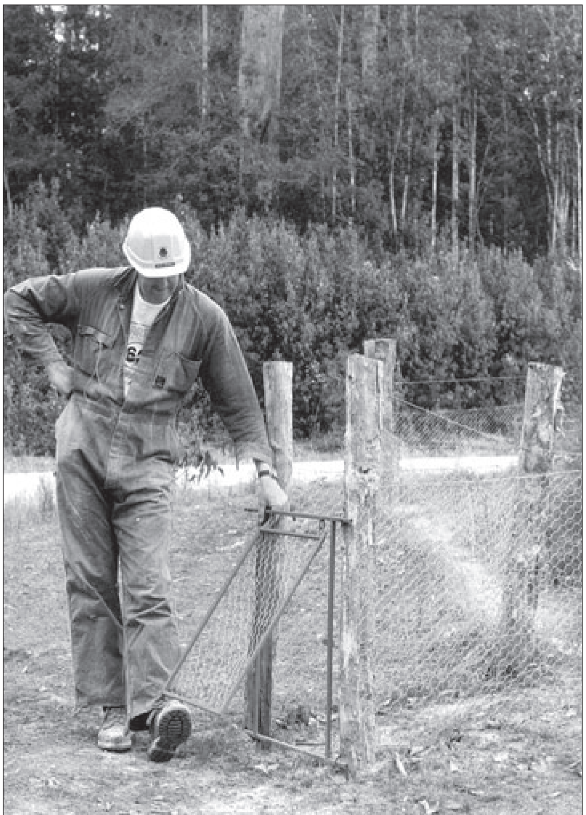
Studies by Sue Jennings and Helen Statham (nee Fletcher) in the Smithton District (now Murchison) in the early 1980s showed that the most abundant herbivore and the species thought locally to be responsible for severe and extensive browsing of blackwood was the red-bellied pademelon (*Thylogale billardierii*). Other browsing animals recorded were Bennett's wallaby (*Macropus rufogriseus*), eastern swamp rat (*Rattus lutreolus*), long-tailed mouse (*Pseudomys higginsii*), European rabbit (*Oryctolagus cuniculus*) and domestic livestock (Statham 1983). Poisoning with 1080 (sodium monofluoroacetate) was tried against black-

Trials of different fencing materials to protect blackwood against browsing animals. Onion bag (left) and barrier mesh fencing (centre) show deterioration from exposure to the elements, but blackwood within a wire-netting fence, which provided the best protection in the trials, established successfully (right). (Warren Johnson pictured.)

wood browsers, but this control method was ineffective because of the very high browsing pressure and the length of time that seedlings stay vulnerable to the browser. Areas where poisoning was used without any other control methods remained understocked for many years (Jennings *et al.* 2000).

Observations showed that young blackwood seedlings can receive some natural protection from competing vegetation or logging debris. Dense thickets of teatree (*Melaleuca* spp., *Leptospermum* spp.), dogwood (*Pomaderris apetala*) or cutting grass (*Gahnia grandis*) give some degree of browsing protection provided they establish and grow fast enough to accompany the young blackwood seedlings before browsing occurs. However, it soon became clear that artificial protection of seedlings from browsing was a major requirement for successful blackwood silviculture. Consequently, in 1985, Smithton District, through an initiative of Ross Lucas, commenced the practice of fencing eucalypt coupes that contained a significant blackwood component, following the standard clearfell, burn and sow treatment for wet eucalypt forests. This practice, now known as fenced intensive blackwood (FIB, see later section), was a major step forward in obtaining a good stocking of blackwood in eucalypt coupes and has been used successfully ever since. Currently, 100–200 ha of fenced regeneration are established each year. In the blackwood swamps, fencing of coupes immediately after harvesting was also found to be essential for obtaining reasonable blackwood stocking, but the fencing was sometimes difficult to maintain because of flooding and wet soils.

Research into different types of fencing was conducted using various materials, including a range of plastic meshes, hinge-joint wallaby wire fencing and wire netting. The plastic meshes were not durable under field conditions except for a black windguard material, but this snagged on vegetation and was difficult to support. The best value for money proved to be wire netting; it was easy to use and remained intact and undamaged at the end of the two-year monitoring period (Jennings 2003). The difficulties encountered with protecting blackwood seedlings inspired staff in the Smithton District to develop some ingenious fencing methods such as 'Blakey's' one-way wallaby exit gate (named after its inventor, Kevin Blake) which allowed fenced-in animals to escape. The gates were positioned at the corners of the fence and animals moving around the internal perimeter of the fence were directed through the gate. Electric fencing was found to be generally unsuitable in native forest coupes because of short-circuiting from winter flooding, and



A fenced blackwood regeneration area with a 'Blakey's' one-way wallaby gate, 2005. These gates (an innovation developed by Kevin Blake in the Smithton, now Murchison, District) allowed browsing animals trapped inside the regeneration area to escape through the one-way swing gate built into the corners of the fence. (Leigh Edwards demonstrates the gate's operation.)

damage from windthrown trees adjacent to the coupe (Forestry Commission 1991c).

In the riverine blackwood forests, selective logging of blackwood, down to a minimum diameter limit and with retained myrtle stems as a nurse crop, was recommended because clearfelling was not a suitable harvest method for these environmentally sensitive river flats. In cut-over areas where the stocking of advance growth blackwoods and seedlings arising from ground-stored seed was less than 150 stems per hectare, enrichment planting with nursery-raised seedlings was carried out in the 1970s and 1980s. These seedlings were individually caged for protection against browsing animals, using plastic bags, plastic mesh or wire netting supported by wooden stakes. But in the late 1980s, their use was discontinued due to the high cost of seedlings, cages and labour and the general ineffectiveness of the treatment. Also, most river flats were included in formal streamside reserves under the Forest Practices Code introduced in 1987, and very little harvesting of river-flat blackwood has taken place since.

Developing logging and regeneration regimes for blackwood forests

Selective logging of blackwood was conducted at fluctuating levels in the north-west swamp forests from the 1830s to the 1970s. Silvicultural work and management planning was initiated in the 1920s but lapsed in the Depression years of the 1930s (Forestry Commission 1982b). The first blackwood silviculture investigations at the Smithton Station were set up by Bob Mesibov in the late 1970s. They included a small-scale logging and release growth study at Plains Creek in 1978, thinning trials at Welcome Swamp and Sumac Road, and regeneration trials at Montagu River and Salmon River Road. The Welcome Swamp trial in 40-year-old blackwood showed impressive release growth, with diameter increments of 0.75 cm/yr in the most heavily thinned block, compared with 0.16 cm/yr in the unthinned control area (Forestry Commission 1980a). The growth of naturally regenerated blackwood was measured in several sites, and plantings were established in corridors cleared in existing forest and in open areas.

In 1980, the first large-scale blackwood logging and regeneration trial was established. This was a selectively logged, 20 ha area at Sumac 15B, a river flat area south of the Arthur River, half of which was lightly scrubbed with a bulldozer, leaving a good stocking of mature myrtles and other species. A fauna survey and studies of the effectiveness of 1080 poison (see browsing section above) were conducted in this trial area by Helen Statham and Sue Jennings. Very large numbers of blackwood seedlings arose from ground-stored seed but they were heavily browsed. The stocking levels of regeneration were higher on the scrubbed area of the trial but this mechanical disturbance led to unacceptable mortality of retained myrtles from myrtle wilt disease (Forestry Commission 1982b). These were valuable research results as they gave early insights into the key factors necessary for the successful regeneration of harvested blackwood forests and assisted the development of the Blackwood Working Plan.

In 1982, an area of 7880 ha was selected for management in the Swamp Working Circle on a sustained yield basis, using a 70-year rotation as prescribed in the Blackwood Working Plan. The selective logging method used for some 150 years was replaced by patch clearfelling and regeneration. The method of regeneration used in the swamp forest under the Working Plan was light burning of the logging residue to regenerate clearfelled patches by encouraging germination of seed and then protecting the blackwood seedlings from browsing with a wire netting fence (Forestry Commission 1982b).

By the late 1980s, refined silvicultural prescriptions for the extensive management of blackwood had been incorporated into the

Working Plan for the Smithton Blackwood Working Circle. Key features of these prescriptions were:

- Use of ground-stored seed;
- Seedbed preparation by mechanical disturbance or fire;
- Protection from browsing by fencing blackwood-rich areas following harvesting;
- Use of natural nurse crops of teatree, paperbark or dogwood to encourage good form and branch control.

This system was used for several years, with the main drawback being the difficulty of fencing in the swamps.

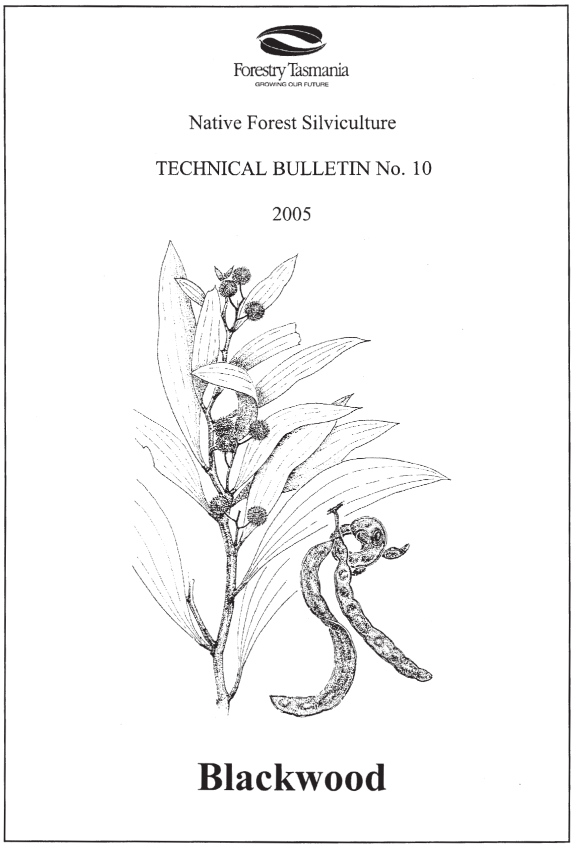
Adequate stocking standards for regeneration areas were determined by fixing a minimum acceptable sawlog volume for future crops. The Blackwood Working Plan suggested a minimum of 50 m^3/ha at harvest, with a mean diameter of 50 cm. Using a rough correlation of 1 m^3 of sawlog for every stem, areas with less than 50 stems/ha were considered understocked (Forestry Commission 1991c).

Further investigations of the effect of disturbance on ground-stored blackwood seed showed that burning was the most effective treatment for stimulating germination. Burning needed to be used with care because trials showed that high-intensity burning destroyed 67% of the viable seed in the upper soil horizon and stimulated 95% of the remaining seed to germinate. This left little or no reservoir of seed if the first flush of seedlings failed from browsing or other causes. Therefore, it was critical that fences be in place within a three-week period between logging/burning and start of germination. However, soil disturbance without burning caused germination of up to 21% of the seed, with the rest retained as a reservoir for future germinations. Burning the logging slash in blackwood-rich forests produced a mosaic of different burning intensities, resulting in varying seedbeds; all seedbed types had acceptable stockings of blackwood. From this research, it was concluded that the current practice of slash burning was unlikely to have a detrimental effect on the overall stocking of seedlings in blackwood regeneration areas (Wilkinson and Jennings 1994).

In 1991, the information on blackwood silviculture gained from some 15 years of research was summarised and presented for use by forestry staff in Native Forests Technical Bulletin 10, *Blackwood Silviculture* (Forestry Commission 1991c). It prescribed the following logging and regeneration systems for the three commercial types of blackwood forests:

- Swamp forests – clearfell in dry seasons, burn and fence;
- Blackwood-rich rainforest – selectively log, minimise damage to retained trees and control browsing;
- Wet eucalypt with a blackwood understorey – clearfell, burn and sow with eucalypts, and fence.

In 1992, interim prescriptions based more on blackwood ecology were developed, following a study of the classification and ecology of the swamp forests by John Pannell (Pannell 1992). Different prescriptions were developed for stands with high and low amounts of rainforest species. In forests with a low component of rainforest species, sawlog harvesting could be heavy in even-aged stands but cull trees were to be maintained. A minimum of 50% cover was to be left in uneven-aged stands to protect them from windthrow and maintain structural diversity. Sawlog extraction from areas with a high rainforest component could occur but special provisions were needed to protect peat and patches of rainforest trees. Top-disposal burning was recommended in preference to broadscale burning, and poisoning, rather than fencing, was used to control browsing if necessary. These measures worked well when



Native Forests Technical Bulletin No. 10 was first published in 1991 and then revised in 2005. It contains silvicultural prescriptions, ecological information, and descriptions of forest types.

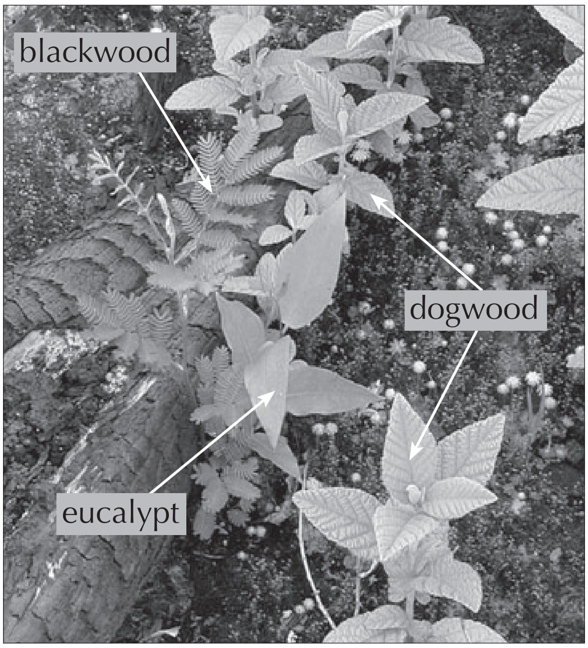
first used in the 1995–96 swamp harvesting season, although browsing was still severe and more research was needed on different fence-line preparation techniques and on alternative materials and construction methods. Soil care was much improved by introduction of 'shovel logging', a technique in which excavators move only when not loaded. Logs are transported by swinging the loaded boom while the machine is stationary (Jennings 1998).

Blackwood regeneration in 13 swamp coupes treated between 1978 and 1992, using nine different silvicultural treatments, was assessed for stocking, density, early growth and form. This study clearly confirmed that the most successful regeneration treatments for blackwood involved a high level of disturbance and successful browsing control. Hence, clearfell, burn and fence, and scrub-roll, burn and fence were the most successful treatments. Clear-felling without fencing, and selective logging, achieved much lower success due to high browsing levels (Jennings *et al.* 2000)

Further refinement of blackwood silviculture, incorporating greater recognition of the need to conserve biodiversity, particularly in the swamp forests, was contained in the revision of the Blackwood Technical Bulletin (Forestry Tasmania 2005c). The current recommendations for blackwood harvesting and regeneration in the different forest types are summarised below.

- In swamp blackwood/tea tree forest, all merchantable blackwood should be harvested but areas of sassafras with no merchantable blackwood should be retained. Low-intensity burning should be carried out where high fuel loads remain after harvesting. Scrub-rolling of non-commercial species maximises the opportunity for blackwood regeneration in understocked areas within or near commercial blackwood harvesting.
- In swamp blackwood/myrtle forest, merchantable blackwood should be harvested without disturbing the 'myrtle peaty banks' common in this type. Retention of the peaty banks maintains some structural and species diversity throughout the rotation. Coupes should not be burnt because the rainforest component is unlikely to survive a fire. Regeneration is only expected where there is harvesting disturbance.
- In riverine blackwood forest, very little harvesting occurs because most of the forest is protected within streamside reserves. Any harvesting requires specialist advice to take account of the local consitions.
- Fenced intensive blackwood forest — see next section.

A fenced-intensive-blackwood (FIB) coupe, shortly after regeneration establishment burning and construction of the wire-netting fence (mixed eucalypt/blackwood).



Blackwood, eucalypt and dogwood seedlings regenerating in the FIB coupe.

Blackwood, eucalypts and other species regenerating in an older FIB coupe.

Intensive management of blackwood-rich eucalypt coupes

Analysis of stocking and growth of eucalypts and blackwoods on coupes showed that all fenced-intensive-blackwood (FIB) coupes were adequately stocked with eucalypts, and protection from browsing provided by the fencing resulted in a mean blackwood stocking of 2500 stems/ha compared with 70 stems/ha in unfenced coupes. The form of blackwood in the fenced coupes was very good because of the nurse-crop effect of dogwood. Height growth of both eucalypt and blackwood regeneration was also significantly higher on fenced coupes (Jennings and Dawson 1998).

The Forests and Forest Industry Strategy (FFIC 1990) established a policy of increasing the intensification of forest management, mainly focussing on establishing plantations of eucalypts and some blackwood (see Chapter 5) but also thinning of native forests to increase the productivity per hectare. The high stocking levels and good form of blackwood in the FIB coupes provided an opportunity under this strategy to explore the benefits of release thinning the blackwoods to increase diameter growth rates.

To assess the effect of competition between blackwoods and eucalypts and from the understorey species, a blackwood release trial was established in 1995, in which the eucalypt and dogwood competition was removed at different rates within a six-year-old fenced wet eucalypt coupe. Six years after the treatments were imposed, the diameter growth of the blackwood had increased in the eucalypt-only removal treatment, small gap and large gap treatments by 75%, 100% and 160% respectively compared with the untreated blackwood. Height growth of the blackwood was not influenced by the increased light availability in the gaps but form was affected by the release treatments, with increased retention of branches on the trees with increased light availability (Jennings *et al*. 2003). Manipulating the nurse species in these release thinning experiments, with the consequent effect on the light environment of blackwood, showed that this approach could be an effective silvicultural tool in improving the crown dynamics and the branching habit of the blackwood and achieving improved form and length of branch-free bole (Unwin *et al*. 2001). Importantly, sampling blackwood for wood

Well-formed blackwood, surrounded by dogwood, in a fenced-intensive-blackwood coupe.

properties in young swamp stands, FIB stands and a similar-aged plantation stand from the same seed provenance showed there were no significant differences in most wood properties, including basic density and colour, under the different silvicultural regimes (Bradbury 2005).

Work is continuing on developing the most effective stand management regime for blackwood in the 1500+ ha of fenced wet eucalypt coupes that are now a substantial part of the total blackwood resource. Trials have been established to examine thinning options. Data from these trials suggest that a heavy pre-commercial thinning (75% reduction in basal area of the eucalypts) at age 10–15 years will significantly benefit both the final eucalypt crop trees and the blackwoods. These results have led to a recommendation for the following regime for highly stocked stands with high numbers of blackwoods where management objectives include enhancement of blackwood growth and commercial thinning of the eucalypt crop (LaSala and Jennings, in press):

- Pre-commercial thinning of 75% eucalypt basal area at age 10–15 years; followed by
- Commercial thinning of 50% of eucalypt basal area at age 30 years; and
- A final eucalypt stocking of no more than 200 stems/ha.

Production and Conservation

There have been two major outcomes of the research on special timber species described in this chapter. The first relates to their conservation. In the course of silvicultural research and management of rainforest areas, extensive knowledge of the species' ecology has been gained. This information will assist the management of the majority of forest containing these species, which is in conservation reserves.

The second concerns management for ongoing and sustainable supplies of timber from special species. Although the volumes produced of blackwood, myrtle, sassafras, leatherwood and other species are small in commercial terms, these timbers are highly valued for the craft and furniture industries in Australia and internationally. Consequently, they are an important part of Tasmanian forestry.

In the 30 years since the establishment of the Smithton Research Station, the rainforest and blackwood research and development programs described in this chapter have progressively refined the silvicultural and management options for special species. This work by District and research staff has placed the management of these species for timber production in the Special Timber Management Units on a sustainable basis while increasing the potential yields per hectare of individual species at future harvests.

Future research work is likely to further refine the silvicultural regimes, particularly fenced intensive blackwood management, to increase the efficiency of production and to tailor products for specific markets such as veneers for overlaying on pre-formed panels. Timber figure and colour characteristics will have increased importance and command higher prices in the market, so silvicultural research that assists the development of these features may also be factored into future programs.

Chapter 5

Plantation Forestry

Introduction

The first moves towards establishing a plantation forestry industry for Tasmania occurred some 20 years prior to the formation of the Forestry Department, when the Lands and Surveys Department was responsible for forestry. The Secretary of this Department, Mr Counsel, reported in 1902:

> *… a commencement has been made towards establishing a State Nursery for the production of plants of such softwoods as may be required for local purposes and for distribution throughout the Island by the importation of a case of carefully selected seeds from Denmark. This is undoubtedly a step in the right direction, and one which I hope to see extended, and bear good fruit. It is a feasible, unpretentious and reasonable measure, the importance and prospects of which would seem to fully justify the expenditure. Our hardwood timbers are unsuitable, and there are no Tasmanian soft-woods in quantity to take the place of those required for doors, window-sashes, and light boxes, &c., and therefore such woods must continue to be imported from abroad until they are produced at home. This can only be accomplished by the initiation of a system of State Nurseries, with a view to the free distribution of plants to local bodies, mining companies, and individuals for transplanting.* [Lands and Surveys Department 1902, p. 21]

However, in the next few years there was little progress towards the establishment of a nursery and no record of the fate of the imported seeds. Eventually, in January 1908, a State Nursery Board was formed to advise the Minister 'in matters of constructive forestry'. The Board comprised E.A. Counsel (Secretary for Lands, and Chairman), L. Rodway Esq. (State Botanist), and H.J. Colbourn Esq. (Agricultural Expert). This Board appears to have contented itself with establishing a small tree nursery in the Hobart Botanical Gardens and an experimental plantation on land belonging to the Hobart Corporation at Ridgeway (Steane 1947).

Counsel reported in 1908 that about two acres (0.8 ha) of land had been obtained at the north-western end of the Hobart Botanical Gardens and this had been prepared for nursery work. Also, a gardener had been employed and the trustees of the Gardens had allowed their expert, Mr Wardman, to act as a superintendent of nursery operations. Seeds of the following species were ordered from Copenhagen: larch, Norway spruce, Menzies' spruce, Corsican pine, Bhutan pine, yellow pine, white Californian cedar, giant thuja (western red cedar), American ash and hardy catalpa. The Government Botanist of New South Wales forwarded seed of valonia oak, canary pine, various eucalypts, and other species. Mr Guilfoyle, of the Melbourne Botanical Gardens, sent seed of Portugal oak, swamp yate and cuttings of white willow. The scientific names for these and other species mentioned in this chapter are shown in Box 7.

The Domain Improvement Committee gave permission for the nursery gardener to gather any available seed required from the pines planted on the Domain. Having established the nursery, the Board now turned its attention to finding land for planting out the seedlings it

Box 7

Common and scientific names of tree species mentioned in Chapter 5.

Aleppo pine	*Pinus halepensis*	Larch	*Larix* sp.
Alonia oak	*Quercus* sp.	Lodgepole pine	*Pinus contorta* var. *murraya*
American ash	*Fraxinus americana*	Lombardy poplar	*Populus nigra italica*
Bedford willow	*Salix viridis*	Maritime pine	*Pinus pinaster*
Bhutan pine	*Pinus bhutanica*	Menzies' spruce	*Picea sitchensis*
Bishop pine	*Pinus muricata*	Mexican weeping pine	*Pinus patula*
Black gum	*Eucalyptus ovata*	Monterey cypress	*Cupressus macrocarpa*
Black peppermint	*Eucalyptus amygdalina*	Mountain pine	*Pinus montana* var. *uncinata*
Black poplar	*Populus nigra* var. *betulifolia*		
Black walnut	*Juglans nigra*	Norway spruce	*Picea abies*
Black wattle	*Acacia decurrens, A. mearnsii*	Oriental plane	*Platanus orientalis*
Blackwood	*Acacia melanoxylon*	Pedunculate oak	*Quercus robur*
Blue gum	*Eucalyptus globulus*	Ponderosa pine	*Pinus ponderosa*
British oak	*Quercus robur*	Portugal oak	*Quercus suber*
Brown barrel	*Eucalyptus fastigata*	Radiata, Monterey or Remarkable pine	*Pinus radiata* or *P. insignis*
Bunya pine	*Araucaria bidwillii*		
Californian redwood	*Sequoia sempervirens*	Scots pine	*Pinus sylvestris*
Canadian poplar	*Populus* x *canadensis*	Shining gum	*Eucalyptus nitens*
Canary Island pine	*Pinus canariensis*	Silver wattle	*Acacia dealbata*
Carolina poplar	*Populus* x *canadensis*	Sitka spruce	*Picea sitchensis*
Common lime	*Tilia europea*	Stringybark	*Eucalyptus obliqua*
Cork oak	*Quercus suber*	Sugar pine	*Pinus lambertiana*
Corsican pine	*Pinus nigra* subsp. *laricio*	Sunshine wattle	*Acacia terminalis*
Cricket bat willow	*Salix coerulea*	Swamp gum	*Eucalyptus regnans*
Dogwood	*Pomaderris apetala*	Swamp yate	*Eucalyptus occidentalis*
Dolly bush	*Cassinia aculeata*	Sycamore	*Acer pseudoplatanus*
Douglas fir	*Pseudotsuga menziesii*	Tea tree	*Melaleuca*/*Leptospermum* spp.
Eastern white pine	*Pinus strobus*	Valonia oak	*Quercus aegilops*
English oak	*Quercus robur*	Varnished wattle	*Acacia verniciflu*a
European ash	*Fraxinus excelsior*	Virginian oak	*Quercus virginiana*
European hackberry	*Celtis australis*	Western red cedar	*Thuja plicata*
European larch	*Larix europea*	Western yellow pine	*Pinus ponderosa*
European silver fir	*Abies alba*	White ash	*Fraxinus alba*
False acacia	*Robinia pseudoacacia*	White Californian cedar	*Libocedrus decurrens*
Giant thuja	*Thuja plicata*	White gum	*Eucalyptus viminalis*
Gum-topped stringybark	*Eucalyptus delegatensis*	White oak	*Quercus alba*
Hardy catalpa	*Catalpa speciosa*	White poplar	*Populus alba*
Hickory	*Carya* sp.	White willow	*Salix alba*
Horse chestnut	*Aesculus hippocastanum*	Yellow pine	*Pinus ponderosa*

grew. Suitable land was obtained at Ridgeway, near Hobart, for this purpose and planting of a wide range of species began immediately:

> *The Board considers it advisable to establish a forest reserve in the vicinity of the capital, where trees of varied sorts will be planted under scientific forest conditions. This will afford means of experiment in the cultivation and management of trees; a centre from which fresh seed supplies can be procured; also a place where practical forestry may be taught. The Corporation of Hobart has permitted the Board to commence this work on its estate at Ridgeway. On this land 1 acre has been cleared, fenced and planted with Portugal, alonia, white, and British oaks, also English ash. Round this acre the land has been cleared for a breadth of 1 chain, and planted with sycamore, white and Bedford willows, and black, white, Canadian, Lombardy, and other poplars. Beyond this, plots have been sown of seed of British, white, Portugal, and Virginian oaks, walnut, horse-chestnut, hickory, ash, and sycamore. These outer plots are designed to afford nurses when desirable pines shall be available for planting.* [Lands and Surveys Department 1908, p. 6]

By 1909, the Board reported that some 14 514 seedlings of various tree species were available for planting out from the nursery at the Botanical Gardens. The main species were horse chestnut, black walnut, cork oak, white oak, pedunculate oak, European ash, white ash, sycamore, oriental plane, common lime, European larch, Norway spruce, Sitka spruce and Corsican pine. It was claimed that if some more space and an extra employee were made available then there would be 'no difficulty in maintaining an output of 100 000 young trees per annum'. The Board's report for this year also stated that the Ridgeway plantation already contained 5000 British oaks, 5000 sycamores and an unstated number of other species. In addition, an area at Interlaken owned by Mr R.W. Elliston had been planted with young pines.

Unfortunately, by the next year, progress at the nursery and the Ridgeway plantation was halted, as reported (rather dramatically) by the State Nursery Board:

> *The State nursery and forest-construction for the last 12 months have made very little advance. Last spring, just when active operations were commencing, the trustees of the Botanical Gardens withdrew their foreman from superintending the work. In consequence of this, no seed-beds were stocked, and no stock was transplanted. This threw the work back severely, and it will be some years before the evil effect of this action will be overcome.* [Lands and Surveys Department 1910, p. 11]

No more was heard of the Ridgeway plantation and a search in 1930 failed to locate any trace of it (Steane 1947).

The Department of Agriculture took over the nursery and plantation parts of the Lands and Surveys Department's forestry responsibility in 1910. In the following year, the Department of Agriculture transferred the nursery to its farm at Deloraine, and no more was heard of the Board which had been appointed in 1908 to advise on forest policy. During the years 1911 to 1919 'several thousand conifer trees' were raised at the Deloraine farm and distributed free to schools and public bodies. A plantation of 24 000 trees (22 000 radiata pine and 2 000 Douglas fir) was established at the farm itself. In 1917, the Department of Agriculture's forestry expert reported that, 'owing to the expense of the upkeep of the nursery and the little return therefrom, the scale of work was being reduced to a minimum pending the adoption of a re-afforestation policy … ' (Steane 1947).

In 1915, the Chief Forest Officer in the Lands and Surveys Department, Mr Compton Penny, provided some early advice on the silvicultural techniques which should be applied to areas allocated for the development of softwood plantations:

> *Suitable areas should also be selected and reserved in desirable situations for the plantation of such exotics as may be chosen, with a preference for*

softwood, as being most desirable; but here the experience of other States would form a guide in the selection of the species of trees to be planted. These lands would require to be fenced, grubbed, ploughed, and drained, and allowed to lie in fallow for a period to sweeten the soil. It should then be harrowed and thoroughly cultivated before being planted. After planting, the young trees would require continual attention, and must not be allowed to suffer from neglect in the early stages of their growth. During the summer months succeeding the planting it would be necessary to water the young trees until the roots get down into the ground and they become firmly established, otherwise a large percentage of them would die, and others would receive a check in their growth from which they would never properly recover. All this work is absolutely necessary in the first few years of the existence of a plantation; therefore, all that is required is to thin, prune, and keep the ground free from undergrowth, and to take precautions to safeguard the trees from destruction by fire. [Lands and Surveys Department 1915b, p. 24]

By the following year, there were positive signs from the Government for the development of a State forestry policy that included establishment of softwood plantations and expanding the resource for the wattle bark industry on Tasmania's east coast:

> *… it is gratifying to report that the Cabinet has determined on taking the first step forward by selecting and planting out a number of experimental plots in various localities and at various elevations above sea level. These experiments will test their adaptability to the growth of soft exotic woods, with a view to entering upon a prudent and economical policy of afforestation and reafforestation. Such a policy should include the preservation and planting of areas for the production of our valuable black wattle (Acacia decurrens[1]) the bark of which is so much sought after, by reason of its rich tanning qualities.* [Lands and Surveys Department 1916a, p. 3]

[1] The name used formerly in Tasmania for *Acacia mollissima,* which is now *A. mearnsii.*

The report of the Secretary of Lands in 1917, four years before the creation of the Forestry Department, showed Counsel's strong views on the desirability for embarking on plantation forestry in Tasmania and his optimism for success in this venture:

> *... in the meantime the money is much needed, and if made available could be spent to advantage in preparing the way for the introduction and cultivation of soft quick-growing woods, the value of which is well known all the world over, and for which it is said £3,500,000 are yearly going out of the Commonwealth for the imported article. Such a policy, if carried on systematically and consistently, could be relied upon to give good results in the future. That the time must come when it will be recognised as an actual necessity is as certain as that day follows night, and the sooner it is entered upon the better for the ultimate prosperity of the industry. With a fair rainfall, a temperate climate, all kinds of soils and elevations available, it must be admitted that if afforestation can be carried on anywhere successfully, it should be possible in Tasmania. It could not be expected to be immediately reproductive, but after a few years there would be a gradually increasing return from the use and sale of the surplus growths, until in time it would yield a direct revenue to the State.* [Lands and Surveys Department 1917, p. 7]

In 1919, the Department of Agriculture appears to have washed its hands of this forestry business—undoubtedly encouraged by the Minister's announcement, in October 1919, of the Government's decision to appoint Mr Llewellyn Irby as Conservator; he was appointed in December that year. At the same time, the comments of the Farm Manager at Deloraine, Mr A.T. Bonney, in the Department of Agriculture's Annual Report for 1918–19 may have had some contributory influence. He described the planting of 20 acres (8 ha) of good agricultural land with pines as folly and waste and a public laughing stock – *in which he at least showed a vigour and independence of spirit unusual in the Public Service* (Steane 1947; Steane's comment in italics!).

Delegates to the Forestry Conference in Hobart, 21 April 1920. This conference played a significant role in shaping the directions for the new Forestry Department, which started operating on 1 January 1921. Messrs Counsel, Irby and Rodway were directly involved in the development of plantation forestry in the State. From left to right – front row: Owen Jones (Chairman, Forests Commission, Vic.), Walter Gill (Conservator of Forests, SA), Hon. J.H. Coyne (Minister for Lands, Qld), Hon. Alec Hean (Minister of Lands, Tas.), R. Dalrymple Hay (Chief Commissioner, Forestry Commission, NSW), H.R. MacKay (Commissioner, Forests Commission, Vic.), E.A. Counsel (Surveyer-General, Tas.). Back row – C.H. Chepmell (Secretary to the Conference), W. Watson (Secretary, Forestry Commission, NSW), Secretary to the Hon. J.H. Coyne, MLA), E.H.F. Swain (Director of Forests, Qld), I.C. Boas (Officer-in-Charge, Forests Products Laboratory, WA), L.G. Irby (Conservator of Forests, Tas.), L. Rodway (Government Botanist, Tas.), C.E. Lane-Poole (Conservator of Forests, WA), P. Seager (Chairman, National Park Board, Tas.), C.E. Lord (Curator of Museum, Tas.).

Llewellyn Irby's Vision for Plantation Forestry

Apart from perhaps some remnants of the first plantings mentioned above, there were no forestry plantations under the control of the new Forestry Department in 1921. Conservator Irby expressed great optimism for the future of plantation forestry in the State, particularly in the large areas of treeless buttongrass plains (referred to by Irby as 'waste lands') in the west and north-west. In the first year of the Department, Professor E.H. Wilson, Assistant-Director of the Arnold Arboretum, Harvard University, was taken to look at some of these 'great waste lands of the State', particularly Sisters Hills in the north-west and the buttongrass plains and vast stretches of sand dunes on the West Coast between Strahan and Zeehan. Irby commented after the visit:

> *The depth and nature of the soil of these areas were investigated, and from all indications and with the rainfall of those parts, the celebrated dendrologist was deeply impressed with the latent possibilities for the growth of exotic conifers, and in fact expressed the view that in much of our waste lands Tasmania possessed the finest tree-planting propositions in the world.*

Such an expression by so renowned an expert goes far to strengthen the opinion given by numerous foresters that Tasmania holds the key to the main supply of softwoods for the whole Commonwealth eventually ...

Had the people of Tasmania realised the wonderful asset that lies dormant in much of the waste lands of the State, and the vast potentialities of softwood plantations if established thereon, there can be little doubt but that the money to proceed with the planting of same would have been raised somehow many years ago, and what are to-day still waste lands would, in part at least, have stood now as an offset to the national debt of the State. [Forestry Department 1921, pp. 9–10]

Irby also saw a great opportunity to provide employment for young people in the operations required to plant the large areas he had identified. At the Australian Forestry Conference in Brisbane in March–April 1922, the following resolution reflecting Irby's vision was passed:

That this conference appreciates the wideness of the Tasmanian conception for bringing into a forestry partnership of practical usefulness the waste lands of Tasmania and the waste childhood of the Empire, and hopes, with the Tasmanian Forest League, that the conception may be reduced at an early date to practical actuality. [Forestry Department 1922, p. 12]

Tasmania signed a British migration agreement in 1923. As a Tasmanian project in accord with this agreement, Irby proposed a 'Forest Plantation Homes' scheme along the lines of the 'Fairbridge Farm' scheme which had been established in Western Australia a decade earlier. Irby planned to bring 150 British boys—orphans or homeless children, referred to as 'waifs'—per year to Tasmania to plant 60 000 acres (24 000 ha) of pines in return for training and their keep. Commonwealth endorsement was needed for the scheme and it was referred to the Development and Migration Commission, which later conducted an inquiry into Tasmanian forestry (see later section). The scheme never eventuated, mainly because of Irby's departure from the Forestry Department in 1928 and the subsequent Depression years (www.uncommonlives.naa.gov.au).

The Conservator was particularly impressed that little or no clearing would be required in these waste lands prior to planting:

Tasmania is fortunate … in that over the areas which it is proposed to ultimately plant little or no clearing is required, nor any other preparation of the land, with the one exception of fire-breaks, always a vital necessity where plantations are concerned. [Forestry Department 1921, p. 10]

Irby considered that over 30 000 acres (12 000 ha) of old sand dunes merging in parts with buttongrass moorland between Macquarie Harbour and the Henty River was probably 'without parallel' as a tree planting proposition in the Commonwealth. He noted that steps were being taken to have this area dedicated as State forest and to establish a forest nursery there so that planting out could commence the next year. Species selection for this venture was clear:

The main species to be planted for some little time will be Pinus insignis[2], *which has obtained the appellation of 'Remarkable Pine' for the rapidity with which it comes to maturity, and its amazing adaptability to almost any conditions throughout Australia. While the timber of this tree is not of a very high-class quality, it is nevertheless an excellent wood for case material, &c., and always finds a ready market ...*

With its ideal soil conditions for pines and its immunity from droughts, there is every indication that equal yields [to those obtained from radiata pine in New Zealand and South Australia] *could be obtained on the Strahan sand dunes in a much shorter period, probably in 20 to 25 years. Trees planted 12 years ago on the beach at Strahan, in virtually pure sand, are to-day 12 inches in diameter, having grown an inch a year. This rate would represent 5 feet in girth at 20 years.* [Forestry Department 1921, pp. 10–11]

[2] A name formerly used for *Pinus radiata.*

Sand dunes near Strahan, described in Forestry Tasmania's Annual Report for 1921 as 'Ideal pine-planting country, estimated extent of thirty thousand acres'.

Sand dunes near Strahan in the vicinity of the Forestry Department's first nursery established in 1921 at Lake Koonya.

Several other species were also under consideration for these early plantings and it was anticipated that experimental plots would soon be established at Sisters Hills and other waste tracts in order to fully investigate their possibilities for exotic tree growth:

> *Such exotic conifers as redwood, maritime pine, remarkable pine, Canary Island pine, Western yellow pine, and many others grow to perfection here, and very rapidly. As a matter of fact, some of these grow much better here than they do in their native country.* [Forestry Department 1922, p. 8]

The Annual Report of the Forestry Department, after its first full year of operation, contains a strong summary statement on the potential for plantations of exotic species, which sets the scene for an active planting program in these areas:

> *… it is a well known fact that much of our waste lands is definitely known to be capable of growing certain of the most valuable of these exotic pines and other softwoods which Australia continues to import, an unassailable case is presented for making such use of these waste areas.* [Forestry Department 1922, p. 8]

A general view of the area at Sisters Hills, north-western Tasmania, where a Forestry Department nursery was established in the early 1920s.

Planting operations in progress at the Sisters Hills plantation in the 1920s. The nursery is in the background adjacent to the hut. In the very early plantations, there was often very minimal site preparation, seedlings being planted in small clearings amongst existing vegetation.

Thus, Irby had a clear vision for the role of plantations in Tasmanian forestry. Although, as discussed later, many of these early sites were unsuitable for commercial plantings, he can certainly claim to have initiated commercial softwood planting in the State.

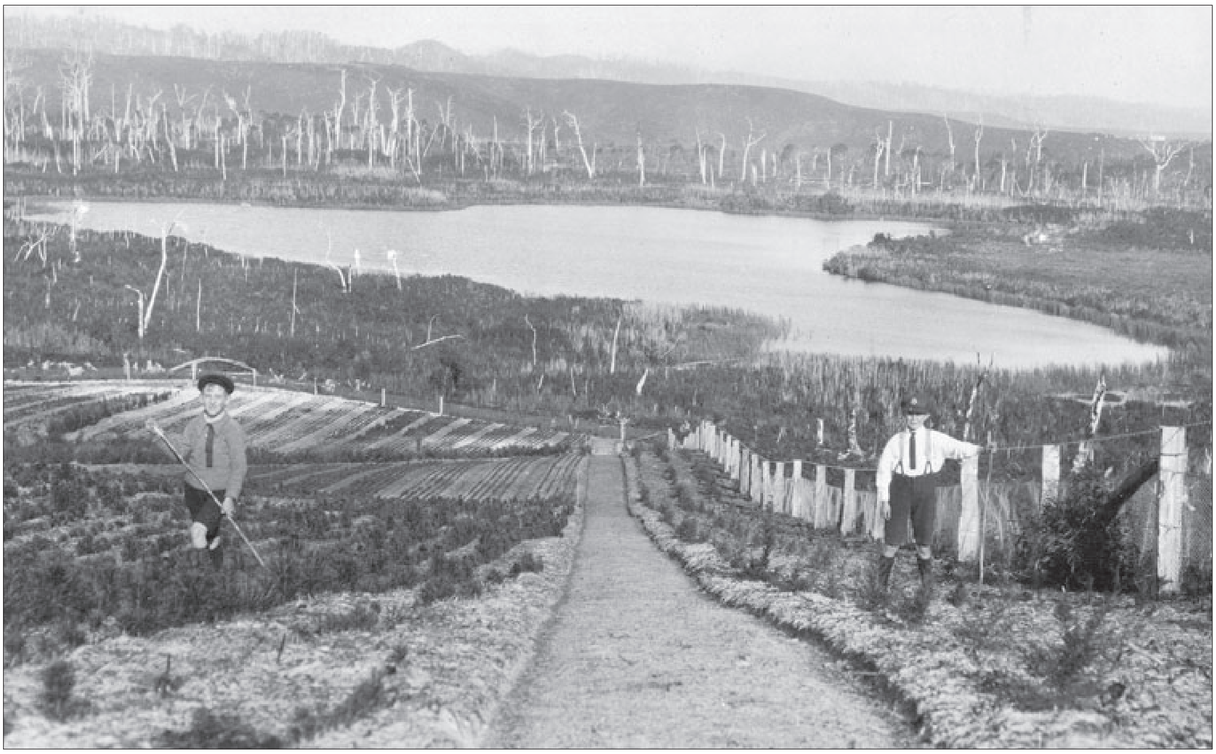
After leaving the Forestry Department in 1928, Irby continued to pursue his vision of 'conquering the buttongrass plains and heath-lands', conducting long-term trials on his family property at Boat Harbour (Irby 1955, 1959).

Early Nurseries, Species Trials and Plantations

The early plantation research by the Forestry Department was directed at establishing nurseries to raise stock of many species for planting on a range of sites to determine the best species/site combinations. Remnants of some of these plantings survived into the 1970s; examples included small patches of pines at Sisters Hills in the north-west, Strahan and Queenstown in the west, Beaconsfield in the north and Strathblane in the south.

The first two Forestry Department nurseries for growing plantation stock were set up in 1921–22. The larger of these was a four-acre (1.6 ha) area at Lake Koonya, about two kilometres north of Strahan on the West Coast, where approximately 3000 seedlings of remarkable pine (radiata pine), Douglas fir, aleppo pine and Monterey cypress were raised. The seed of remarkable pine used at the Lake Koonya nursery was considered inferior, so one ton of cones was collected, with permission from the Strahan Municipal Council, from street trees in Strahan. In a statement sure to raise the eyebrows of today's tree breeders and nursery staff, the Department's Annual Report of that year comments enthusiastically on this cone collection: '… from which it is expected to obtain a supply of first class seed'. The other nursery was established at Sisters Hills in the north-west where seeds of remarkable pine, ponderosa pine, Canary Island pine, Douglas fir, Californian redwood and other unspecified species were sown.

Hand cultivating at the Forestry Department's nursery at Lake Koonya, shortly after its establishment in 1921–22.


The Lake Koonya nursery in the early 1920s, with established beds of various species.

In probably the first plantation establishment trial by the Forestry Department using introduced species, some eight acres (3 ha) of the 1200 acres (480 ha) dedicated as State forest between Strahan and the Henty River were spot sown with remarkable pine (radiata pine) within the existing vegetation to determine how this method was suited to the soil and other conditions. Similarly, at Sisters Hills, 33 acres (13 ha) was treated in the same way using remarkable pine, Douglas fir, Californian redwood, and Norway spruce.

Right from the start of the Forestry Department's plantation forestry operations, seed of a wide range of species (mainly exotic conifers) was obtained and used in test plantings in many areas. In 1921–22, the 30 000–40 000 acres (12 000–16 000 ha) of land between Strahan and the Henty River, identified by Irby as being 'without parallel' for plantation, was considered suitable for conifers such as Corsican pine, sugar pine and remarkable pine. Sheltered valleys near Mount Dundas were considered suitable for Douglas fir. In north-eastern Tasmania, small areas at Mathinna Plains, Pioneer, and in some places between St Helens and Scamander were identified as suitable for plantations, and the sowing of wattle seed on the east coast was recommended for future supplies of bark for the tanning industry. Plantations were even considered for the slopes of Mount Wellington to provide a valuable asset and for preserving the watershed, with suitable areas for nursery sites identified near the Springs.

By the end of 1922–23, there were 500 000 plants in the Lake Koonya nursery, mainly remarkable pine, and a similar number at the Sisters Hills nursery, mainly remarkable pine, ponderosa pine, maritime pine, Corsican pine and Douglas fir, with smaller numbers of Norway spruce, European larch and Monterey cypress. At Sisters Hills, soil surveys were conducted which included testing for porosity and depth, and these showed that the plantable area comprised about 60% of the 540 acres (216 ha) dedicated as State forest. The original

Cupressus macrocarpa seedlings at the Pioneer nursery in the north-east, established in the mid 1920s.

nursery was also extended to four acres, a similar size to the Lake Koonya nursery, and this extended area was ploughed, cross-ploughed and harrowed many times ready for the transplants. The expanded Sisters Hills nursery was considered to be capable of supplying the needs of the plantations in the north-west of the State for many years to come. This nursery also had several trial beds containing Bishop pine, eastern white pine, Bunya pine, and some remarkable pine grown from New Zealand seed.

Species trials were also conducted at this time in the north-east, where Douglas fir, Western red cedar, Californian redwood, Monterey cypress, remarkable pine and aleppo pine were sown in an experimental plot between Herrick and Mount Cameron. A small nursery had been started at Pioneer in the north-east 'where there is much poor land suitable for plantations'. This theme was repeated on King Island where potential plantation areas were inspected:

> *These are areas of barren country at present practically useless in the south and north east of the island suitable for plantations of softwoods.* [Forestry Department 1923, p. 6]

Through the mid 1920s, the plantings at Sisters Hills and on the West Coast at Strahan and Queenstown were gradually extended, mainly with remarkable pine, maritime pine and Douglas fir. Much of this planting continued to be experimental, with investigations of suitable species, spacing for weed suppression, and performance on different soils. At Sisters Hills, some Carolina poplar and European hackberry (obtained from Gosford, New South Wales) and cricket bat willow (obtained from the Forestry Commission of Great Britain) were planted out, and four quarter-acre plots were established on different soil types and planted with remarkable pine, maritime pine and Douglas fir. In 1925–26, more experiments were conducted at Sisters Hills, where 13 acres (5.2 ha) of peat and sand in an exposed area were planted with remarkable pine, ponderosa pine, Corsican pine and maritime pine. Growth on this area was compared with that on another small area which was drained and planted with similar species. Experimental plantings showed that maritime pine appeared to be more suited to hills carrying sparse scrub whereas remarkable pine performed well on land carrying dense scrub. In the late 1920s, remarkable pine, Douglas fir and black

Transplanting seedlings at the Sisters Hills nursery in the early 1920s.

wattle were reported as doing well at Sisters Hills, and an experimental acre plot was marked out at Rayna Siding in 'good average button-grass country'. Part of this was planted with European silver fir, Norway spruce, remarkable pine, Corsican pine, maritime pine, ponderosa pine and Scots pine.

Tremendous optimism was expressed at this time for softwood plantations in the Queenstown area:

> *By following up a vigorous and sustained planting policy, the future of Queenstown and Gormanston, as also of Strahan, will be assured even should mining ultimately fail completely. Within 10–12 years from now it should be quite possible to switch over from mining to paper pulp and artificial silk production, or for such works to start as an additional industry for the District. Failing such establishment, the trees now being planted should, in this District, be fit for milling at from 20–25 years.* [Forestry Department 1925, p. 13]

Plantation establishment began in the Beaconsfield area in the north in the mid 1920s using seedlings raised at the Sisters Hills nursery; some 300 acres (120 ha) were planted by the

Remarkable pine (radiata pine) at the Strahan Nursery in 1925, grown from seed planted during the 1922 season.

Early plantings of remarkable pine (radiata pine) at the Beaconsfield plantation in the mid 1920s. About 300 acres (120 ha) were planted using seedlings raised at the Sisters Hills nursery.

end of the decade, mainly with remarkable pine, ponderosa pine and Douglas fir. At Sheffield in the north-west, a small nursery and arboretum were planned. A shelterwood system was proposed for part of the area, with pines being planted within the existing sparse eucalypt scrub. This method was considered to have great potential for producing good trees at low cost:

> *The costs of such a method of planting will be very slight, while the tendency to produce long clean boles will be greatly enhanced. Instances of mixed planting referred to above point to apparent beneficial results to both conifers and eucalypts, and opens up a very interesting field for future determination*. [Forestry Department 1925, p. 14]

In the following year, 20 acres (8 ha) were planted with maritime pine at Badgers Hills (now part of Stoodley plantation) in the north-west and an arboretum of 24 acres (9.6 ha) established with 100 seedlings each of maritime pine, ponderosa pine, Corsican pine, remarkable pine, Norway spruce, Sitka spruce, Douglas fir and European larch at eight feet (2.4 m) spacing. Small areas of eucalypt scrub were spot sown with Canary Island pine at a similar spacing, and blackwood and black wattle planted at three feet (0.9 m) spacing.

The early plantings on the good sites in the north and north-west (e.g. Beaconsfield and Stoodley) showed that very good growth of conifers could be achieved (Cubit 1996). This encouraged the development of the large areas of highly productive pine plantations across the north of the State.

Trial plantations were also established at this time in the south at Strathblane and Ida Bay, and the comment on these areas from the 1927 Annual Report was that 'Stocks are looking well, and are assured of success'.

Wattle plantations were initiated in the mid 1920s at Sisters Hills and Triabunna. Stripping of wattle bark from native forests for use in the tanning industry had been an important part of forestry activities in the State for several decades, and the Bark Mill at Swansea is a reminder of this once flourishing industry (also see Chapter 4). Even before the formation of the Forestry Department, the Chief Forest Officer, Mr Compton Penny, had commented on the possibility of growing wattle in plantations for this industry:

> *I am now evolving a scheme to submit for your consideration having for its object the cultivation of the black wattle on some of the waste Crown lands on the East Coast, which is the natural habitat of the black wattle in Tasmania.* [Lands and Surveys Department 1916b, p. 24]

The trial plantings of black wattle on the worst soils and conditions at Sisters Hills showed initial promise, with the rate of growth far exceeding anything on the east coast. This good growth of wattle was seen to complement the conifer plantings:

> *As it is quite certain that valuable conifers will grow in the better class of soils of the Sister's Hills, should the wattle prove an ultimate success in the more barren parts, a great future lies before those hitherto waste lands.* [Forestry Department 1926, p. 8]

However, by the following year it was noted that the trial plantings of black wattle near Triabunna had failed due to exceptionally dry seasons, although the wattle plantings at Sisters Hills were still flourishing.

Reviewing the Early Plantation Trials

In 1928–29, when Mr T.J. Stubbs became Acting Conservator, he initiated a review of the plantation estate in Tasmania. This review was timely as there had been some eight years experience of establishing many different softwood and hardwood species on a range of sites across the State, and the performance of these plantations had varied enormously. It should be noted that, prior to the 1920s, none of these species had been successfully established in commercial plantations in the State. This review was followed by further analysis over the next two to three years of the reasons for success or failure of plantings. The results of this work, together with recommendations for future plantings, are summarised below from information in the Department's Annual Reports.

Queenstown: Variable results. Sulphur fumes and fire caused problems, but 16 acres (6.4 ha) of Douglas fir, radiata pine and maritime pine were thriving. The seedlings planted within existing scrub failed, so clearing for future plantings was now considered necessary.

Strahan: 192 acres (77 ha) planted; planting of radiata pine discontinued and maritime pine seen as having a better chance of success. There was to be no further planting on an extensive scale until more results from experimental plantings were available. Radiata pine had failed on the heathy portions of the sand dunes near Strahan and some 88 acres (35 ha) had so far been replaced with maritime pine and 39 acres (16 ha) replanted with radiata pine. In 1929–30, it was noted that the problems of successful planting of heathy coastal sands at Strahan were not yet solved.

Sisters Hills: There had been much criticism of this project but the Conservator noted that it was purely an experimental operation to determine what percentage of barren country was capable of afforestation and the suitability of species for various localities. Much replanting had been necessary and there were variable results but the nursery was flourishing.

In 1928–29, the peat soils in the north-west were examined by Mr Forbes, a noted authority on peat soils, to report on the possibilities for establishing plantations on the various types of buttongrass plain. He inspected Sisters Hills plantation and recommended other conifers for testing, including mountain pine and lodgepole pine.

The Conservator, Mr Steane, reported in 1930 that, before extending the planting at Sisters Hills, it was intended to observe the results of work already done. In the early 1930s, Mr C.G. Stephens of the Soils Division of CSIR (the

Assessing the performance of conifer plantings in the Sisters Hills plantation in 1927.

forerunner of CSIRO) sampled soils at the Strahan, Sisters Hills and Beaconsfield plantations and showed that, where difficulties had been encountered, the soils were almost completely devoid of potash and phosphates, and had pH values amongst the lowest recorded in Australia. The 1932–33 Annual Report (p. 4) noted:

> *Mr. Stephens, of the C.S.I.R. Soils Research Division, completed his report on the plantation soils examined. From that report, it is apparent that, with our present inadequate knowledge, it would be dangerous to embark on planting soils with pH less than 4.75.*

Needle fusion and the pine aphis were also a concern in this area and were investigated by CSIR (see Chapter 6). Also in this year, 120 acres (48 ha) of 1928 planting were destroyed by fire and the Sisters Hills nursery had been abandoned; practically all plants were being raised at Sheffield.

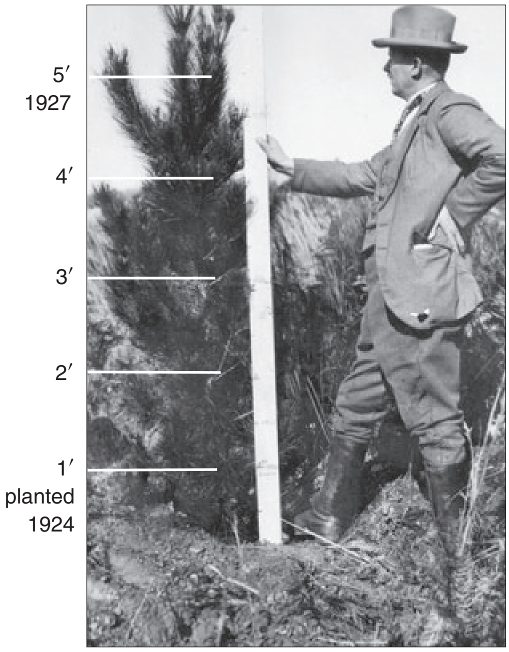
Sheffield: 205 acres (82 ha) planted, most of which were successful, although the seedlings on the hillsides were not as good. It was noted that, at Sheffield, the better parts had produced good growth but there were failed areas on the pink quartzite slopes of the main ridge:

> *A detailed soil and ecological examination will have to be made of the various types in this area. If we cannot at present solve the difficulty of planting certain types of soil, we must learn to recognise those types and so avoid wasting money on them.* [Forestry Department 1931, p. 7]

Beaconsfield: 212 acres (85 ha) of plantation had been successfully established. Results were considered to justify commercial-scale operations in this locality and other suitable Crown land in the District was sought.

> *Most of the trees planted are* Pinus insignis, *for which species the soil and other conditions appear very satisfactory. In this connection it may be well to point out that the growth obtained on agricultural land is not to be expected on the soils available for afforestation.* [Forestry Department 1930, p. 7]

King Island: 10 acres (4 ha) of experimental plantings of maritime pine, ponderosa pine



Joseph Memory Firth, District Forester North-East, measuring a radiata pine in 1927, three years after it was planted in the Beaconsfield plantation.

and Scots pine at six feet (1.5 m) spacing and Corsican pine at four feet (1.2 m) spacing.

***Triabunna**:* Plantings of radiata pine, maritime pine and ponderosa pine using seedlings from Sisters Hills and Strathblane nurseries; much replanting was necessary due to drying out from gales.

***Strathblane**:* 48 acres (19 ha) planted, with a low percentage of misses. A nursery established in 1925 was now able to supply all stock for the Southern District in the current season.

***Ida Bay**:* 80 acres (32 ha) planted. A large percentage of misses were recorded due to drying out of plants from Sisters Hills and Strahan used for the 66 acres (26 ha) planted in 1926. The general growth in the area was not satisfactory, as reported by Mr Stubbs:

> *The Ida Bay plantation has very little to show for the time spent on its formation, most of the trees having been swallowed up by cutting grass, and only about half an acre of more or less weak-looking trees are now showing any prospect of thriving.* [Forestry Department 1931, p. 7]

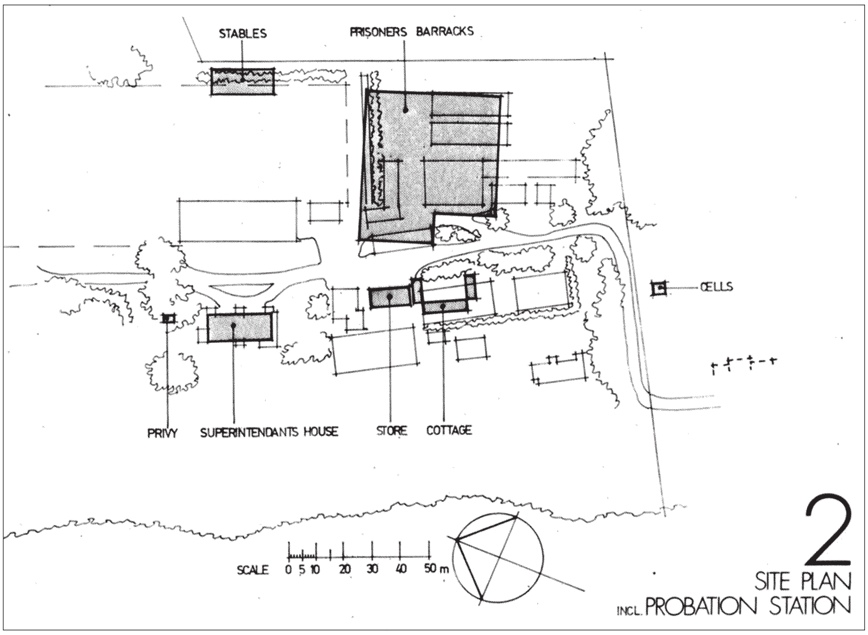
Following the review of these early plantation trials in all Districts, the Conservator, Mr Sam Steane, summarised the plantation efforts of the Department up to the early 1930s:

> *With regard to the much discussed 'success' or 'failure' of the plantations, it cannot be too strongly emphasised that, as far as they have gone, most of them must be regarded as experimental. Only in Beaconsfield and Warrentinna have attempts been made to plant on anything like a commercial scale, and even there such attempts have not gone very far. Whether the results obtained to-date are to be called 'success' or 'failure' depends on the main objective aimed at. If the Department, from the first, regarded these plantations as commercial undertakings most of them must, from that point of view, be regarded as failures. The overhead charges on small experimental areas would render commercial success almost impossible. If, as the writer believes, the plantations are to be regarded as experimental, then they are not failures.*
>
> *Both at Sister's Hills and at Strahan and, to a lesser degree, in some parts of Beaconsfield, conditions have been encountered in which the ordinary planting technique is unsuccessful at any rate with the species tried. The hopelessness of planting in such situations on a large scale with our present limited knowledge of the factors involved is immediately obvious, and the warning has not cost much either in time or in money. The real risk in planting untried types of country lies in a false sense of security induced by apparent success in the early stages. In such cases the loss may be very serious indeed.* [Forestry Department 1932, p. 5]

From the mid 1930s, in accordance with these informed views, planting was concentrated in the better performing areas of the north-east and north-west, particularly Warrentinna, Myrtle Grove, Stoodley and Castra. In the 1940s, ex-farmland with good soils was purchased and planted to pines in these highly productive areas (Cubit 1996). On some sites, the third rotation of radiata pine crops is now present.

The Perth Nursery was established in 1936, mainly for growing young trees for sale or free distribution in the Midlands, north-central and north-eastern areas. Then, in 1938–39, 7025 acres (2810 ha) of land were purchased for use in the plantation program; this area was to be planted with seedlings arising from the development of Perth and Mawbanna nurseries. Mawbanna was to supply local requirements in the North-Western Division while Perth was to meet the Department's main plantation requirements and supply trees required by the public. Perth was in a position to supply 250 000 plants for the 1940 season.

Above: Aerial view of Perth Nursery in the early 1980s. When it was first purchased in 1937, it already comprised established premises (a probation station), unlike most of the other early nurseries that were literally 'carved out of the bush'. The main building, Chatsworth (right), was the Superintendent's home. Many small alterations have changed the appearance of this building.



Right: Site plan of the Probation Station around the time it was sold to the Forestry Department. (From Howroyd and Forward 1980.)

The Commission's View

When the Forestry Commission was formed in 1947, the Chief Commissioner, Alec Crane, made a very clear statement on the Commission's view of the future for Tasmanian plantations:

> *The Commission is satisfied that areas in the north coastal part of the State will produce high quality exotic softwood plantations with growth rates comparable to those recorded in other mainland States.* [Forestry Commission 1947, p. 7]

The main plantings in the first years of the Commission were at Warrentinna, Myrtle Grove, Castra and Oldina, in line with the policy of concentrating conifer plantations (mainly radiata pine and Douglas fir) in the more productive sites in the north-east and north-west of the State. Some species trials continued to be established, with four acres of poplars planted at Castra and various experimental plots of miscellaneous species planted at Goulds Country and Takone. There were also several arboreta established in the 1940s, some of which (e.g. Hollybank near Lauceston) are still largely intact today.

In the section entitled *Forestry in Tasmania* appended to the 1947–48 Annual Report, the Commission set out the following policy for plantations:

> *Apart from the King Island project where local considerations may indicate the desirability of some hardwood, plantation projects will be entirely softwoods for the time being. Monterey Pine (*Pinus radiata*) and Douglas Fir (or Oregon) will be the species mostly used on present information, although experimental plots of other species are proposed, particularly* Pinus patula*, a tree rarely seen as yet in Tasmania.* [Forestry Commission 1948, p. 20]

The Commission espoused a policy of managing conifer plantations for the production of high-grade softwood for plywood and joinery

Douglas fir, one of the favoured species in early plantings, at Myrtle Grove in 1950.

manufacture and, in accordance with this policy, a large pruning program was initiated. This policy continued to the present day, and some of the work to achieve this objective is reported later in this chapter. Some 390 acres (156 ha) of plantations were pruned at Stoodley, Warrentinna and Myrtle Grove in the Commission's first full year of operations. Figures were also published on the growth being achieved at Warrentinna. In one compartment of radiata pine, the merchantable volume per acre at age 13 years was 38 987 super feet (this equates to 230 m^3/ha and a mean annual increment of 17.7 m^3/ha/yr). These figures were accompanied by the following positive statement on softwood plantations:

> *Provided rapid rates of growth can be maintained by early and periodic thinning, there seems to be little doubt of the ultimate success of the Commission's softwood plantations.* [Forestry Commission 1948, p. 11]

Thinning operations commenced in October 1950 in Warrentinna and volume data were compiled from Stoodley prior to thinning there. The pruning program continued at a high level using three progressive lifts to 8, 16 and 22 feet (2.4, 4.8, 6.7 m), with the aim of restricting the knotty core to 4–5 inches (10–13 cm) in the butt log of the tree. By the end of that year, seven nurseries were in operation, with Perth being the largest, and a record annual production (before culling) of 2 703 760 seedlings, mostly radiata pine, was achieved. By 30 June 1951, the total plantation area was 5864 acres (2346 ha), including 234 acres (94 ha) of eucalypts on King Island.

From the early 1950s, in order to support the large investment in the more intensive management now occurring in the Commission's conifer plantations, an expanded research program was developed aimed at specific problems of establishment and management. By far the bulk of the initial research effort was directed at radiata pine, but there was a gradual expansion of the plantation research program to cover other species, particularly eucalypts, as policy directions and markets changed.

The following sections cover the history of research to support the planting of the main commercial species from the 1950s to the present day.

Assessing Land Suitability for Plantations

Some of the early plantings failed completely (such as those on very poor soils on the west coast) or had low survival and growth. Although there were some investigations into soils and other site factors affecting suitability for plantations, no defined system for site selection existed for many years after plantation

A radiata pine stand at Warrentinna, north-eastern Tasmania, 1972. The stand was planted in 1935 and thinned three times, with the third thinning in 1970.

establishment became a major operational focus for the Forestry Commission. Local knowledge of tree growth on particular areas and the nature of the native vegetation were often the main indicators used in selecting areas for plantation development. These factors can be useful pointers to the suitability of sites for plantations, but they are not always reliable indicators of potential growth over short rotations. However, a successful site-selection system used in the 1950s was to plant only areas having a high proportion of tall bracken on the site. Experience had shown that bracken was a good indicator of what would be successful establishment and growth (J. Quick, pers. comm.).

A more rigorous approach to site selection was adopted in the 1960s, when soil surveys were undertaken prior to the development of a large plantation program at Fingal in north-eastern Tasmania. Bob Ellis conducted a survey at Tower Hill, which included profile descriptions and chemical analysis. Despite evidence from this survey raising doubts, pointing to shallow, rocky soils and low levels of nutrients, some unsuitable sites were planted. Surveys, which included detailed soil information, were also undertaken on the west coast and at Long Hill.

In the 1960s, a number of research trials were established in various parts of the State, including the west coast and north-western Tasmania, to evaluate the performance of pines on various land systems defined by the Department of Agriculture. Soil information and early growth of trials indicated that some of these sites were unlikely to grow satisfactorily, and the results provided a better basis for decisions on site selection for plantations. Nutrition research investigating the response to a range of fertiliser treatments in the Fingal plantations commenced in the mid 1960s by Wilf Crane (see later this chapter).

A systematic evaluation of an area in relation to a land classification system was conducted on Forestier Peninsula in the early 1970s, with the growth of radiata pine, identification of nutrient deficiencies, and response to fertiliser being assessed on four land units (Ellis *et al.* 1975). Bill Neilsen and Wilf Crane developed a large-scale land classification system for plantation suitability for the Fingal plantations. Areas of potential and existing radiata pine plantations in the then Fingal District were classified into one of three suitability classes, and land units were correlated with site potential based on existing knowledge of soils and performance of plantings on similar sites (Neilsen and Crane 1977). The work was done to identify sites that needed fertilising and would respond to aerial application of fertiliser. Mapping of areas for plantation suitability was later extended Statewide by Wally Pataczek, Graeme Clark, Brett Miller and Tony Lade.

In the early 1980s, Gordon Davis and Peter Volker started preliminary work on criteria for selection of eucalypt plantation sites. About this time, the Commission established a committee for the 'Intensification of Management of Native Forests'. Their recommendations for increased thinning of native forest and expanded establishment of eucalypt plantations made the work on site selection a critical research area.

Adam Gerrand and Bill Neilsen began a study of quantitative methods to assess the potential of land for eucalypt plantations in north-eastern and central northern Tasmania in the late 1980s. This work was carried out with the Centre for Resource and Environmental Studies at the Australian National University, which was undertaking a project in co-operation with the Private Forestry Division to identify potential suitable plantation areas using climatic modelling. The aim was to develop plantation suitability classes using mean annual increment as the variable. Sources of data on tree growth used were 14 Associated Pulp and Paper Mills/ Forestry Commission plantation species trials aged 7–8 years (from trials established by John Smith of APPM and Keith Orme of the Forestry

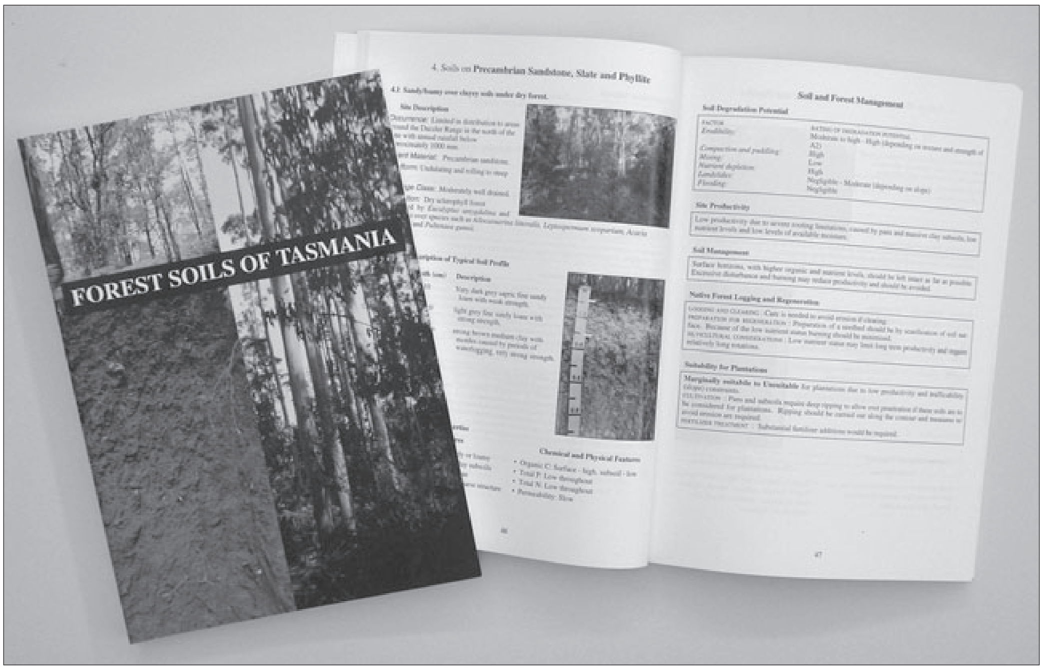
Commission), 88 Private Forestry plantation plots aged 3–13 years, and 202 continuous forest inventory (CFI) native forest plots of varying age.

For each plot in an existing plantation, plot height and diameter were measured and volume per hectare calculated. Site index was estimated using the mean dominant height at the measured age and the Southern Forests Yield Table. Climate (BIOCLIM computer model) and soils (Department of Primary Industry land systems, and Mines Department maps) data were obtained. Future growth rates were estimated from the Victorian STANDSIM model, and the GIS was used to map 'Plantation Suitability Classes' by using the peak MAI estimated by STANDSIM for each plot based on its site index and assuming a stocking of 1100 stems per hectare. This was essentially a pilot study which identified subject areas, such as soils, where more information was required before the technique was further refined. However, the output of maps showing estimated peak MAI on State forest with slopes less than 30% was an important step forward in the development of more sophisticated site-selection methods for plantations (Gerrand 1991).

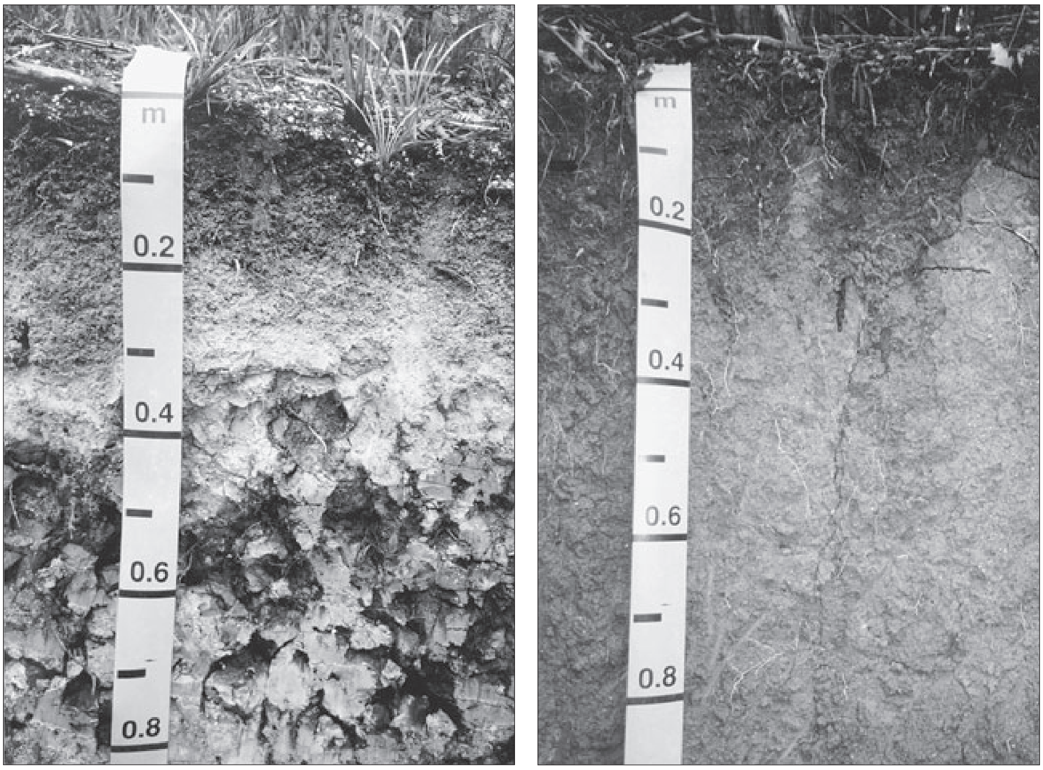
An eight-year-old plantation of *Eucalyptus nitens* on a gradational soil formed on granodiorite. Relating plantation growth to specific soil properties has been a major advance in assessing land suitability for plantations in Tasmanian forests.

The major deficiency in assessing site potential up to this time was the lack of detailed information on the wide range of soils in potential plantation areas across the State. In the 1980s, detailed soils research commenced with the establishment of a project under the National Soil Conservation Program (NSCP) investigating the effects of forest operations on soils (Williamson 1990; Williamson and Neilsen 2000, 2003a, b). This work was continued with a large project in north-eastern Tasmania, partially funded by the NSCP and undertaken by Tom Lynch and later by Graham Brown. The work included some Statewide evaluation of soils.

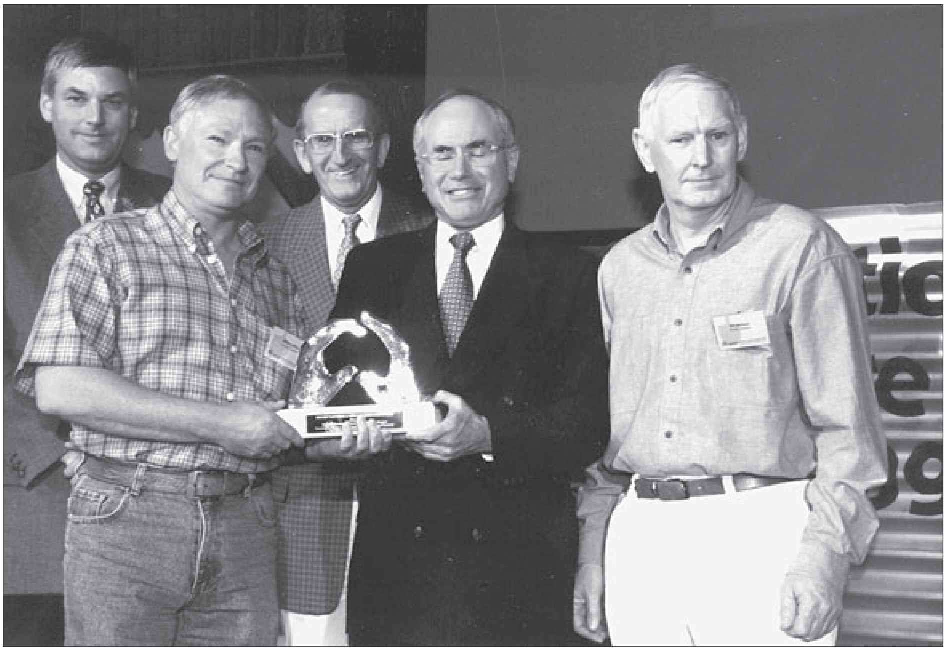
In the early 1990s, soils research accelerated with the appointment of Mike Laffan and John Grant (later assisted by Reece Hill, Darren Kidd and Andrew Herbert) to begin a five-year project studying land capability classes of Tasmanian forest soils. The project was funded under the Intensive Forest Management Program (IFMP) and the National Landcare Program (NLP). It aimed to describe and map soils, with special reference to sustainable forest management and site suitability for plantations. By the end of the project, the soils on three 1:100 000 map



Forest Soils of Tasmania, co-authored by John Grant, Mike Laffan, Reece Hill and Bill Neilsen, is a handbook on the identification and management of forest soils commonly found in Tasmania. It was published in 1995 and much of the information in the book resulted from the studies of land capability classes funded under the Intensive Forest Management Program and the National Landcare Program.



Examples of the soil profiles formed on granite under dry forests (left) and under wet forests (right).



Mike Laffan (second from left) and Bill Neilsen (right) receiving the 1997–98 BHP National Landcare Research Award from the Prime Minister, the Right Honourable John Howard.

sheets (*Pipers*, *Forester* and *Forth*), covering 154 000 ha of State forests and containing important plantation areas, were characterised and mapped (Laffan and Neilsen 1997). Maps of soils and interpreted maps of productivity, suitability for plantations, erodibility and trafficability by machinery were produced and made available on the GIS. Appropriate sustainable practices were prescribed for forest management on these soil types. Largely through the work on this project, a handbook, *Forest Soils of Tasmania,* was produced for the identification and management of a range of common forest soils (Grant *et al.* 1995).

The significance of the work on forest soils and their suitability for plantations was appropriately recognised when Mike Laffan, Bill Neilsen and supporting staff received the prestigious National BHP Landcare Research Award in 1997–98.

The establishment of greatly increased areas of eucalypt plantations under the IFMP and Regional Forest Agreement (RFA) programs made decisions on site selection critically important. These plantations were established and are being managed by high investment, intensive regimes for production of solid wood products, with the sawlogs and veneer logs being destined to replace those foregone when production forest was transferred to conservation reserves. During the IFMP, a method of site selection was developed based on site productivity, defined in terms of peak MAI, and land suitability classes which prescribed the limiting factors affecting plantation productivity and/or management, or erosion and other hazards that degrade soils (Laffan 1994). This system and subsequent modifications became the basis for site selection for all plantations established by Forestry Tasmania. Recognising that there would always be limited soils expertise available to support field staff involved in plantation site selection, Mike Laffan subsequently produced practical guides for assessing site suitability based on soil and site attributes (Laffan *et al.* 1998; Laffan 2000). These guides interpreted technical information so that good results could be obtained by staff with a basic knowledge of soils and good observational skills.

The Exotic Conifers: Radiata Pine and Douglas Fir

From the late 1940s, radiata pine and, to a much lesser extent, Douglas fir were the only conifer species being planted in any significant quantity by the Forestry Commission. These early plantations used imported seed, and plantation establishment and management practices were, by today's standards, very basic. The progressive developments in conifer plantation practices which followed are summarised in the following sections.

Tree improvement

The growth of conifer plantations in the early 1950s on reasonable sites was generally good but the form of the trees was very variable. This period saw the beginning of the Commission's tree-breeding work under Max Gilbert (assisted by Murray Cunningham), an area of research which, over the years since then, has paid handsome dividends. Volume production, tree form and wood quality of all plantation species have been greatly improved, with wood quality testing being undertaken by CSIRO as part of the process of selection.

The path initially followed had four stages:

- Select trees in the plantations which had good growth and form, and collect seed for operational planting of such trees;
- Obtain offspring from crossing the best of these select trees and establish progeny trials to obtain trees with the best growth, form or other desired traits;
- Establish seed orchards from the best of these trees, with seed from the orchards being used in nurseries for production of planting stock;
- Repeat selections and trials, and consider the use of artificial crossing (control pollination[3]).

The first stage, which began in the mid 1950s, involved the systematic searching of Commission plantations. Elite trees (those with the highest ratings for stem straightness, branch size and branch angle) were identified and the first open-pollinated progeny trials were established to test the qualities of the progeny of these elite trees. From this time, seed was also collected from the best trees in the plantations for routine planting. Planning commenced for the establishment of seed orchards containing trees raised from cuttings and grafts taken from trees of superior form and vigour.

The period 1958–59 was important for the conifer plantation program because it was the first time that sufficient seed was gathered from selected trees in Tasmanian plantations to grow the whole of the planting stock needed for the following year's establishment program. Increasing amounts of seed had been collected from selected trees in the Commission's plantations since 1954, but seed was still being imported, principally from South Australia and New Zealand, until that year.

Moves towards the establishment of radiata pine seed orchards initiated in the early 1950s had proceeded as planned, with the first orchard being established at Upper Castra in 1960 from the progeny of 10 trees selected for outstanding vigour, form and timber characteristics. The orchard trees were propagated from grafts and cuttings taken from elite parent stock. The elite tree search continued in the late 1950s and grafts were made from a further 18 trees. Seven of these were selected on the basis of wood properties for inclusion in the Upper Castra seed orchard.

By 1963, establishment of the Upper Castra seed orchard had been completed, although the

[3] The process of obtaining seed by transferring pollen from a known parent tree to the female parts of another known parent tree.

search for elite trees continued, with all radiata pine compartments being searched in the year they reached 11–12 years of age. The objective at the time was to search some 12 000 acres (4800 ha) by 1970 and to establish a second seed orchard by 1973 from about 20 of the best trees. By 1972, the selection of plus trees (trees with superior desired traits) to provide material for another seed orchard was completed and, in the following year, radiata pine candidates for this orchard (located at Upper Natone) were scored for vigour, form and branch characteristics. Buds from the best 55 trees were grafted onto pine seedlings at Perth Nursery; stock was planted in 28 randomised blocks in September 1973. Wally Pataczek was involved with the establishment of the Upper Natone seed orchard, and Neil Parker supervised the management of an expanded seed orchard at Goulds Country. A radiata pine clone bank was also established at Perth Nursery in 1973, and the first assessment of open-pollinated pine progeny trials at Inglis and Nicholas plantations was conducted in 1975–76. A trial of radiata pine open-pollinated clonal progenies from New South Wales was planted at Forester in 1979.

A radiata pine plus tree (one with superior desired traits) in Stoodley plantation in 1953, aged 14 years. These plus trees were the source of seed used in progeny trials in the Forestry Commission's tree improvement program.

Improved stock of Douglas fir for Forestry Commission plantations was also acquired through tree-breeding programs in the 1960s and 1970s. In co-operation with the Forest Research Institute in Canberra, progenies of a range of Douglas fir provenances from western North America were planted in several provenance trials in northern Tasmania in the 1960s. Some years later (1973–74), large provenance trials were planted at Star of Peace, Kamona and Smiths Plains plantations, again in co-operation with the Forest Research Institute.

These trials demonstrated the high growth rates that were achievable with provenances originating in the Pacific North West of the United States of America, particularly northern California and southern Oregon. In 1982, Peter Volker obtained seed from these provenances with the intention of establishing seed-production stands

The seed orchard at Upper Natone, not long after it was established in 1973.

should an expanded Douglas fir planting proceed. In collaboration with Colin Crawford (Mersey District), plantations were established in riparian zones of the recently clearfelled radiata pine and Douglas fir at Stoodley in 1983. No further planting of Douglas fir has been undertaken since (P. Volker, pers. comm.).

In April 1978, the Forestry Commission's tree improvement program for radiata pine was reviewed by Dr Alan Brown, Assistant Chief of the CSIRO Division of Forest Research in Canberra. He confirmed the views of plantation research staff that future seed production at the Upper Natone orchard would be limited, and recommended that another seed orchard for radiata pine be established as soon as possible.

In the late 1970s, following Alan Brown's recommendations, the Commission developed an objective for all nursery sowing of radiata pine to be of seed-orchard seed within three to four years. Some 3000 grafts were completed

Table 1. Genetic improvement from Forestry Commission seed orchards (Forestry Commission 1992b).

Seed orchard	Volume (% gain)	Stem straightness (% gain)	Branch form (% gain)
Upper Natone	12	13	13
Perth sect. A	16	13	13
Perth sect. B	13	15	12
Perth sect. C	11	11	11

for the new orchard, with an 85% success rate and, in 1979–80, the orchard was planted at the Perth Nursery. The orchard area was divided into three sections, one to produce seed for general purpose plantation stock, another for seed for production of fine-branched trees, and a third for seed from progeny-tested parents.

The first commercial collection of 53 kg of radiata pine seed was taken from the Upper Natone seed orchard in 1982–83 for use at the nursery in the next season. In the following year, the Upper Castra orchard had reached the end of its working life and was clearfelled over the next two years for maximum recovery of seed. This orchard had supplied valuable seed for nearly 20 years.

In 1983, in response to the Brown report, Peter Volker, with the assistance of Paul Cotterill (CSIRO) developed a breeding plan for radiata pine in Tasmania. This was the same year that the Southern Tree Breeding Association (STBA) was formed.

In 1982, the Australasian Plus Tree Progeny Test consisting of 317 open-pollinated families of radiata pine from Australia and New Zealand was established at Upper Castra (adjacent to the orchard site described above) by Peter Volker, Leigh Edwards, Keith Orme, Sue Jennings and Wally Pataczek. This trial contained material from all the Australian State pine breeding

The hazards of tree measurement at high altitude! Radiata pine in a plantation establishment trial at Maggs Mountain, 1991. (Peter Kube pictured.)

programs (except South Australia) as well as the New Zealand '880' selections. A further two trials utilising about 200 families from South Australian 'Super 80' selections were planted at Kamona and Gog. These trials were to provide a basis for a well-resourced tree improvement program and lead to increased collaboration with interstate breeding programs. As a result, the STBA became a national breeding co-operative which the Forestry Commission joined in 1990.

The STBA conducted an ongoing tree-breeding program for radiata pine and managed seed-production facilities for its members. The Forestry Commission supplied radiata pine seed into the co-operative, as did some other members, and all members received seed from the co-operative for their planting programs. At the time of joining the STBA, genetic gains from the Commission's seed orchard program for volume, stem straightness and branch form, compared with randomly chosen trees (unselected seed), were estimated at 11–16%, 11–15% and 11–13% respectively, the range for each character representing the variation from orchard to orchard (Forestry Commission 1992b).

The STBA established a number of progeny tests on State forests to evaluate the products of its national breeding program. Peter Kube led the tree improvement research program during this time and was a constant driver for deployment of the best genetic material in the operational plantation program. Along with Stuart Vance and Peter Moore at the nursery, Peter Kube established stool beds from control-pollinated seed which supplied high-quality cuttings for operational deployment (see p. 217)

A new seed orchard was established at Perth in the early 1990s. This included a control pollinated section which provided seed for increased gains in particular tree characters and also for specific purposes, which included growing trees resistant to particular diseases such as spring needle cast (see Chapter 6). This orchard continues to supply seed for external sale.

The sale of the pine plantation resource to Taswood Growers in 1997 resulted in Forestry Tasmania withdrawing from the STBA radiata pine breeding program and the end of the control-pollination and cutting production program. Rayonier Tasmania, as the manager of the Softwood Joint Venture since 1999, took control of the sourcing of genetically improved material for the plantation estate.

Plantation establishment

Quality of planting stock

The first radiata pine seedlings varied greatly in size and quality, being raised by very labour-intensive methods. In the early 'bush nurseries' scattered across the State, seed was sown by hand and germinants thinned out to produce pine seedlings for plantings. Later, open-rooted (or bare-rooted) seedlings were raised by machine-sowing into open nursery beds. This was (and still is) the main method used for growing pine seedlings.

The main concerns in the early days of raising large numbers of conifer seedlings in the nursery were weed control in the nursery beds, determining the best time to sow, and how to reduce the overall costs of seedling production. Weed control was very expensive and labour-intensive, with hand-tending commonly used.

Early studies in the nursery designed to produce cheaper plants addressed time of sowing, particularly late sowing to give plants more than one year in the seedbed, and also root pruning *in-situ* of one-year-old seedlings.

In the 1950s, planting stock was being produced at Perth Nursery and at small field nurseries at Myrtle Grove, Kamona, Castra and Stoodley. The small nurseries had stock-quality problems but produced a large amount of stock, including two-year-old seedlings for heavy bracken areas. Murray Cunningham initiated small nursery and planting trials at Perth to improve stock quality (J. Quick, pers. comm.). Major benefits for radiata pine plantation establishment were then realised in the late 1950s after completion of an integrated research project by Max Gilbert and John Quick. This study comprised six replications over four years, of planting over six months, with three grades of nursery stock and two handling treatments. Consistent results were obtained and applied to the 1958 planting season. Based on the results of this large trial, it was decided to do all planting in spring (although some late summer–autumn planting was successfully undertaken) and to sort pine nursery stock into strictly controlled grades. This technique enabled the establishment of more uniform stands of trees having consistent growth potential, allowing more effective weed suppression and better branch control, and with better adaptability to site conditions.


Max Gilbert inspecting 18-month-old transplanted radiata pine seedlings at Myrtle Grove nursery in north-eastern Tasmania, 1950.

Heeling-in of planting stock was also established in the late 1950s as standard practice for the first time. This technique entailed the lifting of plants from the nursery beds but, instead of planting them in the plantation areas, they were loosely planted in trenches in the nursery for a short

Heeled-in seedlings of radiata pine at Nicholas plantation, north-eastern Tasmania, 1966.

period. This imposed a planting shock on the seedlings and stopped them growing strongly in the nursery in the active spring growth period. By the time they were taken from the heeling-in trenches, they had initiated new root growth and could start growing rapidly when planted out, thus having a better chance of survival, especially when planted late in the season. This practice was applauded:

> *The success of spring planting has now been assured by the development of the heeling-in technique.* [Forestry Commission 1958, p. 10]

Trials in Fingal in the mid 1960s of heeled-in radiata pine (heeled-in one-year-old trees for two months) also proved beneficial. Operationally, heeling-in was also a very useful development, since, with the threat of attack by the sirex woodwasp (see Chapter 6) on plantations in northern Tasmania, it had become necessary to organise pruning as winter work to avoid increasing the risk of attack in the sirex flight season (summer/autumn). Thus, with later planting, District labour could be directed at pruning in winter and planting in spring. Heeling-in can still be used today when there are significant delays between seedling delivery and planting, or seedlings need toughening for planting in exposed areas or for late planting (Neilsen 1990). However, experience has shown that with today's quality of site preparation and seedlings, establishment in the field is best if seedlings are planted as soon as possible after being delivered to the planting area.

Despite the improvements in uniformity of seedlings from the trials in the late 1950s, variability in time of germination and seedling vigour remained a problem through the 1960s, and is still one familiar to today's nursery managers. Many tests were conducted of the performance of seedlings grouped into a range of vigour classes so the ultimate performance of seedlings with defective form and/or low vigour could be more confidently predicted. Storage and treatment of radiata pine and Douglas fir seed were also investigated. The effects of time and conditions of storage, particularly pre-germination treatments of exposure to wet cold conditions, on the viability of seed and the rate and period of germination were studied. The viability of seed taken from cones of various ages was also investigated. The effects of different depths of soil on germination of radiata pine seed and different densities of sowing on seedling growth and form were also tested. Various fertilising regimes for the nursery beds, mainly using different types of manure, were trialled, and a joint project between the Forestry Commission and the Department of Agriculture was initiated on the occurrence of mycorrhizae on seedling roots and effects of inoculation into nursery beds.

There were also significant advances in nursery practices in the 1960s which improved the growth of Douglas fir plantations. Stagnation of growth of young fir plantations had been observed, and planting trials indicated that the use of large plants from nursery beds inoculated with mycorrhizae was probably the best way to overcome stagnation in the early years. Mycorrhizae were collected in the field and introduced to Douglas fir seedbeds. Results of these trials indicated that the long periods of growth check of this species when planted in the field might be overcome. Also, it was considered that site preparation would have to be more thorough than for radiata pine, and it would be beneficial to apply fertilisers after planting.

The small field nurseries established in several plantation areas were closed in the 1960s and stock production was concentrated at Perth Nursery and at a river-flat site at Branxholm, the latter being closed in 1982 because of infection of nursery beds by the root-rotting fungus *Phytophthora cinnamomi*. These nurseries became the focus for the introduction of mechanisation and production-line techniques developed by Nobby Nobes, Neil Parker and Hans Dorgelo (J. Quick, pers. comm.).

In 1965, a 10 acre (4 ha) extension for Perth Nursery was purchased to raise production to two million pine seedlings, and mechanical means of raising open-rooted nursery stock were developed. In 1978, another 25 ha of land adjacent to the existing nursery was purchased by the Commission. Gordon Davis

Radiata pine cones in a polythene-covered seed extractor at Branxholm nursery in 1968.

Lifting radiata pine seedlings with a wedge at Branxholm nursery in 1968.

The *Forest Nursery Manual,* published in 1996, was prepared for Perth Nursery by Peter Kube, Tim Wardlaw and Peter Moore.


An early method of transporting seedlings to field sites using bagged stock in open trucks, 1975.


Methods of seedling transportation introduced in the 1990s gave far better protection to seedlings during transfer to the planting site and also during the planting process. Seedlings were placed in coreflute boxes which were then packed in modular ‘pods’ for transport.

Radiata pine seedlings ready for lifting at Perth Nursery, 2001.

conducted detailed investigations in New Zealand and interstate nurseries of techniques for raising radiata pine seedlings. He developed a nursery manual to guide future radiata pine production on the expanded nursery site; this manual was later revised and expanded to cover all nursery procedures and crops (Kube *et al*. 1996). Updated methods of management, including rotation systems using green crops, a large irrigation system and wind protection were introduced, resulting in a significant improvement in seedling quality.

In 1995, a major program began at the nursery for the production of rooted cuttings of radiata pine. The source of cuttings was seedling stocks derived from control-pollination of superior parents. This is known as family forestry. The production of hundreds of cuttings from one seedling allows the grower to rapidly increase the number of plants for deployment in operational plantations, thereby capturing genetic gain much earlier than through traditional seed orchard systems.

Additional benefits of cuttings are: tree form is improved, nursery stock is more robust, and special breeds can be selected. By July 1997, there were 60 000 cuttings available for the annual program, and annual production reached two million plants by 2000. Eight hectares of stock plants produced from elite control-pollinated seed were established at the nursery to supply the cuttings for the program. By the end of the program, 125 000 micro cuttings were being produced annually from the latest selections of plants grown from control-pollinated seed. These plants were grown as replacements for the older stock plants and the selections were chosen for high levels of production, having small branches, long internodes and resistance to pine needle blight (see Chapter 6). The cuttings program ceased soon after Rayonier Tasmania became the manager of the radiata pine joint venture in 1999; cuttings were replaced by control-pollinated and open-pollinated seed due mainly to cost factors and experience of the manager with particular seed sources.

Radiata pine cuttings one year after setting and ready for lifting from the beds. These show uniformity and good, straight growth.

Site preparation

Successful establishment of pine seedlings on the early commercial plantation areas was not possible without first burning the areas where bracken occurred. Clearing of scrub and burning were the first large-scale site-preparation techniques. As the range of soil types and terrain where plantations were established expanded through the 1950s and 1960s, field staff gradually developed methods to suit the different areas. Collaboration with staff in the forest industry and the Tasmanian Department of Agriculture and other agencies was an important part of this development.

The establishment of radiata pine plantations on heavy clay soils at Long Hill in the 1970s saw the introduction of cultivation in the form of mound ploughing and ripping prior to planting. Bert Witte organized the operations, which were extended to other plantations, along with research by Bill Neilsen and Wally Pataczek to measure advantages obtained. Cultivation and deep ripping were shown to provide large benefits in growth. A winged ripper was used routinely to loosen compact subsoils to promote better root growth. Further experiments with different methods of site preparation for new (1R) and second rotation (2R) radiata pine plantation establishment were conducted through the 1970s and 1980s by District and research staff, particularly Beverley Beer and Gordon Davis.

In the late 1970s, field trials were conducted using chopper rollers to break up slash. The Marden B8GK-Duplex chopper roller was demonstrated at Myrtle Grove, but more trials were needed to convince forest managers at the time that it could be effective in plantation establishment. Many plantation sites had large volumes and piece sizes of slash after harvesting. These areas required more powerful tractors to pull the two water-filled drums of the chopper roller, and improved operator expertise was also needed. Subsequently, giant mound ploughs with an accompanying ripper were found to provide the best site preparation in several areas.

Site-preparation trials continued on a range of heavy soils, and ripping depths of 80–90 cm were achieved with the winged ripper. Mound ploughing improved growth of young seedlings but the results varied across sites. At some sites, the benefits were short term and smaller than those provided by fertilising. On the West Coast, Stuart Vance constructed a monstrous mouldboard plough (this became famous as the Strahan Plough) to create huge mounds for improved drainage on heavy clay soils. In order to provide a better basis for applying site-preparation treatments to particular sites, Gordon Davis conducted a major study of radiata pine root morphology across a range of soil types (Davis *et al.* 1982). His studies showed that gross differences occurred in root development over the trial sites and provided valuable information relevant to site preparation for radiata pine on the different sites encountered across the State. In the early

Ripping and mounding equipment (left and below) is commonly used on many sites to prepare a good planting environment for pine and eucalypt plantations.

Spot cultivation using the Ro-Tree cultivator mounted on an excavator. This method of site preparation can be preferable to ripping and mounding in areas of erodible soils, on steep slopes, or in some sites with thick layers of slash, as it minimises clearing costs or avoids the need to burn.

Early harvesting of 38-year-old pines in north-eastern Tasmania, planted in the 1930s/1940s. Commercial-scale clearfelling of radiata pine started in the 1970s, and research trials followed to test second rotation (2R) techniques.

1980s, the results of this research were implemented into regular plantation establishment work, and ripping with the winged ripper and mound ploughing became recommended practice, ripping being applied to all sites with heavy subsoils. Trees on ripped areas had smaller but deeper root systems, while those on mounds had a flat, spreading root system. Further research conducted in the Co-operative Research Centre for Temperate Hardwood Forestry in the mid 1990s demonstrated that ripping was not providing the perceived benefits on a wide range of soils but mounding was generally essential.

Commercial-scale clearfelling of radiata pine started in Tasmania in the mid 1970s and a research trial to test 2R establishment techniques was set up by Bob van Schie at Scottsdale, in co-operation with Tasmanian Board Mills. Treatments ranged from broadcast burning only, through to windrowing, stump removal and cultivation. Preliminary results indicated that a hot fire was needed to destroy pine seed and cones on the ground, the source of pine wildlings. Windrowing and burning of one- or two-year-old slash destroyed most seedlings and left little or no viable seed for further germination. Stumps cut close to the ground gave a significant reduction in site-preparation costs. Ripping and pushing stumps was very costly, and stumps of normal height could be ploughed over with Little Giant Discs, but there was a marked increase in quality of ploughing and area effectively ploughed when stumps were low.

In the early 1980s, the results of 2R site-preparation investigations at Warrentinna showed that broadcast burning (although undesirable for long-term productivity) was a better technique than windrowing and heaping because of reduced soil disturbance and a larger available planting area. No effective chemical control of radiata pine wildlings in second rotation establishment was available at this time, and hand pulling and chipping was the major control technique. A prescription was adopted for sites with many wildlings, where a very hot broadcast burn was used to kill the pine wildlings and seed and reduce slash. At other sites where wildlings were not so plentiful, it was recommended that planting should be through unburnt slash wherever possible. Tony Lade and Colin Crawford from the Devonport District developed a system of V-blading and ploughing between rows of old pine stumps, which avoided burning and reduced the cost of planting. Wildlings, occurring mainly between the planted rows, were easier to control. A similar system was introduced into first rotation sites where logging debris was not too heavy.

Increased areas of second rotation plantation sites and the desire to reduce clearing costs on native forest sites led to the introduction of spot cultivation techniques, commencing with the RoTree in 1993; Peter Volker at ANM encouraged its use in 2R sites in the Plenty Valley. Subsequently, Brian Farmer (Forestry Commission) also trialled its use in North Retreat. Alternative spot cultivation equipment such as the Willco were introduced by Brent Donaldson in Bass District and this equipment soon gained more widespread use than the RoTree. The results of the spot cultivation techniques demonstrated a number of advantages, including reduced site disturbance during preparation and similar growth outcomes to traditional line cultivation techniques (Laffan *et al.* 2003). Spot cultivators are now used for some sites throughout the plantation industry in Tasmania.

Weed control

Weed competition was the main problem encountered when establishing the early radiata pine plantations in the 1950s and 1960s, growth and form of the young pine seedlings often being severely affected. Bracken was usually successfully controlled by burning, but the clearing of native forest areas was often followed by rapid growth of coppice from cut eucalypt stumps and accelerated development of shrubs and grasses in the cleared area.

In the early 1960s, Neil Parker and Wilf Crane carried out trials of herbicides in pine plantations to control eucalypt coppice and shoots from lignotubers. By 1966, the use of the chemical picloram to suppress eucalypt coppice ahead of planting pines had become standard practice. Further research showed that less coppice occurred with hotter establishment burns, and autumn burning was more effective than spring burning. Hand tending of coppice was best done in summer and autumn rather than winter and spring, but chemical control was usually cheaper and more effective than hand tending.

Most chemical control was obtained by pre-planting spraying. Planting after spraying caused damage to the young pines, prompting commencement of research into methods of stem injection of chemicals to control the eucalypt coppice. By 1968–69, Tordon®, as a low-volume foliage spray, was found to be effective for coppice control. Trials of basal bark spraying and stem injection continued and the use of picloram for stem injection increased, but basal bark spraying appeared to be almost as effective if eucalypt stem diameter was less than three inches (76 mm). All these methods required labour-intensive, hand application of the chemicals. Alternatives to dieseline, the carrier for herbicides used in basal bark spraying, were also tested in the mid 1970s. Dieseline facilitated quick penetration of bark by the herbicides but was unpleasant for the operators to use.

In the early 1970s, a series of good growing seasons led to aggravated weed problems in young plantations where large quantities of wattle seed were stored in the soil. Large numbers of wattle germinated and grew vigorously. Preliminary trials of post-planting applications with 2,4,5-T showed that this chemical was effective as a control for wattle,

Cultivating between rows of six-month-old pines to control weeds, using tractor-drawn discs, c. 1996. Post-planting weed control in plantations was one of the more successful techniques introduced as an alternative to the use of chemicals.

but it was very difficult to get complete coverage at reasonable cost without damage to the pines. As part of a weed control research program conducted by Bob van Schie in the mid 1970s, a trial was established to test the feasibility of aerial spraying of weeds under Tasmanian conditions. This followed successful wattle control in Victoria using 2,4,5-T in oil applied from the air. Stream water was sampled for data on concentration and dispersion of the chemical applied in this trial. The trials resulted in a complete kill of silver wattle and sunshine wattle, 20% kill of varnished wattle and 80% kill of eucalypts within about nine months. Contamination of streams occurred almost exclusively from direct contact with their surface and this fell to trace levels within three to four hours. From the results of these trials, operational guidelines were drawn up for large-scale spraying of weeds in radiata pine plantations.

Major trials of pre-emergent herbicides were set up at Long Hill by Bob van Schie and Leigh Edwards in 1974–75, where dolly bush was the main weed stimulated by site preparation and fertiliser application. Further trials of pre-emergent herbicides and application methods were conducted at Long Hill, with atrazine proving the most promising. Plots were established to monitor weed development after the herbicide treatments used in plantation establishment. The 1975 Long Hill trial showed that chemical application at planting to control dolly bush, grass and herbaceous weeds as they germinated was very effective, and that a combined weed control/fertiliser treatment could double the height increment in at least the first and second years after planting. Chemical control was shown to be essential for grassland planting. The best establishment in grasslands was achieved by line ripping and/or mound ploughing and spraying before or after planting with a mixture of knockdown and residual herbicide. Results of trials using ultra low volume (ULV) herbicide application indicated that it was easier, more effective and could be


Aerial application of herbicides such as glyphosate prior to planting is a commonly used method of controlling weeds in plantation areas.

used under a wider range of weather conditions than conventional knapsack spraying, if used with translocatable herbicides.

In the late 1970s, there was public concern over the use of 2,4,5-T, and basal bark spraying using that herbicide was discontinued by the Commission. Trials commenced into the use of alternative herbicides for control of woody weeds by spraying after planting, and hexazinone showed considerable promise. Glyphosate was used on a trial basis with atrazine but more work was required before definitive recommendations were possible. During the 1980s, after more research, a combination of the herbicides amitrole and atrazine became the most commonly used pre-planting treatment for weeds in radiata pine plantation establishment for both first (1R) and second (2R) plantings.

In the mid 1990s, following Forestry Tasmania's decision to cease using the triazine herbicides atrazine and simazine, a research program to investigate alternative weed control measures for pine (and eucalypt) plantations was initiated with the appointment of Paul Dredge. The aim of this program was to establish which weed species were important and what were their effects on the crop trees, to evaluate reduced herbicide techniques (different herbicides, formulations and application methods) and alternative control strategies such as use of cover crops.

Grasses, dogwood, silver wattle, dolly bush and fireweed were identified as the most significant secondary weeds in most districts. Cover crops and slashing/cultivation showed some promise as alternative weed control methods, but a hot water treatment applied to weed species was not operationally viable. Inter-row cultivation with shallow discs was successful in controlling weeds, particularly in pines which are more tolerant than eucalypts of minor damage to their feeder roots. Flaming treatments and mulching were also tested as alternative methods, with only limited success. The results of this weed management research were incorporated into a Bulletin entitled *Weed Management in Forestry Tasmania Plantations* (Dredge 1997). The Bulletin provided information on alternative weed management methods, including herbicide use, site-preparation techniques, integrated weed management systems and weed-crop relationships.

Alternative weed control research was continued in the late 1990s by John Borger. His research was aimed at getting better weed control from less herbicide by using better timing, improved application methods and different herbicides. An important part of this work was the introduction of the seed-set control system. It required regular monitoring of the development of weeds and precise timing of control measures so major weed species were killed before seed-set occurred.

Currently, the most common weed-control regime in plantations is aerial or ground application of herbicides such as glyphosate and/or sulfonurea herbicides to the plantation area following site preparation and prior to planting (Hodgson 2003). Herbicide use is targeted to minimise the amount of herbicide required and to improve efficacy. Herbicides are applied as close as possible to planting to enable a good kill of potential weed crops. In eucalypt plantations, this is especially important as there are no suitable broad-spectrum products available for post-planting control of woody weeds.

Development of fertilising regimes: the Fingal Valley project

Fertiliser treatments of young plantations, designed to get good establishment and early growth, were first carried out in experimental plots in the Beaconsfield plantation in 1951–52. Within a year of treatment with superphosphate at the rate of three hundredweight per acre (380 kg/ha) young needles had better colour, new season's needles were twice as long

An early fertiliser trial (mainly phosphate application) in thinned and unthinned radiata pine plots at Warrentinna, north-eastern Tasmania, in the 1950s. (From left: Max Gilbert, Murray Cunningham, Emil Johnston and John Ruiter.)

and trees which carried fused needles produced normal needles and, in some cases, previously fused needles had separated. By the end of the third growing season, mean diameter increment on the treated plots was nearly twice that of the untreated plots. This research led to top-dressing of the sufficiently well-stocked parts of Beaconsfield plantation with ground rock-phosphate at two hundredweight per acre (255 kg/ha). Trials of application of trace elements to radiata pine stands growing on marginal soils were also conducted at this time.

The Commission's plantation research program entered a new phase with the commencement of the Fingal plantation project in the winter of 1962. This project was initiated following a desire by the Tasmanian Government to employ miners made redundant by the closure of coal mines. The project provided an opportunity for the Commission to expand its plantation base, as well as providing more local employment.

Problems of survival and growth of pines on some areas being planted were anticipated by the Commission, and fertiliser trials were established in the first year of planting. They continued in the Fingal plantations for some two decades and provided detailed information on the nutritional requirements of radiata pine which was successfully applied, not only at Fingal, but Statewide. The early nutrition research at Fingal was undertaken by Wilf Crane and Bill Neilsen, with Bill and Wally Pataczek conducting extensive fertiliser trials and associated nutrition research. Their work led to the adoption of at-planting and later age fertiliser regimes for a wide range of sites across the State.

In the early to mid 1960s, the timing and rates of application of fertilisers to be used at planting were determined and, by 1968, this research had led to the routine application of nitrogen and phosphorus to over 2000 acres (800 ha) of young radiata pine plantation annually. Survival of young plants was affected in some early trials but the research showed there was no adverse effect as long as fertiliser was not applied until about two months after planting.

Analysis of soils at Fingal showed that phosphorus was the only element in critically short supply. Following spot applications at planting, later age fertilising to boost P levels in the soil at large was needed to alleviate this deficiency. A trial was established at Tower Hill to determine response to fertilising and thinning. It incorporated a treatment comprising thinning to 50% of the original stocking and applying six hundredweight per acre (760 kg/ha) of 50% superphosphate and 50% rock phosphate. Tissue sampling was conducted at Fingal to get more information on deficiency symptoms such as fused needles and to check on the effectiveness of aerial fertilising. Large-scale aerial fertilising programs resulted from the trials. Aerial fertilising of radiata pine plantations also commenced at Scamander in 1975 to rectify phosphorus deficiencies.

With phosphate fertilising having been shown to give positive results, research then concentrated on nitrogen fertilising. In 1977–78, trials to determine the long-term effects of thinning and fertilising were established at Fingal. Fertiliser trials on cultivated sites at Long Hill showed that cultivation greatly increased survival and growth on these compacted clay soils and the effect was enhanced by application of N and P. There was no response to fertiliser on sites not cultivated. Potassium was later included in aerial fertilising of some areas at Long Hill to correct the deficiency of this element.

At about this time, foliar analyses also indicated deficiencies in copper and boron in radiata pine plantations growing on old, stabilised sand dunes in the Strahan plantation. Trials of pre-planting soil fumigation, combined with post-planting fertilising, were set up to assess the response to the application of these elements. The rooting habits of radiata pine on the Strahan sands were also investigated by Gordon

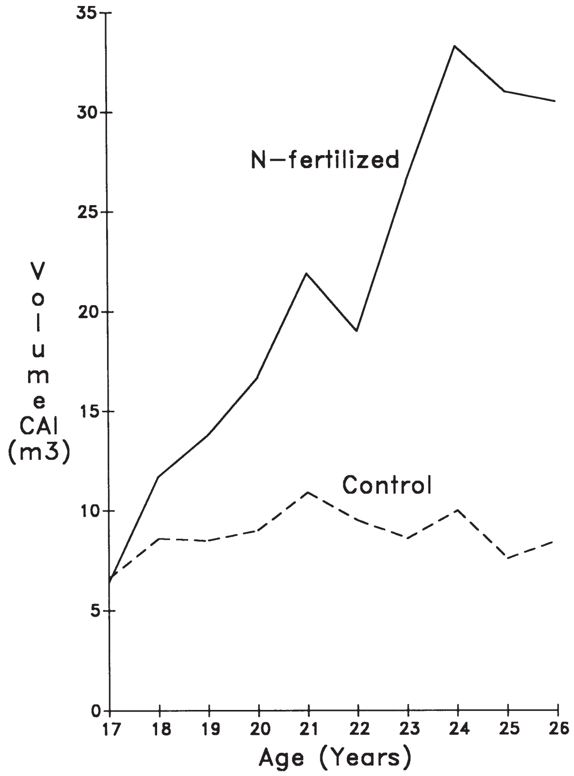
Davis to develop a better understanding of root growth on these soils. Later age fertilising trials were also set up in the mid 1970s in Strahan and Nicholas plantations to test the effectiveness of various types of fertiliser, including rock phosphate, urea, superphosphate and lime, singly and in various combinations. However, on the leached sands in parts of the Strahan plantation, the nutritional problems remained unsolved.

Grinding radiata pine needles for analysis, as part of trials testing responses to fertilisers in 1972. (Bill Neilsen pictured.)

By the early 1980s, studies on effects of later age fertilising based on continued monitoring of areas fertilised in the early 1970s in the Fingal plantations indicated that a prolonged response of about 10 m^3/ha/yr resulted from the current prescription. At this time, the Commission changed the fertiliser used operationally on radiata pine plantations to a premixed superphosphate plus ammonium sulphate (EZ Lightning 11:5:0), using an 8:4:10 formulation where potassium was limiting.

In 1996, Forestry Tasmania accepted a business case for an expanded program of later age nitrogen fertilising of radiata pine plantations based on further research results (Neilsen *et al*. 1992). This fertilising program began in selected compartments in some radiata pine plantations, using a regime where fertiliser was applied for three consecutive years, left for two years and then the cycle was repeated until the compartment was harvested.

The soil-pit team testing their work during studies of root development of radiata pine in the early 1980s! (From left: Leigh Edwards, Ron King, Tim Geard and Gordon Davis.)



Response to nitrogen fertiliser applied annually at the rate of 100 kg N from age 17 years on a poor site previously fertilised with phosphatic fertiliser at age 12 years. Current annual increment (CAI) response in excess of 20 m^3/ha was attained nine years after treatment. (From Neilsen 1990.)

Some very significant publications resulted from the nutrition research at Fingal and elsewhere in the State. In 1976–77, a Forestry Commission Bulletin entitled *The Nutrition of Radiata Pine in the Fingal Plantations* by Bill Neilsen and Wilf Crane was published (Neilsen and Crane 1977), and the research on response to fertilisers at Fingal was summarised in Neilsen *et al.* (1981).

Stand management regimes

The silvicultural management of radiata pine in Tasmania has undergone a series of developmental phases. In the early 1950s, various combinations of pruning (to produce clearwood) and thinning (to concentrate growth on selected stems) were investigated as ways of improving wood quality and volume of high-quality material. The desired small size of knotty core, to maximise clearwood production, was not being achieved, and pruned trees were losing their dominance because of competition from retained, unpruned trees. These unpruned trees could not be removed in production thinnings because the market for small wood was limited. Trials examined the percentage of crown removed, occlusion of pruned branches, retention of dominance and interaction with thinning. The effects of different intensities of thinning on volume growth in radiata pine stands were assessed by comparing basal area increments of the treatments. Research initiated by Alec Crane and John Quick provided valuable information on stand management and, from this work, regimes that maximised production while producing a pruned final crop were developed. These systems were further refined over the next 20 years (Crane 1962).

In the early 1960s, some serious windthrow occurred in radiata pine plantations, prompting research into the causes of windthrow and stem breakage in young plantations after establishment and after thinning. Plots were set up to study factors likely to have a bearing on the ability of radiata pine trees to withstand wind damage. The results of these studies were used to propose modifications to the stand management regimes, where the critical factor in avoiding wind damage was for thinning to begin before the mean dominant height of the stand reached 20 m.

In the early 1970s, a major study began on the effects of possible changes to pruning and thinning regimes. These changes were based on a proposal in New Zealand that involved pruning a selection of the best stems in up to three operations known as lifts, and early (at around age five years) non-commercial thinning to remove all unpruned stems soon after completion of the first pruning. The proposed regimes were designed to increase profitability of the radiata pine plantations by shortening the rotation

An 18-year-old thinned stand of radiata pine with high pruning on selected stems at Warrentinna, north-eastern Tasmania, 1953.

and increasing the returns from production thinnings. The regimes also overcame problems associated with a surplus of small-sized material caused by a lack of a pulpwood market at that time. In summary, these regimes offered more flexibility for managing the plantations, minimised damage from wind and pests and diseases, and simplified the overall management, being designed for particular end products. In the late 1970s, the new pre-commercial thinning, scantling and clearwood regimes were introduced after operational trials had been conducted. Pruning was practised only on the better sites and was combined with waste thinning in order to reduce rotation lengths. Stands on poorer sites were not pruned, and had one production thinning at a mean dominant height of 20 m (Neilsen and Davis 1985b; Neilsen 1990; Shepherd *et al.* 1990).

In the mid 1980s, regimes for thinning and pruning in radiata pine were again modified, with very heavy early thinning (to 250 stems/ha at age four) being adopted in all clearwood areas. This reduced cost and was considered unlikely to seriously reduce options for selection of final crop trees.

By the 1990s, the experience of District staff, silvicultural research, and financial analyses led the Commission to concentrate on three main stand-management regimes for radiata pine: clearwood, knot control and Scottsdale (Neilsen 1990). The clearwood regime was designed to produce large pruned logs from high-quality stands in a short time. The knot-control regime had one commercial thinning at a mean dominant height (MDH) of 20 m and was for poor- and medium-quality sites to produce unpruned logs with small knots acceptable for framing timber. If thinning is done when the MDH is greater than 20 m, then major wind damage is likely. The Scottsdale regime was used where thinning in the knot-control regime could not be

A high-pruned radiata pine plantation managed under the clearwood regime.

conducted by the time trees reached a MDH of 20 m, and wind damage was likely. The regime used high stand density to suppress knot development so the timber could still be used for scantling, with thinning being conducted in two stages to reduce the likelihood of wind damage.

Since the 1990s, perceived future improvement in the softwood pulp market and the development of wood products manufactured from low-quality logs, such as laminated veneer lumber (LVL), provided the option of stopping non-commercial thinning and preserving material for use in future commercial thinning.

In 1999, Rayonier Tasmania became manager of the Softwood Joint Venture pine plantations on behalf of the owners: Forestry Tasmania and GMO Renewable Resources LLC. Currently, clearwood and small knot sawlog regimes are mainly used in these plantations, with variations depending on site specific factors (P.R.C. Smith, pers. comm.).

Eucalypt Plantations

The first eucalypt seedlings for planting on State forests were tube stock raised in the Forestry Department's nurseries in the late 1930s. These plants were not for the establishment of intensively managed eucalypt plantations but for filling small, unstocked areas in some of the northern forests. The first of the eucalypt tube stock was planted across some 162 acres (65 ha) at Mawbanna and Castra in 1939–40 and, in the following year, a further 123 acres (49 ha) of experimental tube planting was conducted at Pegarah (King Island), Mawbanna, Castra and Warrentinna. Tube stock of *Eucalyptus obliqua* was used in the early 1940s to restock repeatedly burnt areas at Mawbanna but the Annual Report for 1941–42 noted: 'So far results have not been too successful'. In the same year, some 20 000 plants of *E. obliqua*, *E. amygdalina* and false acacia (*Robinia pseudoacacia*) were planted on King Island. Refilling unstocked areas with eucalypt tube stock (mainly *E. obliqua*, *E. globulus* and *E. regnans*) continued through the 1940s.

The first significant eucalypt plantation in Tasmania had been established by 1950 on King Island to provide supplies of firewood and fencing material; it covered an area of 106 acres (42 ha). The area of the plantation had been extended by the 1960s to 573 acres (229 ha), while all other eucalypt plantations were much smaller: Stoodley 39 acres (16 ha), Castra 29 acres (12 ha) and Crayfish 23 acres (9 ha). In 1968, the planting of eucalypts on King Island ceased because radiata pine was easier to grow and treated pine made good fence posts. At that time, the total State forest hardwood plantings were 934 acres (374 ha), with 843 acres (337 ha; 90%) being located on King Island.

In the early 1970s, the Commission began to explore the potential of eucalypt plantations to supplement sawlog and pulpwood supplies from native forests, rather than merely filling a specific local need as in the case of the King Island plantings. A series of species and provenance trials were established in order to study the performance of different genotypes on a range of sites (see later section). In addition to this tree-improvement research, there was a short period of increased eucalypt planting by the Commission. Between 1976 and 1981, approximately 700 ha of eucalypts, mainly *E. globulus*, *E. nitens* and *E. regnans*, were established, but some of the sites planted at that time were later shown to be incapable of producing a commercial crop. This prompted the development of silvicultural requirements for successful establishment and growth of future eucalypt plantations (Wilkinson and Neilsen 1985).

The Commission's eucalypt planting program and supporting research received a significant boost with the introduction of the Intensive Forest Management Program (IFMP). The key aim of the plantation component of the IFMP was to manage eucalypt plantations intensively for the production of high-quality logs for sawn timber and veneers, the first time this had been attempted on a commercial scale in Australia. This program lasted from 1990 to 1996, with funding provided from the Commonwealth Government as compensation for the loss of forest resource following the Helsham Inquiry and subsequent political decisions which transferred forest land out of production. Some 6101 ha and 793 ha of eucalypt and blackwood plantations respectively were established under the IFMP (Farmer and Smith 1997), and a large plantation research program was conducted, mainly in the areas of eucalypt and acacia plantation silviculture, pests and disease management, soil mapping and growth modelling.

The intensification of forest management to produce sawlog/veneer from eucalypt plantations was further advanced by the signing of the Tasmanian Regional Forest Agreement (RFA) by the Commonwealth and State Governments in 1997. Under the RFA, some 20 000 ha of hardwood plantations were to be planted over

Site preparation for plantation establishment during the Intensive Forest Management Program in north-western Tasmania, 1992.

A young plantation of *Eucalyptus nitens* and *E. globulus* being intensively managed for production of solid wood products.

the next five years and, to support this program, additional research staff were appointed.

The research programs and achievements in eucalypt plantation silviculture, particularly during the IFM and the RFA programs, are included in the sections below. Research into native forest silviculture, special species and pest and disease management was also conducted under these programs and is described in Chapters 2, 4 and 6 respectively.

Tree improvement

A large *E. obliqua* provenance trial was planted at Lisle by the Forest Research Institute (later CSIRO Division of Forest Research) in 1970. It was thinned and assessed in the late 1970s; a later assessment of this trial in 1989–90 by Forestry Commission staff when the trees were aged 19 years showed that provenance variation was highly significant for all traits. Much of the early work on eucalypt tree improvement was fostered by Keith Orme whilst working in the Commission on other projects. He was appointed to the position of Tree Improvement Officer in 1978–79. The first detailed Forestry Commission trials of species and provenances were planted in 1973–74 at Smithton, Stoodley, Branchs Creek, Fingal and Geeveston.

A joint program on evaluating provenances for eucalypt plantations began between the Forestry Commission and the Tasmanian paper companies, the provenances of *E. globulus* for this program being collected by Keith Orme and Leigh Edwards in November 1975. Early results from species trials at Smithton and Fingal indicated that *E. globulus* was the best performer but *E. ovata*, *E. delegatensis*, *E. viminalis* and *E. regnans* were also doing well. The variable results for different species on different sites in these early trials strengthened the need for a series of species trials over the range of soil types, altitude, rainfall and other site factors contemplated for plantations.

In 1976–77, twenty Tasmanian and twelve mainland provenances of *E. globulus* were

The assessment team at the *Eucalyptus obliqua* provenance trial at Lisle in 1989. (From left: Graham Wilkinson, Bill Neilsen, Dave Allen, Paul Tilyard, Lindsay Wilson, Joe Harries, Peter Kube, Tom Lynch, Leigh Edwards.)

collected, and four provenance trials of *E. globulus,* each of 5 ha, were planted the following year at Lone Star, Geeveston, Rubicon and Natone. This collection became known world-wide as the 'Orme collection' and was the basis for *E. globulus* domestication and breeding in a number of countries (Orme 1977; Volker and Orme 1988; Potts *et al.* 2004). Further trials of this species were planted in the late 1970s and early 1980s at Scamander and Maydena. Eucalypt species trials were established at Inglis, and the 'Barrens' trials were planted at North Retreat and Arnon River in 1978–79. Six provenance trials of *E. regnans* were established in the late 1970s by CSIRO, with Forestry Commission assistance, at Geeveston, Lone Star, Woolnorth, Natone, Maydena and Levendale. Provenances of *E. fastigata* were planted at Maydena and Scottsdale.

Two of the species which performed very well in the early species/provenance trials were *E. nitens* and *E. globulus*. Their performance contrasted with that of *E. regnans*, a species originally expected to do well, which often had poor form and was frequently severely damaged by defoliating insects.

Much of the early work on *E. nitens* introduction and evaluation was done by APPM (Dick de Boer, Geoff Dean, David de Little) and Keith Orme. Keith established a seedling seed orchard of *E. nitens* at Hastings in 1978. This has been a solid base for improved seed production until the present.

Provenance trials of *E. nitens* established in 1981 at Liffey and Esperance showed that the MacAllister and Toorongo provenances were the best performers at both sites. Assessment of these *E. nitens* provenances at age 10 confirmed that there were important differences in growth rates between and within provenances, indicating that identification of good performers at particular localities within provenances was essential rather than relying on a broad provenance specification alone.

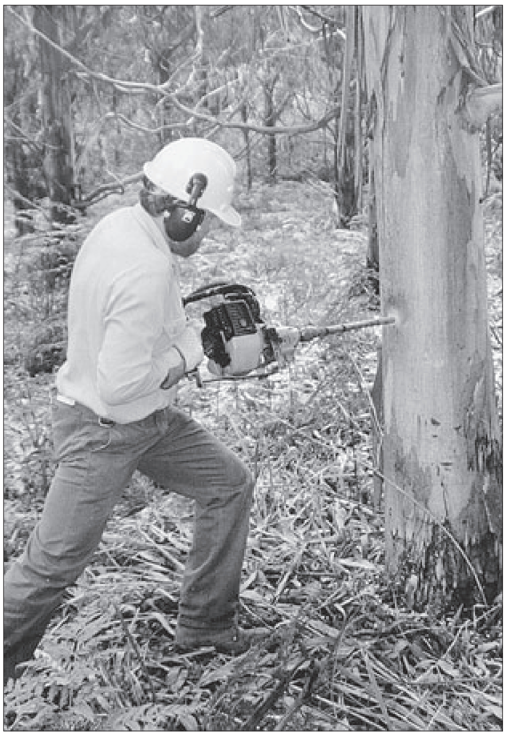
Keith Orme left the Commission in 1981 and was replaced by Peter Volker in 1982. In 1983, Peter and Leigh Edwards established a series of *E. nitens* family trials at Kamona, Gog and Beulah. These became the basis of a Ph.D. study by Peter Kube into genetic variation in wood-quality traits for the species (Kube 2005).

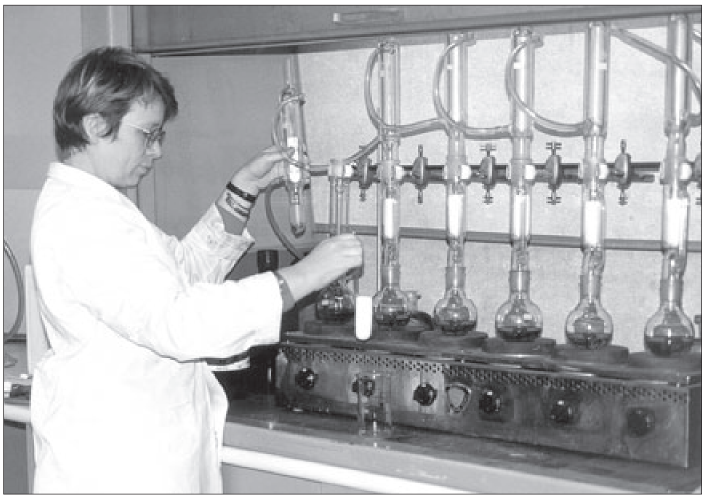
In the mid 1990s, Forestry Tasmania became strongly involved in the national co-operative tree-breeding program for *E. nitens* (being developed jointly by the Southern Tree Breeding Association (STBA) and the CRC for Temperate Hardwood Forestry). Peter Kube, the Tree Improvement Research Officer at the time, was responsible for Forestry Tasmania's contribution. A comprehensive set of family trials was established, led by Peter Volker, then at ANM Forest Management, and Peter Kube. These trials, containing about 300 families, were planted on five sites (Meunna, Southport—Forestry Commission sites; and Tarraleah, Florentine and Hollow Tree—ANM Forest Management sites). The STBA was able to bring together data from a wide range of provenance and family trials throughout Australia. The first stage of the work was the analysis of growth rates of existing genetic selection trials (progeny trials) planted in several States. New analytical techniques which maximised the use of the genetic information were used to select the better genotypes. The analysis showed that early selections of the best performing genotypes, which had been made at age 3–5 years, were similar to those at age 15 years. Genes for growth were expressed across a wide range of sites; growth was under moderate genetic control, and good gains in performance could be made through breeding programs. Information on wood density was also collected as another important trait in the selection procedure. As part of his post-graduate studies, Peter Kube carried out extensive wood-quality testing of *E. nitens* sourced from select trees in various provenance trials.

Seed-production plans were developed at this time for both *E. nitens* and *E. globulus*. Seed supplies for Forestry Tasmania's plantations in the short term were provided by converting breeding trials into seed orchards. Longer term supplies were to come from a new generation of seed orchards, with material for these orchards coming from the second generation of tree improvement. Gains from the new orchards were estimated to be 14% for growth and 2% for wood density. A seed orchard with seedlings from selected trees of *E. globulus* and *E. nitens* was established in 1999–2000, led by Neil McCormick and Peter Kube, at Oigles Road in the south. This orchard is being managed intensively to maximise seed production and genetic quality.

In the late 1990s, a cost effective and non-destructive sampling method was developed during research on the genetic control of wood traits; the cellulose content of a 12 mm diameter core was found to correlate well with the pulp yield obtained by destructively sampling the whole tree. The breeding value (a measure of the extent to which a tree has a superior genotype favouring a trait) of various wood properties of *E. nitens* was determined for use in Forestry Tasmania's program by Peter Kube through joint studies with the Co-operative Research Centre for Sustainable Production Forestry. The key outcome of this study was that wood properties would not be worse under current selection strategies for *E. nitens*—the strategy being used (selecting for growth, form and wood density) appearing safe for expected products and markets. However, there were issues with branching, decay and extractives that, in some situations, might require a modification of selection strategies. Branch size, and therefore knot size, would become larger under selection strategies used at that time. However, the change through breeding was small in comparison to what could be realised through improved silvicultural management.

In 2001, the FT40 project was launched by Forestry Tasmania. It set a target of increasing by 40% the production of kraft pulp per hectare in *E. globulus* plantations established from 2007 onwards. This was to be achieved by developing control-pollinated seed orchards for producing





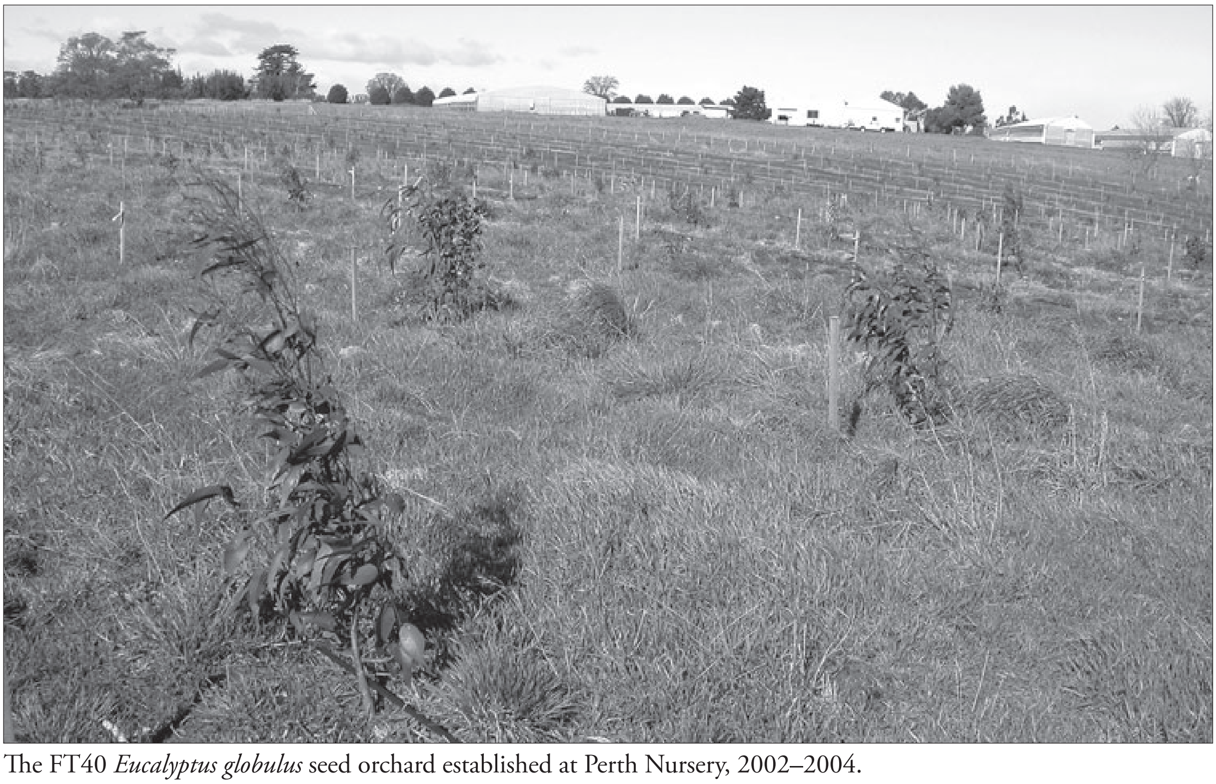
Above: Measuring the extractives content of wood samples – part of a study examining the genetic variation of wood decay in *Eucalyptus nitens*, 2000. (Jacinta Lesek pictured.)

Left: Using a motorised corer to take wood samples of *E. nitens* at Meunna, north-western Tasmania. (Lindsay Wilson, operator.)

high-quality genetic material of *E. globulus*. The project commenced with procurement of grafting material and completing nearly 2000 grafts. The FT40 *E. globulus* seed orchard was established at Perth between 2002 and 2004.

By 2003, all of the seed provided for the year's eucalypt planting was from elite genetic material with an average genetic gain of 30% over unimproved seed. Planting of the *E. globulus* and *E. nitens* seed orchards at Oigles Road in

Tops from 14-year-old *Eucalyptus nitens* trees grafted onto six-month-old rootstocks to produce stock for clonal seed orchards. The selected stock combines attributes of good growth rate and high wood density.



The FT40 *Eucalyptus globulus* seed orchard established at Perth Nursery, 2002–2004.

A planting of *Eucalyptus brookerana* in the Oigles Road seed orchard in southern Tasmania. Several of Tasmania's rare eucalypt species are planted in this orchard in addition to the commercial species *E. nitens* and *E. globulus.*

Culled and topped *Eucalyptus nitens* in the seed orchard at Hastings in southern Tasmania, planted in 1981.

the south and Ben Nevis in the north-east was completed.

In 2006, Forestry Tasmania assumed control of all ANM (now Norske Skög) eucalypt plantations on State forest, including the Tarraleah and Florentine trials. Dean Williams is currently using these trials to expand Forestry Tasmania's *E. nitens* breeding program for pulp and solid wood quality traits.

Plantation establishment

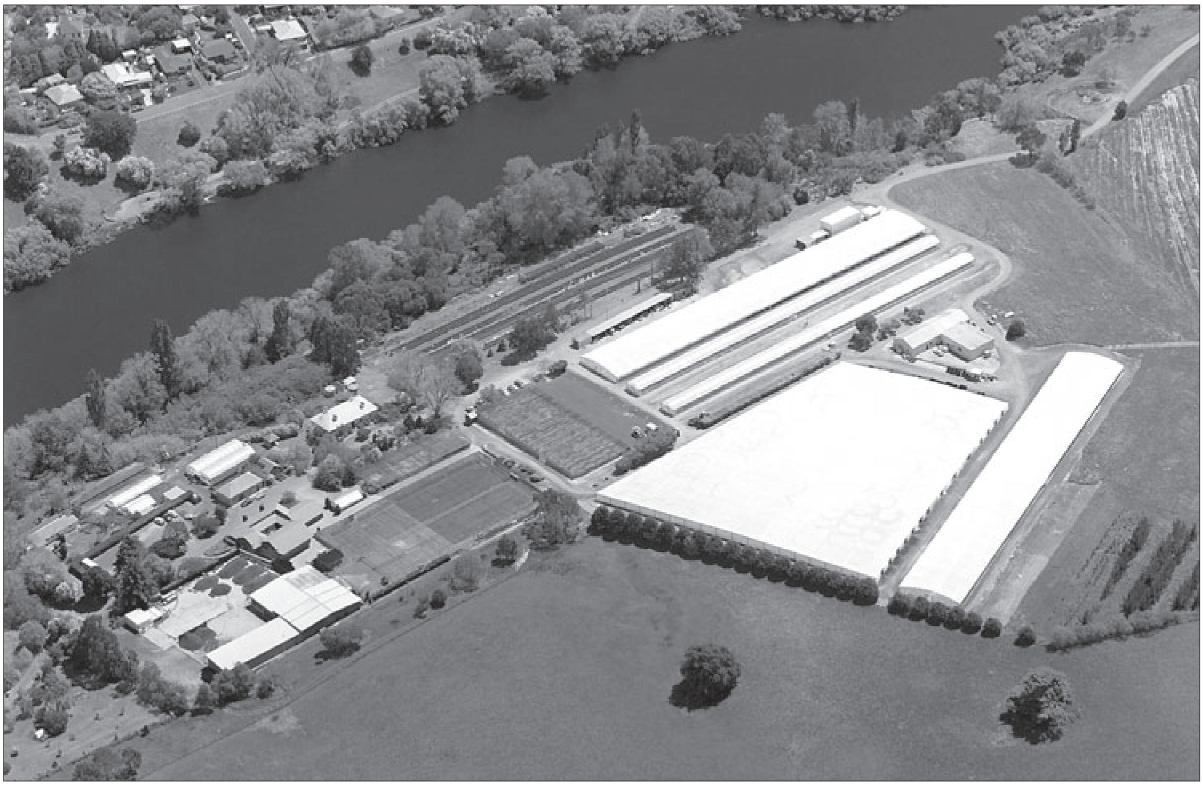
In addition to the work on the performance of different species and provenances of eucalypts, trials began in the mid 1970s on silvicultural requirements for successful establishment of eucalypt plantations. Some of these requirements, particularly the need for planting on good sites, appropriate site preparation and weed control, and fertilising at planting, have been covered in the section on radiata pine. The sections below deal with some specific aspects of research into establishing eucalypt plantations.

Stock types

The early plantations of eucalypts on King Island and elsewhere used tubed stock. In the late 1960s, trials were established to examine a technique developed in Victoria, in which jiffy pots were filled with sand and nutrients supplied using 'Aquasol'. After reaching the required size, seedlings were hardened off by stopping the 'Aquasol' treatment. In the 1970s, open-rooted eucalypt stock was grown at Perth Nursery using root-wrenching, undercutting and lateral pruning methods. The best method for producing open-rooted eucalypt stock was found to be the half-half technique. It entailed germinating eucalypt seed in containers and then transplanting the germinants into the open beds. The container stage was needed because it is difficult to get adequate germination of eucalypt seed by sowing directly into the beds. Trials of open-rooted and container stock were established in the mid 1970s by Keith Orme at several plantation sites. An important finding from these trials was that open-rooted stock was less affected by browsing animals, with a survival rate of 89% compared with 49% for potted stock.

Further trials of container and open-rooted seedlings were carried out by Peter Kube across a wide range of sites in the early 1990s. These were aimed at determining the effects of stock type on growth and survival, and defining the morphological characteristics of seedlings which give the best performance in field situations. Open-rooted seedlings were superior to container stock on some sites but not others. This variability was caused by differences in the retention of foliage on open-rooted seedlings after planting, with foliage loss resulting mainly from insufficient hardening in the nursery or dry conditions at the planting site. Container-

Eucalyptus nitens seedlings being raised in open beds at Perth Nursery in the early 1990s.


An aerial photo of Perth Nursery taken in the early 2000s. The white areas are the modern shadehouses used for growing large numbers of containerised eucalypt seedlings.


One of the modern shadehouses built at Perth Nursery in the 1990s for growing eucalypt seedlings in containers. (Peter Moore pictured.)

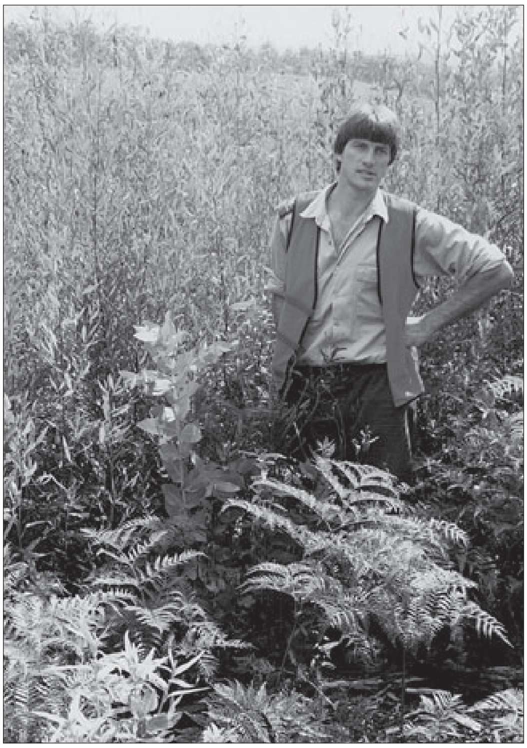
grown seedlings generally performed well but open-rooted stock which retained their foliage had better early growth. The main advantage of open-rooted stock was their ability to tolerate animal browsing, confirming the earlier findings from the 1970s (Forestry Commission 1993).

Through the 1970s and 1980s, most eucalypt seedlings were grown at Perth Nursery, with some also being raised at small nurseries at Dover and Taranna. The small southern nurseries had closed by the late 1980s, and all eucalypt stock was then grown at Perth until the mid 1990s, when some eucalypt stock was supplied under contract by private nurseries. Containerised seedlings are now the stock type used for eucalypt plantations.

Multi-factor establishment trials

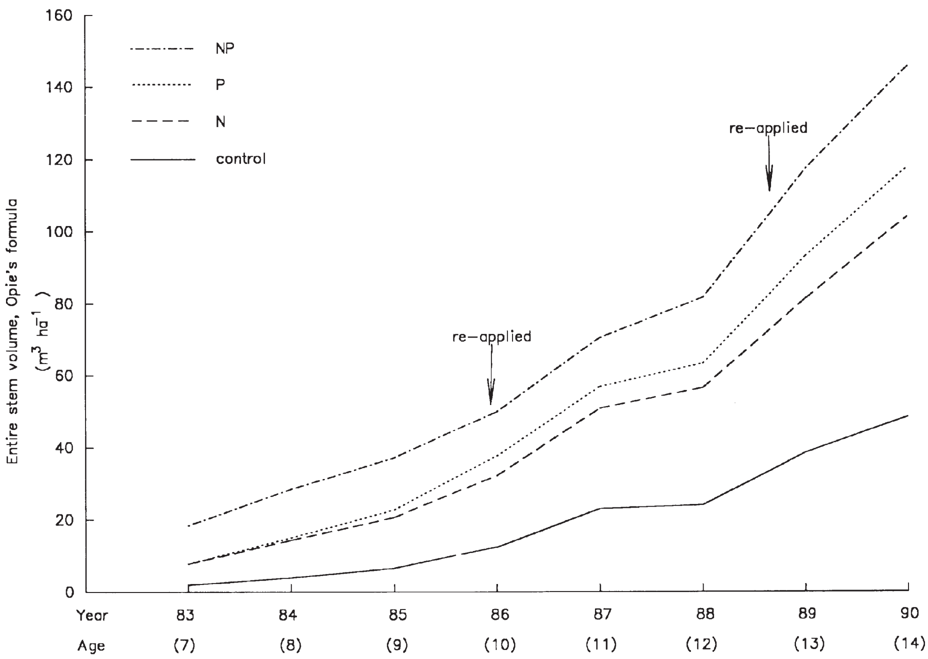
In the mid 1980s, a general inspection of eucalypt plantations showed that there were frequent problems with growth rates and survival, browsing, intense weed competition and insect defoliation. Consequently, major eucalypt plantation trials were established by Bill Neilsen, Graham Wilkinson, Leigh Edwards, Wally Pataczek and Dick Bashford at Goulds Country and Maggs Mountain to test species, cultivation, herbicides, stock types, fertilising, and the effects of browsing and insect damage. Trials investigating secondary fertilising were also set up at Esperance and Retreat.

These trials, particularly the Goulds Country trial, were very important in establishing the basics of eucalypt plantation establishment, and the results guided the continuing improvement in establishment practices over many years. Assessments of the Goulds Country trial demonstrated the importance of effective weed control, cultivation, species selection and appropriate stock types in achieving optimal growth (Neilsen and Wilkinson 1990; Wilkinson and Neilsen 1990, 1995; Neilsen and Ringrose 2001). The *E. nitens* plots with the best establishment practices had volumes of 60 m^3/ha at age four years, whereas plots established with suboptimal techniques had volumes half that figure. This trial also showed that *E. regnans* performed poorly as a plantation species, with the highest volume at age four being only 17.9 m^3/ha (Forestry Commission 1992d). The problems of poor species selection, browsing animal damage and poor weed control were highlighted in a review of the performance of plantations in north-eastern Tasmania (Neilsen and Wilkinson 1995).



Severe weed competition from varnished wattle, *Acacia verniciflua,* in a young eucalypt plantation. (Bob Knox pictured.)

The results of herbicide treatments in the *E. regnans* and *E. nitens* plantation establishment trials at Goulds Country were evaluated 12 years after planting by Bill Neilsen and Carolyn Ringrose. In summary, good site preparation at planting gave adequate weed control to establish seedlings and allowed full growth without the use of herbicides, given suitable planting stock. Despite the potential of *E. nitens* to control the



The response of *Eucalyptus globulus* to secondary fertilising with nitrogen and phosphorus at Tower Hill, north-eastern Tasmania. This was one of the earliest trials of secondary fertilising and although stem volume in the best treatment was three times that of the untreated plantings, costs were high. Later work developed more cost-effective fertiliser prescriptions targeted to specific sites and stand conditions. (From Forestry Commission 1991d.)

Preparing soil samples for analysis as part of studies of nitrogen availability and other aspects of fertiliser application, 1999. (Carolyn Ringrose pictured.)

site, it was concluded that herbicides extended the range of acceptable growth to less favourable planting stock and also allowed late planting. Trees that did not establish dominance over weeds were restricted and grew at a reduced rate (Neilsen and Ringrose 2001).

Later age fertilising

Eucalypt plantations were established on similar soil types to those planted to radiata pine and, as later age fertilising had boosted the growth of pine, a good growth response was also expected for the eucalypts. Results from later age eucalypt fertiliser trials established by Wally Pataczek at Esperance showed that annual applications of nitrogen and phosphorus produced highest growth, but efficiency of fertiliser use was improved with two- or four-yearly applications. This research highlighted possible problems of

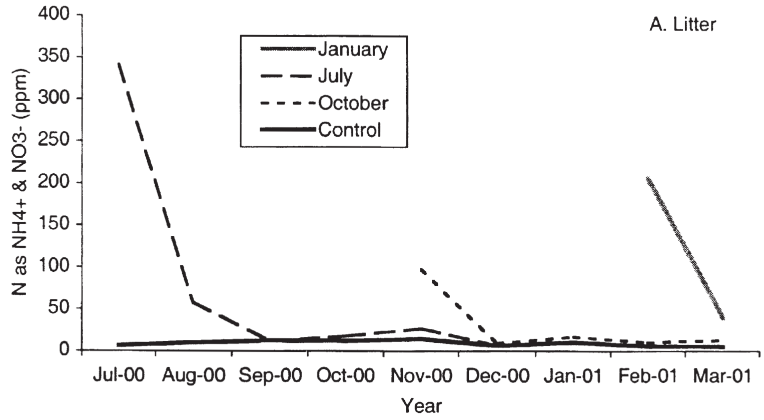
Above: Applying urea to two-year-old *Eucalyptus globulus* in an experiment at Christmas Hills to test whether fertilisers assist plant recovery after leaf blight infection, 2003. (Paul Adams pictured.)

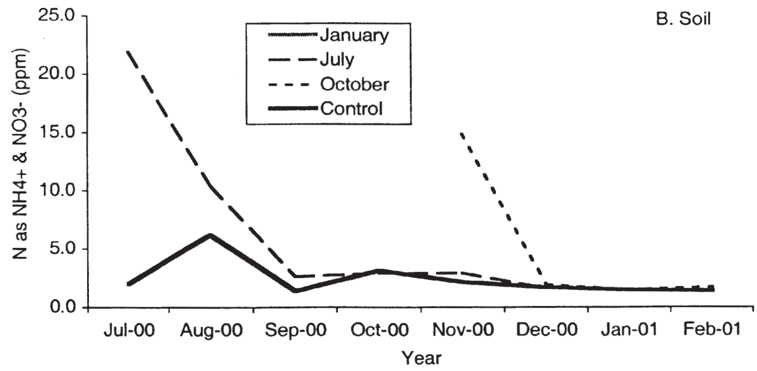
Left: Measuring leaf photosynthetic activity of young *E. globulus* in a fertiliser trial in Esperance plantation, 2000. These measurements allow the growth activity of the tree to be determined. (Paul Adams, left, and Sven Meyer.)

soil acidification if inappropriate fertilisers were used (Ringrose and Neilsen 2005).

In 2001, a later age fertiliser prescription was developed for eucalypt plantations by Paul Adams, after collating information from a range of fertiliser trials. This research result was transferred into operational practice in 2001 using helicopter application in Huon District to successfully treat 360 ha with nitrogen and phosphorus. Aerial fertilising was quickly scaled up to a large program conducted across eucalypt plantations in all Districts and, by 2004, an annual program of some 4000 ha was in place. Fertiliser inputs were progressively matched to particular soil types, species and conditions, and a decision support tool (EucFERT) was developed to assist operations staff to make decisions on fertiliser and nutrition management (Forestry Tasmania 2004b).

In order to provide a more scientific basis for fertilising in eucalypt plantations, nitrogen mineralisation studies were conducted by Carolyn Ringrose. These studies identified the amount of mineral nitrogen (ammonia and nitrate) present, which represented the nitrogen readily available within the soil for uptake by the tree. Time sequence studies of fertiliser applications clearly showed the rapid decline





The levels of available nitrogen over time in soil litter (A) and soil (B) at Esperance, southern Tasmania, after fertiliser application (note different y-axis scales). These experiments showed the importance of litter on nitrogen availability and sustainable management practices for site fertility and productivity. (From Forestry Tasmania 2001a.)

in levels of available nitrogen over time. The studies indicated the importance of litter on nitrogen availability and sustainable management practices for site fertility and productivity. The information is assisting the continual refinement of prescriptions for application of fertilisers (Forestry Tasmania 2001a).

Silvicultural regimes for sawlog/veneer production

By 1992–93, under the IFMP, several large silvicultural regime trials had been established in eucalypt plantations to evaluate the effects of thinning and pruning on young stands of *E. regnans* and *E. nitens*. Thinning treatments covered densities of final stockings of 100, 200, 300 and 400 retained stems per hectare plus an unthinned control. Low- and high-pruning treatments were also imposed to limit the extent of knotty-core development, thus increasing the proportion of clearwood for the production of sawlogs and veneer logs. The trials showed that *E. nitens* was the more promising species for eucalypt sawlog production in plantations. It was concluded that it should be possible to grow sawlog-sized trees of this species in 30–40 years (Gerrand *et al.* 1997). Spacing trials for eucalypt species were also established at Upper Castra, with spacings ranging from 500 to 2000 stems/ha. The trials resulted in a recommendation that initial stockings for plantations be 1000–1100 stems/ha.

High pruning six-year-old *Eucalyptus nitens* plantings in trials of intensive management at Goulds Country, 1992. (Adam Gerrand pictured.)

The provisional management regime proposed from the IFMP studies was to plant *E. nitens* at 1000 stems/ha and select 250 final crop trees for pruning to either 2.7 m or 6.4 m depending on assessment of the risk of decay from pruning wounds. The incidence of decay in pruned stems was a major concern when developing the silvicultural regimes for these eucalypt plantations. This disease risk is discussed in more detail in Chapter 6. Where the risk of decay was considered high, the low-pruning regime should be used and this would also reduce cost. However, if the high-pruning regime was chosen it would double the volume of clearwood produced. A light non-commercial release thinning was recommended for high-pruned stands, and a commercial thinning for pulpwood at age 10–12 was recommended for both regimes. A 30–40-year rotation would allow the final crop trees to reach sawlog size of 50–60 cm diameter at breast height on good quality sites (Gerrand *et al.* 1997).

Measuring tree diameters during pruning studies in a seven-year-old *Eucalyptus nitens* plantation at Castra. (Libby Pinkard pictured.)

In winter 1995, pruning of the IFMP plantation estate began and Forestry Tasmania issued *Guidelines for Thinning and Pruning in* Eucalyptus nitens *Plantations for Sawlog Production*. The guidelines were based strongly on the results of the eucalypt plantation silviculture research carried out under the IFMP and, with subsequent modifications, have guided the operational program to establish a greatly expanded plantation estate. The basis of the guidelines was that, because *E. nitens* has persistent branches, stems must be pruned to 6.4 m if knot-free clearwood is to be produced in large quantities. The risk of decay entry must be minimised by appropriate timing and method of pruning. Pruning regimes outlining the operations required at each age and the criteria for selecting trees to be pruned were produced.

Research continued through the mid to late 1990s on the regimes for growing eucalypt sawlogs in plantations, particularly aspects of pruning and thinning treatments. An operational release thinning trial for eucalypt stems which had received two and three pruning lifts and were not the dominant trees in the stand, was conducted in a six-year-old plantation of *E. nitens*. In 1997–98, Libby Pinkard reviewed the pruning prescriptions for eucalypts as management objectives had changed, with a reduction in rotation length to 20 years. The revised prescription stated that the majority of sites suitable for pruning would now only be first-lift pruned, with high pruning restricted to sites with a mean annual increment greater than 25 m^3/ha/yr. Form pruning in which a small number of branches were removed to improve form and help control branch size was also introduced (Forestry Tasmania 1998d).

Later trials of form pruning in *E. nitens* stands showed that, in most cases, it would not reduce the number of trees with an unacceptable number of large branches at the time of first lift and that the problem of large branches was best overcome by careful timing of pruning. Consequently, it was no longer recommended that form pruning be used routinely in *E. nitens* plantations (Forestry Tasmania 2000c). Later pruning studies by Libby Pinkard in *E. globulus* stands showed that trees can withstand removal of 50% of the crown without any long-term reductions in growth. This level of pruning removes 80% of the leaf area but trees could increase the area in the mid and lower residual crown (Forestry Tasmania 2001c).

A collaborative program between Forestry Tasmania and the CRC for Sustainable Production Forestry resulted in a model which assists identification of sites for pruning. The model is based on site productivity, predicted leaf area index (LAI) and target piece size, scheduling pruning operations based on height to the base of the green crown and LAI, and scheduling thinning to minimise height-related windthrow risk following thinning.

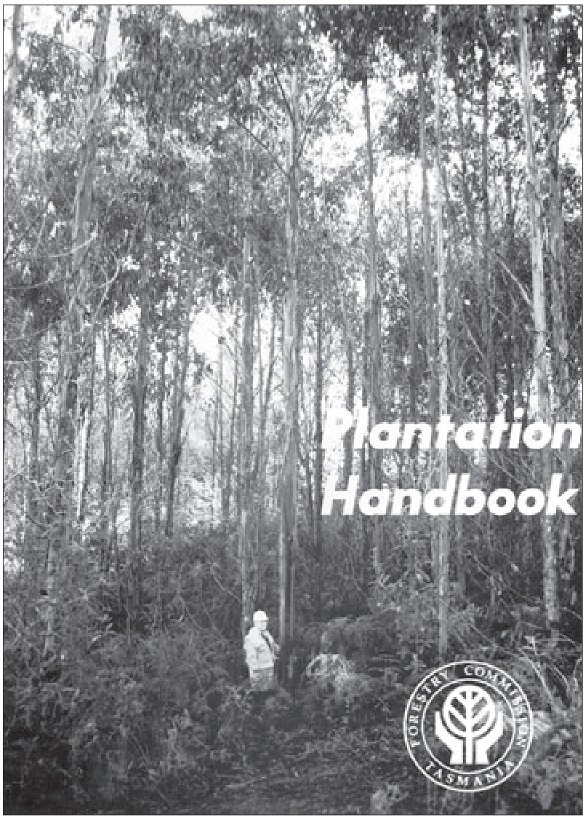
Matt Wood has continued to develop prescriptions for thinning of eucalypt plantations to maximise growth of the final crop trees and to produce interim harvests, where possible, for pulp, veneer and small log products. The development of WINDRISK (Wood *et al.* 2005), a decision support tool to evaluate the appropriate time for thinning, has led to operational improvements in the scheduling of thinning operations.

A system of topographic exposure mapping has also been developed using the GIS to identify areas of State forest (native forest and plantations) that are at risk of wind damage, especially following harvesting operations. This exposure mapping has been applied to plantation and native forest thinning operations as well as aiding in design of retained patches in the new variable retention silviculture in native forests.

Currently (2006), the policy for Forestry Tasmania's eucalypt plantations is to high-lift prune (to 6.4 m) all of the estate which meets the growth and form criteria, in order to maximise the production of clearwood for sawn timber and veneer (P.R.C. Smith, pers. comm.).

Plantation handbook

The publication of the *Plantation Handbook* (Neilsen 1990) was the culmination of all the development work over the previous four decades on all aspects of plantation establishment and management techniques for radiata pine, Douglas fir and eucalypts. This very significant publication became the 'bible' on the subject for plantation managers in Tasmania and was also an important reference for foresters in other States.



The *Plantation Handbook* is a comprehensive guide to establishing and managing plantations. It was published by the Forestry Commission in 1990.

Acacia Plantations

Black wattle

Attempts were made to establish plantations of black wattle in the mid 1920s at Triabunna and Sister's Hills. In 1944, six half-acre (0.2 ha) trial plots were sown with black wattle on the Freycinet Peninsula to test the suitability of the area for future establishment of wattle plantations. Wattle bark for tanning was used in a small industry on the east coast for many years, a clear reminder being the Swansea Bark Mill (now a tourist attraction), and wattle plantations may have provided a productive resource. The fate of these small plantations and trial plots is not known (they were probably burnt by wildfires) but no large-scale wattle plantations eventuated.

Silver wattle

Silver wattle and black wattle were included in several species trials established on low-quality sites in north-eastern Tasmania in the 1970s and 1980s as part of early investigations into hardwood plantation forestry. Growth rates for both species in these trials were low (Orme *et al.*1992). Silver wattle was also planted in the early 1980s in a species trial at Calder and in two small blocks at Chester Creek and Welcome Swamp in north-western Tasmania. Growth rates were very low at Calder, but survival and growth were good at the latter two sites, particularly Chester Creek (Kube and Brooks 1996).

The silviculture of silver wattle was investigated as part of the Intensive Forest Management Program (IFMP) in the early 1990s. Silver wattle had been harvested for many years in the Florentine Valley and other areas as a by-product in native forest harvesting. It was a useful source of pulpwood, having a high pulp yield, and there was also a small craftwood market for wattle timber. Some silver wattle timber was reputed to be stained with dye and sold as blackwood!

The timber and pulping characteristics of silver wattle warranted its inclusion in the evaluation of alternative species conducted under the IFMP. The main objectives of the research were to evaluate provenance variation and develop silvicultural methods for the production of silver wattle plantations. Twenty-eight provenances, including some from Victoria and New South Wales, were collected and planted at five sites by the Forestry Commission and ANM Forest Management. Survival was very low at three of these sites, but useful information on provenance variation, early growth and form was obtained from the trials at Westfield in the south and Meunna in the north-west.

Trees with multiple leaders were common in trials in the 1990s to test the potential of silver wattle, *Acacia dealbata*, as a plantation species.

Overall, the limited research on silver wattle showed that it has reasonable growth potential but growth rates and form are highly variable, and form pruning would be required in plantations (Kube *et al.* 1997). Silver wattle is also often severely defoliated by the fireblight beetle, *Acacicola orphana*, and this has been a major factor in tempering research efforts into developing wattle plantations. This pest is discussed in Chapter 6.

Blackwood

Blackwood was included in several species trials in the 1970s and 1980s (Orme *et al.* 1992) and planted in small woodlots on private land from the late 1970s, with assistance from the Private Forestry Division of the Forestry Commission. Early research into growing blackwood in plantations (as opposed to natural forest) was guided by observations of how blackwood grows in natural forests. Information from other areas was also examined, particularly from New Zealand, where there were numerous small private plantings, both pure and in combination with other species. In natural forests, blackwood grows in competition with nurse species, which restrict branch development, resulting in a trunk of forest form. This is particularly evident in the swamp forests of the north-west where blackwood is often accompanied by dense stockings of tea tree (discussed in Chapter 4). Thus, two of the key aims for research were to determine the appropriate spacing for the blackwood and nurse-crop species, and the right amount of sidelight suppression to be provided by the nurse species. Sidelight suppression, to obtain good growth and form of blackwood in a plantation

A blackwood plantation established during the Intensive Forest Management Program in the mid 1990s, showing the layout of blackwood and the pine nurse crop. A shrouded spray system has been used to achieve good weed control between the pine/blackwood rows, and the wider rows between the pines have been slashed.

situation, could be varied both by spacing and by the nature of the nurse-crop species.

Two small plantations of blackwood (both approximately 0.5 ha in area) established on private land in 1982 were particularly useful in early blackwood research. One at Abbotsham near Ulverstone had a radiata pine nurse crop at an initial stocking of 2100 stems/ha and 800 stems/ha of blackwood; the blackwood was planted alternately with the pine in every second row, with other rows being pure radiata pine. In the other, at Nabageena near Smithton, the blackwood was planted with a nurse crop of *E. nitens*, with stockings of 1600 and 800 stems/ha of shining gum and blackwood respectively, and the same layout as Abbotsham. Blackwood was also included in the Forestry Commission's plantation trials at Goulds Country discussed above, in pure plantings and in separate plots with *E. nitens* and radiata pine as nurse crops.

Blackwood plantation research was included in the Tasmanian component of the National Rainforest Conservation Program which commenced in 1988 (see Chapter 7). The aims of the blackwood research under this program were to report on plantation trials of blackwood in Tasmania, establish further trials where needed and assess the feasibility of commercial blackwood plantations (Jarman and Hickey 1996). David Allen was the Research Officer for this work, which included provenance trials and plantation silviculture trials. Four blackwood

A section of the extensive plantation silviculture trials at Meunna, north-western Tasmania, showing blackwood/eucalypt plantings. (Dion McKenzie, left, and Bill Neilsen.)

provenance trials involving over 50 provenances, including several from mainland locations, were established in the north and north-west. There were significant differences in early height growth and survival between provenances. Plantation silviculture trials were established at Meunna and Peegra Road in the north-west to test the performance of blackwood planted with a range of nurse crops (radiata pine, *E. nitens* or *E. globulus*). Radiata pine appeared to be the best nurse crop as it was less likely to overtop the blackwood, and the form of the blackwood was better. In addition, the radiata pine nurse crop could be managed for sawlog production, thus improving the economics compared with eucalypt nurse crops which, because of their rapid early growth, need to be managed for pulpwood production (Allen 1992).

These trials enabled the formulation of interim prescriptions for blackwood plantations to be incorporated into the Plantation Handbook (Neilsen 1990). Two very important factors which emerged during this research were the selection of sites which were not frost prone and the need for very effective control of browsing animals (Allen 1992). The preferred silvicultural prescription at the time was to plant radiata pine and blackwood at 800 and 400 stems/ha respectively, row for row with an inter-row spacing of 3.5 m and intra-row spacings of 2 m for radiata pine and 4 m for blackwood. The radiata pine would be grown on a clearwood regime at 200 stems/ha final stocking, with three pruning lifts imposed at mean dominant heights of 7, 9 and 12 m and clearfelling at 60 cm diameter. The blackwood would be clearfelled between 35 and 40 years.

Blackwood plantation research was also an important component of the IFMP. Under this program, blackwood plantations totalling 793 ha were established (Farmer and Smith 1997), with most of this area located at Beulah in north-western Tasmania. These were the first commercial-scale blackwood plantations in Australia and were mostly established using a radiata pine nurse crop with initial stockings of 800 and 500 stems/ha for radiata pine and blackwood respectively. The silvicultural regime for these plantations was based on the previous research conducted in the early 1990s, with some modifications. The regime entailed planting the pines at 5 m row spacing, with blackwood rows planted after each second row of pine. The pruning regime for the blackwood involved a form pruning and then three pruning lifts to bring the pruned bole height to 6.4 m by the time the trees had a mean dominant height of 11 m. The first form pruning of the blackwood and the first and second lifts were designed to correspond with the first, second and third pruning respectively of the radiata pine (Farmer and Smith 1997).

Much of the IFMP research was directed at refining the silvicultural regimes, particularly pruning regimes, for blackwood grown with radiata pine and *E. nitens* or *E. globulus* nurse crops. Financial analyses were also conducted for these regimes and the general conclusion was that the economics of blackwood plantations were satisfactory, provided at least the same stumpage rates as those for radiata pine could be obtained. However, the economics of radiata pine alone were superior, so a premium price for the blackwood needed to be sought if the blackwood/radiata pine plantings were to achieve the same return as a pure radiata pine plantation (Neilsen and Brown 1997).

Included in the total area of blackwood plantations established under the IFMP were 85 ha of research trials, planted at Meunna, Goulds Country and other sites, to study seedling protection methods, provenance variation and to refine the silvicultural regimes (Neilsen and Brown 1997). Several different seedling protectors were tested and some types of grow tubes (a plastic tube surrounding the seedling) gave good protection of seedlings from browsing animals. Fencing was found to be essential for large commercial plantations. Provenance variation was significant, particularly for frost sensitivity; data on early height growth and survival were obtained for provenances planted at a range of sites. Recommendations for suitable provenances for future plantings were developed. Several seed treatment methods designed to achieve high germination percentages in the nursery were tested, with clipping seed (removal of part of the seed coat) giving the highest percentage germination. But for bulk seedlots, the recommended treatment from the research was scarification of the seed in 100 g lots and then immersion of the scarified seed in a hot water bath immediately prior to sowing.

Blackwood plantation research continued through the late 1990s and early 2000s, particularly on the further refinement of the pruning and thinning regimes for the nurse crop and the blackwood, and appropriate fertiliser regimes and response to nitrogen, phosphorus and magnesium (Pinkard 2003). By 2001, detailed prescriptions for blackwood plantation management were prepared following the results of form pruning and thinning studies conducted by Libby Pinkard with strong support from the Co-operative Research Centre for Sustainable Production Forestry (Forestry Tasmania 2001d). These prescriptions included recommendations on form pruning and the level and timing of removal of the nurse crop.

Although the research on growing blackwood in plantations resulted in sophisticated and viable regimes, they are expensive to apply and the form of the plantation-grown blackwood is generally poorer than that of trees grown in intensively managed native forest. Consequently, in the early 2000s, Forestry Tasmania directed a higher proportion of expenditure on blackwood operations and research towards silvicultural treatments for blackwood in native forests (see Chapter 4).

A seedling seed orchard containing blackwood families from throughout the range in Tasmania was established near Geeveston in 2001. Gordon Bradbury has commenced work on

Eight-month-old blackwood seedlings in polytubes to protect them from browsing animals in a blackwood trial at Gog, north-westernTasmania, 1993. (Martin Piesse pictured.)

genetic variation in wood quality and growth of blackwood using a number of the trials described above. His work will contribute to further management of the blackwood orchard.

Summary: Four Phases of Plantation Development

The development of plantations on State forest in Tasmania can be grouped into four phases, each relying heavily on the research results and operational experience described in this chapter to achieve the objectives.

The first plantations established by the Forestry Department in the 1920s constituted an *exploratory phase*. It was initiated by Llewellyn Irby and had the clear aim of diversifying timber production in the State by growing softwoods to replace imported timbers. A wide range of species was tested across several sites, including the so-called 'waste lands' in the west and north-west, many of which turned out to be unsuitable. The review of these trials, after a decade of experimentation, enabled the selection of species and sites which could produce softwood timber on a commercial scale.

Five-year-old blackwood in the Goulds Country plantation trials, 1991. (Wally Pataczek pictured.)

The *softwood industry phase* saw the establishment of highly productive conifer plantations mainly in the north-east and north-west and the expansion of good plantation land by purchase of ex-farmland at low cost in the 1930s. This phase demonstrated the greatly increased productivity per area of land that could be achieved in well-managed plantations, and was the beginning of a new industry.

In the 1960s, plantation development entered an *opportunistic phase* through requests from the Tasmanian Government to consider plantations in areas where major unemployment had resulted from industry closures. The Fingal and Strahan plantations were established in this phase. Many of these plantings were on difficult sites, and research, particularly into site selection and fertilising regimes, expanded to address the problems.

Large areas of eucalypt plantations began to be established in the 1990s in a *plantation hardwood phase*. This was a bold move by Forestry Tasmania, it being the first major Australian forest grower to develop regimes for growing solid wood products in eucalypt plantations on a commercial scale. This development was driven by the need to more intensively manage some forest so that the increased productivity could compensate for the loss of native forest transferred out of production area into conservation reserves.

The creation of major softwood and hardwood resources for the forest industry has been a great achievement of the operational and research work in plantations on State forests since 1921. This resource is currently being expanded to increase the plantation resource in Tasmania to a size that is competitive on a world scale.

A high-pruned and thinned 16-year-old *Eucalyptus nitens* plantation in the Arve Valley. This is a fine example of the eucalypt plantation estate being intensively managed by Forestry Tamania for the production of solid wood products.

Chapter 6

Maintaining Forest Health

Introduction

Records of observations on the health of Tasmanian trees date from the earliest landings by European explorers. For example, heart rot of eucalypts at Adventure Bay, Bruny Island, was noted by Captain William Bligh in 1788:

> *Many of them were full one hundred and fifty feet high; but most of those we cut down were decayed at the heart*. [Bligh 1792, p. 47]

A famous example of early landscape-level damage to eucalypt forests in the Central Highlands was the great frost of 1837, graphically described by the Government Surveyor James Calder:

> *For the destruction of the forests of all the lowlands of this extensive district could not have been more perfectly accomplished if even a simoon[1] had passed over them. This extraordinary season destroyed the timber of almost every valley on the vast plateau lying between this quarter and the mountains terminating at the verge of the Westbury and Norfolk Plains districts. The havoc has been indeed tremendous but wholly incalculable.*
>
> *It is impossible to witness the effects of this winter without emotion and the traveller unaccustomed to such a picture of desolation is startled by the amazing scene of ruin which now presents itself. The bush is one interminable mass of dead trees. Except on the hilltops everything around him is dead.* [Calder (1850) in *The Tasmanian Naturalist*, p. 5]

In the same account, Calder also provides his somewhat hard-hitting view of the need for the right approach for investigating the cause of such calamities—sobering words very relevant to unravelling the many complex forest problems encountered since!

> *A person writing of the districts I have taken to describe will not be accused of digressing in pausing to attempt the investigation of the cause which led to the demolition of the forests here. The subject is interesting and that task can never be considered an unprofitable one which has for its object the exposition of the truth and if possible some correction of the vague hypotheses by which some have endeavoured to account for their decay, I believe more with the view of establishing new theories than of coming to the truth. According to some this was occasioned by diseases, to others by*

[1] A hot, dry, dust-laden wind, blowing at intervals in the African and Asian deserts.

lightning, while another class ascribe the calamity to extensive bush fires. But these persons are either ignorant of the true cause or they belong to that class of man who will never adopt a commonsense view of anything whatever. [Calder (1850) in *The Tasmanian Naturalist*, p. 6]

Following the formation of the Forestry Department, pest and disease problems were occasionally encountered and were dealt with at a local level where possible. Most of the early references to pests and diseases in State forests, dating from the 1920s, concern conifer seedlings in nurseries and young plantations. This reflects the priority given by the new Department (and Conservator Irby in particular) to establishing conifer plantations in several areas of the State (see Chapter 5).

This chapter documents the history of the main forest health problems and the research work done by Forestry Tasmania since 1921. Browsing mammals, insect pests, fungal diseases, drought and frost have caused most plant health problems. Nutrient deficiencies have also had significant impacts on plant health. The considerable research and corrective action on nutritional disorders have been described mostly in Chapter 5 (Plantation Forestry) because they have been a significant part of the plantation research program in Forestry Tasmania.

The production of extension literature has been particularly important in this specialist field for information transfer to operations staff in Forestry Tasmania and other forest managers in Tasmania and beyond. This literature

Examples of extension literature produced by Forestry Tasmania mainly to advise forest managers on pest and disease problems. A variety of styles, including books, manuals and leaflets, have been published to accommodate a broad audience.

includes the Forest Health Bulletins, leaflets on individual pests and diseases, the Pest and Diseases Management Plan (Wardlaw 1990), *Insect Pests of Trees and Timber in Tasmania* (Elliott and De Little 1984), and *Insect Pests of Australian Forests* (Elliott *et al.* 1998).

Early Plant Health Problems

The earliest official report of a pest problem by the Forestry Department was noted in the 1922–23 Annual Report. Only 12% of spot sowings of conifers (mainly *Pinus* spp.) at Sisters Hills in that year were successful due to a combination of poor seed and attacks by birds and rodents (Forestry Department 1923). The strangling fungus, recorded in 1926 as *Telephora laciniata*, was 'proving a considerable menace' although it had not caused many losses (Forestry Department 1926). The genus of this fungus is actually *Thelephora* and the species is now *T. terrestris,* a widespread fungus commonly known as smothering or cow-pat fungus which can smother young seedlings with its hyphae.

In the late 1920s in the Queenstown plantation, *Pinus insignis* (now *P. radiata* or radiata pine) and *P. pinaster* seedlings suffered from sulphur fumes emitted by the mine smelters even though it had been assumed that these emissions had been reduced to a level where they would not affect seedling health (Forestry Department 1929). The leaf blister sawfly (*Phylacteophaga froggatti*), the pine aphid (*Chermes pini,* now *Pineus pini*) and the strangling fungus were also mentioned as incidental pests. The earliest control measures were apparently taken in 1930–31 when it was reported that attempts to halt the spread of the pine aphid in the Sisters Hills and Sheffield nurseries had failed:

> *The beds of* Pinus sylvestris *were affected beyond all hope and the disease began to attack individual trees of other species. As soon as the position was realised, orders were issued to cut out and burn all affected plants and if any sporadic recurrence is promptly dealt with it is hoped that no further trouble will be experienced from this source.* [Forestry Department 1931, p. 6]

The pine aphid continued to be a problem in the Department's conifer nurseries for many years, and this insect, together with rabbits and needle fusion (see below), were the most frequently noted plant health problems up to the 1950s.

Considering the unsuitable nature of some of the sites (e.g. Sisters Hills) where pine plantings were first established in the State, it is not surprising that health problems occurred there. The Department sought specialist help from the Council for Scientific and Industrial Research (CSIR, the forerunner of CSIRO) on some of these early problems, particularly for identification of individual pests. In 1933, two scientists employed by CSIR, Dr Tillyard (Chief of the Division of Economic Entomology) and a Mr Tonnoir, inspected the pine aphid

Clusters of the pine aphid, *Pineus pini,* on radiata pine shoots. This insect was a serious pest of the early pine plantings in Tasmania.

problem in the Beaconsfield plantation. Based presumably on advice from the scientists, the Forestry Department noted:

> *There appears to be every hope of the successful establishment in Australia of a predatory control in the very near future, in which case we may hope to have this pest under control before very long.* [Forestry Department 1933, p. 6]

This statement refers to the importation into Australia of a small fly *Leucopis* sp. (Diptera: Chamaemyiidae). The larva of this species preys on scales, aphids and coccids and was considered, in the early 1930s, to have prospects for use as a biological control agent for the pine aphid. CSIR advised the Department in 1933 that efforts to breed this species in Australia had not been successful although they held out more hope for another consignment of the fly. However, *Leucopis* was never established as a successful predator of pine aphid in Australia.

During the 1930s, needle fusion was seen in several areas of the young *Pinus insignis* (*P. radiata*) plantations in the Beaconsfield area.

> *… needle fusion … continues to mystify the experts. ... At present it appears that needle fusion occurs only where, for some reason, the soil is unsuited to the species concerned, but, if that is so, it still remains to determine the nature of the disease-producing condition. Meantime, it will be wise to exercise the greatest caution in extending our pine plantations on a commercial scale.* [Forestry Department 1933, p. 6]

A pathologist from CSIR investigated the needle fusion problem but, as we now know, needle fusion commonly occurs in radiata pine plantations which have nutrient deficiencies, particularly phosphorus; imbalances of copper, boron and calcium can also cause the problem. Application of phosphatic fertilisers to plantations with fused needles usually alleviates the disorder (Forestry Tasmania 2001b).

Problems with the pine aphid and other pests were occasionally referred to in the Department's reports over the following years but there were no co-ordinated research programs for forest health. The next major plant health problems occurred in the 1950s when sirex wasp was found in radiata pine plantations and when dieback of eucalypt forest was reported in the 1960s. These problems are discussed in detail later in the chapter.

The First Forest Health Staff and Facilities

When pest and disease problems arose before the early 1970s, the Forestry Commission sought advice from external organisations, principally CSIR and the Tasmanian Department of Agriculture. The appointment of Chris Palzer as Forest Pathologist in 1972 and Humphrey Elliott as Forest Entomologist in 1974 marked an important expansion by the Forestry Commission into the field of forest health. At the time of these appointments, the Forestry Commission did not have the laboratories or other research facilities required for this type of specialised research. Consequently, for the first few years after their appointments, Chris and Humphrey were accommodated at the New Town Research Laboratories of the Department of Agriculture and the CSIRO Division of Entomology's Sirex Unit at Llanherne respectively. These arrangements were no longer needed when Forestry Tasmania established its own laboratories.

With very limited information available in the field of forest health in Tasmania at the time, much of the early research was directed at determining which pests were having significant impacts. Basic studies of life histories, biology and impacts were conducted for a range of insects and fungi. These studies formed the basis of the Forestry Commission's Pest and Disease Leaflet series, the first of which was published in 1976 (Elliott and Bashford 1976). The first reference collections of pests, diseases and plant parts showing the main symptoms of damage were


The travelling field laboratory of the 1970s! (Humphrey Elliott pictured.)

also initiated at this time. The early material for the Tasmanian Forest Insect Collection (see Chapter 7) came from investigations of specific pest problems, and general surveys in different forest types, such as the studies of insect fauna in dry forests in eastern Tasmania (e.g. Elliott *et al.* 2002).

Pests and Diseases of Conifers

The pest and disease problems encountered in the early conifer nurseries and plantations were mostly localised and, in general, the State's conifer plantations were free from widespread pest damage from 1921 until the 1950s.

Sirex wasp

The first major involvement of the Forestry Commission in forest pest management occurred when the sirex woodwasp, *Sirex noctilio*, was found in the radiata pine plantation at Pittwater near Hobart in 1952. This was the first record of sirex as an established pest in Australia, although closely related species had been intercepted earlier at the Hobart wharves. In 1951, *Sirex juvencus* was found in pre-fabricated house timber imported from France. Early in 1952, live larvae and adults of another related species, *Urocerus gigas gigas*, were found in crating timber from the United Kingdom; shortly after, a live adult of this species was captured on the Hobart wharf. The infestation of sirex in the Pittwater plantation was reported in 1952 by Max Gilbert (Silviculturist with the Forestry Commission) and Len Miller (Chief Entomologist with the Department of Agriculture) (Gilbert and Miller 1952) and, because of its known destructive capacity in New Zealand radiata pine plantations, the discovery of sirex in Tasmania aroused national concern.

The Pittwater plantation was established between 1929 and 1935 at 1700 stems/ha and had subsequently been thinned to 1000 stems/ha by taking out the largest logs for Alstergren's sawmill near Cambridge. In 1950 and 1951, three small fires occurred in the plantation and fire-killed trees of merchantable size were salvaged. In March 1952, sirex adults, pupae and larvae were found at the mill in flitches which had been sawn from trees killed in the 1950 fire, and sirex flight holes were found in some standing trees. This information, combined with knowledge of the wasp's life cycle, led Gilbert and Miller to conclude that the adult wasps must have been

SOFTWOOD PEST FOUND IN STATE PINE PLANTATION

TIMBER KILLER

SIREX wasps which attack softwoods have been found in a pine forest in Southern Tasmania.

This was revealed yesterday by the Minister for Agriculture (Mr. Dwyer) who said he had received a report from the Chief Entomologist (Mr. L. W. Miller).

Only fire-damaged trees in the plantation are affected.

The seriousness of the pest in Australian conditions was not yet known, but it would be difficult to eradicate, the report stated.

In Europe it was generally considered as a pest in weakened trees rather than in healthy forests.

Rapid Spread

Mr. Miller reported that the

some other insects that have come from overseas the wasp would be extremely difficult to eradicate from Tasmania.

Mr. Dwyer said that the matter had been reported to the Federal quarantine authorities and also to the Commonwealth committee that has been set up to report on the Sirex wasp problem.

Considerable Concern

Considerable concern had been felt by quarantine officials throughout Australia in recent years at the possibility of introducing the wasps into Australia.

The large volume of imports both of softwood timbers and of goods packed in

The Mercury
Saturday, 8 March, 1952

Early press report of the sirex wasp infestation in the Pittwater plantation near Hobart.

present in the summer of 1950–51, but the scattered, wide infestation in the plantation suggested that the introduction had occurred earlier. In 1953, a plot was established in the Pittwater plantation to study the incidence and effects of sirex. From the initial investigations by Gilbert and Miller and later research, it is clear that the state of the Pittwater plantation at the time, with a high component of smaller, less vigorous trees and some fire damage, was ideal for establishment of sirex.

By 1961, sirex had killed 40% of the standing trees in the Pittwater plantation and, in 1962, this led to the establishment of the National Sirex Fund, with each State providing funding (based on their proportion of the Australian pine plantation area) for research, survey and eradication programs. The CSIRO Division of Entomology established a Sirex Unit at Llanherne in the same year to receive, rear and distribute insect parasitoids of sirex and to study the ecology of the pest and its parasitoids. Michael Coutts, then working in the Forestry Commission's Silvicultural Branch, was made available on a full-time basis to conduct plant physiology and pathological studies at the Forest Research Institute's (FRI) Regional Research Station established at Llanherne (next door to the Sirex Unit). The initial studies were directed at spacing and fertilising in young pine stands, the effects of pruning on susceptibility to sirex, and trials of a systemic fungicide. The work by Michael Coutts and the staff at the FRI station showed that tree death from sirex attack resulted from a combination of a phytotoxic mucus and a pathogenic fungus, *Amylostereum areolatum* (Coutts 1969a, b), both of which are introduced into the tree by the wasp.

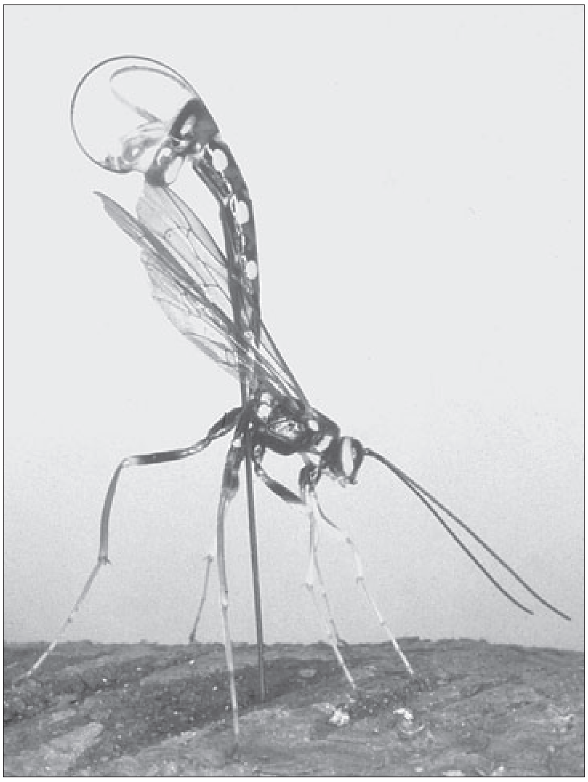
Between 1967 and the late 1970s, 21 species of insect parasitoids were introduced into Tasmania for culturing. Ten species were released in Tasmania and Victoria, five of which became established in radiata pine plantations. Although the culture and release of the parasitoids by CSIRO was a successful program which exerted significant control over the numbers of sirex attacking plantations, the most effective biological control was provided by a nematode *Deladenus siricidicola* (now *Beddingia siricidicola*). The discovery of this

A sirex-infested area of the Pittwater plantation in the 1950s, showing the dead trees left after salvage of trees that were still usable for sawn timber.

nematode in New Zealand plantations (Zondag 1962), the understanding of its extraordinary free-living and parasitic life cycles (Bedding 1967), and its subsequent introduction into sirex-affected plantations in Australia (Bedding and Akhurst 1974) had a dramatic impact on the management strategy for this pest. This nematode became (and still is) the predominant control agent for sirex.

By the 1970s in Tasmania, with the release and establishment of insect parasitoids and nematodes, better stand management (particularly greater adherence to thinning schedules) and the generally favourable climatic conditions, sirex had become a less important pest. However, following the severe drought conditions in 1979–80, sirex damage became significant in some of the lower productivity, unthinned areas within Branchs Creek, Tower Hill and Scamander plantations. Monitoring plots were set up and and nematodes inoculated into the infected areas. At this time, a plantation owned by Associated Pulp and Paper Mills near Railton in north-western Tasmania was severely attacked by sirex and 80% of the trees in the worst affected patches were killed. However, the manager of the mill reported that the salvaged trees actually produced very good pulping material because the moisture content of the dying trees was lower than usual.

During the late 1980s and 1990s, sirex control was routinely conducted in Tasmania in accordance with the National Strategy for Sirex Control (Haugen *et al*. 1990). Trees injected



Megarhyssa nortoni nortoni, an important parasitoid of the sirex wasp. This parasitoid can detect the presence of sirex larvae in the tree and it drills through the wood with its long ovipositor to lay eggs in the larvae. The wasp larvae grow inside the sirex larvae which eventually die and adult parasitoids emerge from the tree.

with weedicide were used as trap trees to detect sirex, and parasitoid releases and nematode inoculations were conducted when necessary. From the late 1990s, aerial surveys undertaken as part of the Forest Health Surveillance System (see later section) were the main tool for detecting attacked trees. In 2006, traps containing chemical lures (terpenes) to attract the woodwasp were introduced by Dick Bashford to replace the old trap-tree method. This trapping technique was also adopted in mainland States and the United States of America for sirex detection.

The strain of the nematode *Beddingia siricidicola* used against this pest in Australian States was first used in inoculations into trees in the Cuckoo and Mount Helen plantations in northern Tasmania in 1970 (Bedding and Akhurst 1974). The strain became ineffective across Australia early in the 1990s, but collections by Dick Bashford in 1991 of a *B. siricidicola* strain from the Kamona plantation allowed the nematode stock cultured by CSIRO in Canberra for sirex control to be revitalised.

In recent years, the sirex levels in Tasmanian pine plantations have been low, but monitoring of parasitoids emerging from infected pine logs kept in enclosures has shown that the main parasitoids are present in reasonable numbers. Some South American countries have had severe sirex infestations in recent years and have been very keen to import some of the more effective parasitoids such as the large wasp *Megarhyssa nortoni*. Forestry Tasmania has been able to rear and export small numbers of this and other species of parasitoids to the affected South American countries on a commercial basis to assist their control programs.

Fungal diseases

Several fungal diseases of conifers occur in Tasmanian plantations, particularly those causing needle casts and cankers, but most have caused only local and limited damage. Information on the occurrence and significance of these diseases has been accumulated over the past 30 years by Chris Palzer, Tim Wardlaw and, more recently, by the Forest Health Surveillance staff—Karl Wotherspoon, Robin Doyle, Sue Jennings and Nita Ramsden.

Spring needle cast

Spring needle cast (SNC) causes severe yellowing and loss of needles in radiata pine plantations and has probably been the most serious fungal disease of pines in Tasmania. Several observations of yellowing and needle shed in pine plantations in the spring months were recorded by Forestry Commission staff through the 1960s and 1970s.

For many years, the cause of the disease was unexplained, with nutrient deficiencies, stress and fungal pathogens, or combinations of these, being proposed as possible causal factors.


Culturing fungal pathogens in the laboratory so they can be identified. (Chris Palzer pictured.)

Frank Podger (CSIRO) conducted studies of this disease from 1976, following a case of severe needle cast in high-quality plantations in north-western Tasmania. Tim Wardlaw joined Frank in further studies of the disease in the mid 1980s. Their detailed work provided a better understanding of the problem and its effects on the growth of affected trees (Podger and Wardlaw 1990a, b). They postulated that SNC resulted from infection by one or more needle-cast fungi, including *Cyclaneusma minus* and *Lophodermium pinastri,* following the influence of stress factors on affected plantations.

The effects of SNC on growth were severe in closed-canopy plantations, particularly in the wetter areas of the north-west and north-east. For example, in the spring of 1991, a survey for SNC in Oonah plantation in the north-west showed that the average incidence of the disease was 33% of trees affected, with an average severity of needle loss on affected trees of 21%. This level of infection was calculated to result in an estimated reduction in tree diameter increment of approximately 30% compared with unaffected stands (Forestry Commission 1992c). All radiata pine plantations on State forest were surveyed in 1997–98 by Karl Wotherspoon to map the areas most affected by the disease.

SNC posed some interesting management problems in relation to reducing the incidence of the disease in plantations being managed under a clearwood regime involving early pruning and thinning operations. In higher altitude plantations such as Oonah, although height growth was less than in lower altitude stands, diameter growth was not; therefore, early thinning and pruning of these stands was required to limit development of the knotty core in accordance with the aims of the clearwood regime to produce a high proportion of knot-free timber. However, the reduced height growth meant that pruning and thinning occurred before canopy closure and therefore prior to the expression of the disease. As a result, SNC-affected trees could not be culled in the thinning process, thus necessitating a trade-off between knotty core reduction and selection against SNC.

Breeding for resistance is considered the most viable method of reducing the increment losses from SNC infection (Forestry Tasmania 2000b). In the mid 1990s, assessments by Peter Kube and Tim Wardlaw of the incidence of SNC in the large Australasian Plus Tree Progeny Trial at Upper Castra showed wide variation in the resistance of some parental lines of radiata pine to SNC infection. This finding offered some prospects for the use of more resistant genetic stock of radiata pine to be used in future plantings in SNC-susceptible areas.

Resistant lines from the Upper Castra trial were subsequently planted in high SNC-risk sites such as Oonah. In 2003, Peter and Tim conducted a major review of SNC management. Following this review, clearwood and knot-control regimes were adopted for radiata pine plantations on high and moderate risk sites, combined with the use of SNC-resistant seed. This was a good example of a management approach which integrated genetic control with appropriate silviculture.

Pine needle blight

From the time that specialist pathology studies began in Tasmania in the early 1970s, the State's plantations were monitored for the pine needle blight, *Dothistroma septospora.* This disease is a native of North America and had caused severe defoliation of radiata pine plantations in New Zealand and some mainland States. When pine needle blight was first found in New South Wales in 1974, Chris Palzer convinced Tasmanian authorities to impose quarantine restrictions on the movement of live pines from the mainland—a measure which undoubtedly delayed its establishment here. It was first found in Tasmania by Frank Podger (CSIRO) in October 1984 in plantations south of Burnie at Oonah, Hampshire and Peak Plains and also in the north-east at Cascades and Payanna. Coincidentally, a group of Australia's forest pathologists had visited this site one year earlier; however, no connection between these events is implied! Following the very wet year of 1989, the disease spread more widely and, in 1994, was first found in southern Tasmania near Maydena.

The plantations where pine needle blight was first seen in Tasmania were being managed on a clearwood regime involving early thinning and pruning. The infection was locally severe on unpruned trees but these trees were waste thinned as part of the regime. The view was taken that the disease could be kept in check in these clearwood areas by pruning and thinning on schedule, combined with basic hygiene measures. This has largely proved to be the case, although there have been occasional more severe infections, particularly following wet spring and summer seasons. The level of infection in one private plantation in north-western Tasmania in the early 1990s reached 40%; this plantation was successfully treated with copper oxychloride.

Although there were early predictions by some visiting pathologists that pine needle blight would be a severe disease in Tasmania, this has not been the case. The studies of the last 20 years have clearly shown that Tasmania's winter-dominated rainfall pattern does not favour full expression of the disease, which is encouraged by warm, humid conditions accompanying summer rainfall, typical of affected areas in mainland Australia.

Crown-wilt fungus

The crown-wilt fungus, *Sphaeropsis sapinea* (formerly *Diplodia pinea*), was first isolated by Chris Palzer in 1975–76 from tall radiata pine exhibiting death of leading shoots in the Retreat plantation near Launceston. Pathogenicity of this fungus was proven by inoculation into healthy seedlings, observing symptoms and re-isolating the species, Koch's postulates thereby being satisfied. This record was followed by an outbreak in Oldina plantation in 1977 following severe wind and hail damage. Extensive dieback of leading and some lateral shoots occurred but no long-term damage to the plantation resulted.

In the late 1970s, small patches of dead pines, from which the crown-wilt fungus was isolated, appeared in several high-quality pine plantations. However, although the fungus was present, the cause of the problem appeared more complex because the patches did not increase in area. Eventually, after studying weather records and seeking advice from interstate physicists on the likely pattern of lightning discharge in these plantations, it was concluded that the dead patches probably resulted from lightning strikes causing intense horizontal discharge, perhaps related to the high moisture content in the plantation. The fungus was considered to be a secondary pest, invading trees after they were damaged by lightning.

Several further occurrences of crown-wilt disease have been noted in pine plantations and in nursery beds and this disease is now known to be widely distributed across the State's plantations (Forestry Tasmania 2000a). However, it generally causes only low levels of damage.

Pests and Diseases of Eucalypts

Dieback of native forests

The term dieback has been defined in many ways by different authors but its core use in Australian forestry describes a progressive decline in the health of the crown of a tree, sometimes leading to tree death. Small amounts of dieback are seen so frequently in the crowns of eucalypts as to be normal, and it must be remembered that any tree will eventually lose vigour and die. Specific causes of the condition can be hard to determine, a complex of interacting factors often being the best explanation. However, in some circumstances, especially where death of trees in a restricted area is common, an abnormal situation can be recognised.

The term high-altitude dieback was used in the early 1960s to describe an abnormal condition in mature native eucalypt forests in the north of the State where *Eucalyptus delegatensis* had either died or had severe crown dieback. As the trees did not seem to have died of old age and were standing over well-developed and healthy wet scrub or rainforest understoreys, it was obvious they had not been fire-killed as had been suggested by some initial observers.

From the mid 1960s, it became clear that the crowns of some dominant and co-dominant eucalypts in some patches of regrowth forests in the south of the State were also in decline. There being no obvious reason for this decline, the term regrowth dieback was applied. Then in the late 1960s, Ken Felton collected and collated information on unexplained deaths in eucalypt forest causing concern amongst forest managers (Felton 1972). Other diebacks were recognised later, six separate phenomena eventually being distinguished:

- High-altitude dieback in *E. delegatensis* forest in north-eastern Tasmania;
- Regrowth dieback, mainly in southern Tasmania;
- Gully dieback in north-eastern Tasmania;
- Calder dieback, mainly in the Calder and Inglis Valleys in north-western Tasmania;
- East coast dieback;
- Rural dieback in pastoral areas, particularly in the Midlands.

*Root-rot fungus (*Phytophthora*) and dieback*

Around 1970, when some of the eucalypt diebacks listed above were noticed, the root-rotting fungus *Phytophthora cinnamomi* was receiving nationwide publicity as the cause of jarrah (*Eucalyptus marginata*) dieback in Western Australia and of other species in some other States. Newspapers reported that *P. cinnamomi* would decimate Australia's forests and, for a time, the popular press ascribed almost any death of any tree to the effects of this fungus. As there were no specialist pathologists employed by the Forestry Commission at the time, two scientists from the Australian National University in Canberra were invited to Tasmania to advise the Forestry Commission on the likely causes of the diebacks. After a short visit in which they isolated *P. cinnamomi* from roots and soil from some dieback areas, they concluded it was the likely cause of most, if not all, the dieback problems.

A dry sclerophyll forest understorey, showing dead and dying grass trees, *Xanthorrhoea australis,* after infection by the root-rot fungus, *Phytophthora cinnamomi.*

In view of the extent of dieback occurring across the State in various forest types and the report of the visiting pathologists, the employment of a specialist to work on this problem became a high priority. Accordingly, in 1972, the Commission appointed Chris Palzer as a Forest Pathologist. His initial task was to investigate the causes of eucalypt forest diebacks in the State, particularly the distribution and importance of *P. cinnamomi*. Chris took thousands of samples of soil and plant material from across a range of forest and woodland environments in order to determine the distribution of *P. cinnamomi* in Tasmania. He established that the fungus affected many native plants, particularly in heathlands and dry sclerophyll forests. It was also isolated from rainforest species indigenous to cool temperate rainforest in western Tasmania (Podger and Brown 1989). Frank Podger (CSIRO) worked with Chris and Tim Wardlaw to map the distribution of *P. cinnamomi* and they recorded 136 host plants in Tasmania (Podger *et al.* 1990a).

Phytophthora cinnamomi does not flourish in cold soils, so Chris studied soil temperatures in Tasmanian forests. He concluded that soil temperatures were too low for *Phytophthora* in most of the commercial forest areas and that any infection would largely be confined to the small feeder roots of trees rather than spreading into the large roots as occurred in warmer mainland areas. He also concluded that *P. cinnamomi* was not consistently associated with dieback and mortality of eucalypts in Tasmania, although in the drier forests there was a strong association between *P. cinnamomi* and death of some understorey species. Each of the eucalypt diebacks noted above was considered to have a separate cause, usually involving interacting factors such as drought, root rot, insect attack and altered land use.

Two extensive areas were found to be largely free of the disease: forests south of the Arthur River in the north-west, and around Tebrakunna Road in the far north-east. Chris initiated hygiene measures for these areas which required *P. cinnamomi*-free gravel to be used in road building to limit the spread of the fungus. Overall, these measures were successful, as indicated by a much lower incidence of the disease near roads on State forest in these areas compared with roads constructed by other agencies. Later, in the 1990s, further work on identifying priority areas for restricting the spread of *P. cinnamomi* was conducted by Phil Barker. This work is described in the account of conservation research (Chapter 7).

High-altitude dieback

High-altitude dieback was the term used to describe the serious and widespread decline in the health of natural forests of *Eucalyptus delegatensis* growing at high altitudes on the Camden Plateau in the north-east (Ellis 1964) and in the north-west (Needham 1960). Some 2000 ha of *E. delegatensis* with a dense rainforest/ wet sclerophyll understorey growing above 800 m in the north-eastern highlands were affected by this dieback. It occurred over several

High-altitude dieback on the Camden Plateau, north-eastern Tasmania, 1973. The *Eucalyptus delegatensis* trees have died following extensive development of the rainforest understorey.

decades and, by the 1960s, all the *E. delegatensis* were dead in some stands, and dead and dying trees of all ages were common in others. Bob Ellis conducted research on the problem for the Forestry Commission in the 1960s and also in the 1970s when working with CSIRO.

Detailed investigations showed that the health of the *E. delegatensis* overstorey generally decreased with increasing age of the understorey, which in turn was related to time since the last fire. The age at which the dieback commenced decreased with increasing altitude (Ellis 1964). This research led to a hypothesis that mortality of *E. delegatensis* in these high-altitude forests was due to significant reductions in soil temperatures following invasion of the stands by the rainforest understorey. Tree mortality was attributed to the inability of established trees to adapt their root to crown ratios to accommodate the changes in soil microclimate (Ellis 1971).

Long-term plots were established on the Camden Plateau to test the effect of understorey control on the health of the eucalypts. These experiments involved comparison of the health of untreated plots with plots where the understorey was felled and left, felled and burnt once, and felled and burnt several times. The trial showed that the rate of growth of badly affected *E. delegatensis* increased by 75% over 12 years after understorey felling followed by burning compared with untreated stands (Ellis *et al.* 1980). As felling the understorey alone (i.e. without burning to remove the large amount of organic debris) did not improve tree health, it was suggested that some unknown inhibitory factors might be present in the unameliorated soils.

On the basis of this research, periodic burning of the understorey was put forward as a means of maintaining high-altitude *E. delegatensis* stands in good health. Unfortunately, controlled burning is very difficult to achieve operationally in these forests, particularly in the wetter areas with very dense understoreys; very few suitable days for safe burning operations are available each year because of the climatic conditions. However, observation of dieback-affected stands of *E. delegatensis* over rainforests which were clearfelled, burnt and sown with eucalypt seed indicated that the eucalypt regeneration remained healthy and fuel reduction burning could be possible once these stands had reached approximately 20 years of age. Later work by Rod Keenan and others developed silvicultural prescriptions for these high-altitude eucalypt forests (see Chapter 2).

Regrowth dieback

This dieback was first observed in 1959–60 in Tasmania's Southern Forests. It caused crown decline and some death (including trees in the dominant and co-dominant strata) in patches of forest through some 16 000 ha of tall *E. obliqua* and *E. regnans* regrowth forests (West and Podger 1980). Although the term 'regrowth dieback' is usually associated with the Southern Forests, trees with similar symptoms over significant areas were also found in other parts of the State, particularly Weldborough/Ringarooma in the north-east and near Sprent in the north-west.

The problem was investigated between the mid 1960s and the early 1980s by staff of the Forest Research Institute (later CSIRO Division of Forestry and Forest Products). Local Forestry Commission staff from the Geeveston District assisted with survey and measurement work for many years. Although no conclusive explanation for this difficult problem was produced, the generally agreed hypothesis is that the disease may have been initiated by drought, with secondary damage by the root-rotting fungus *Armillaria* sp. and/or the defoliating beetle *Chrysophtharta bimaculata* (West and Podger 1980).

During the 1980s, Chris Palzer investigated the role of low water potentials, heat stress and micro-organisms in the crowns of trees affected by regrowth dieback. Some novel approaches were used when investigating the cause of death in large regrowth eucalypts up to 50–60 m high. One aspect of this work involved taking readings of water potential in the upper crown of these tall trees. These measurements began before dawn and continued for several hours, so for added comfort, Chris installed a platform about 40 m up the tree and reclined on a mattress with a good book between readings! Not so comfortable was his able assistant, Tim Wardlaw, who had to stay by the base of each tree surrounded by battalions of leeches and mosquitos to receive the samples dropped by Chris at hourly intervals!

The time spent by Chris high in the tree crowns enabled him to make very detailed observations of microphylly, interveinal chlorosis, reduced numbers of accessory buds and other symptoms on dieback-affected branches (Palzer 1984). These observations led to investigations of water deficits in tree crowns. Limited sampling indicated that healthy trees had less water deficit and recovered to near equilibrium water potential by dawn compared with diseased trees which did not recoup daytime water deficits during the night even though soils were moist. Leaf temperatures on dieback-affected trees were elevated several degrees above ambient. To test the effects of this change, leaves were artificially heated in the laboratory to temperatures of 46–48°C. This caused chlorosis, followed by premature abscission. It was concluded that high leaf temperatures were not likely to cause regrowth dieback but could contribute to death of leaves and shoots (Forestry Commission 1983).

These findings clarified the physiology of the decline in dieback-affected trees and, combined with the causal hypothesis developed by the extensive CSIRO studies, represented a comprehensive investigation of this difficult and serious problem. No management strategy to arrest the death and decline of the dieback was developed but, as drought was probably the triggering factor rather than a pest or disease, there were few management options available. Salvage logging of trees in the dieback-affected stands significantly reduced the potential loss of timber, and predictions of future yield from these forests were also modified (Wardlaw 1989).

Gully dieback

In the late 1960s and early 1970s, extensive dieback and death of eucalypts, mainly *E. obliqua*, in eastern Tasmania were investigated by Forestry Commission staff, particularly Ken Felton and Chris Palzer. Tree death was restricted to gullies, with the worst occurrences being in the north-east between St Helens and Fingal. However, it also occurred as far south as Buckland. The affected gully forest was predominantly *E. obliqua* growing over tall, dense understoreys. *Eucalyptus sieberi* on the north-facing slopes of gullies in the north-eastern areas was not affected. Comparison of the extent of the disorder using aerial photographs taken in 1950 and 1969 showed a substantial increase in the total area affected, as well as the severity of the disorder within these affected areas (Felton 1972). *Phytophthora cinnamomi* was isolated from affected plants by scientists from the Australian National University and was initially considered as a possible causal agent, in combination with climatic and other environmental changes.

Gully dieback in north-eastern Tasmania, showing dead stems of *Eucalyptus obliqua* in the gully, 1974.

From 1972 to 1974, Chris Palzer conducted a detailed study of gully dieback using climatic records, pathogen isolations from affected gullies and historical observations from forestry staff. Assisted by Mike Castley, Neil McCormick and Tim Wardlaw, Chris also monitored soil water potential and depth to the water table. From these studies, it was concluded that trees suffering from gully dieback had been weakened by a severe drought in 1967; they were then further damaged by defoliation caused by caterpillars of the gumleaf skeletoniser moth, *Uraba lugens*, and some secondary root rot caused by the shoestring fungus, *Armillaria luteobubalina*. The water-table measurements provided some evidence for a hypothesis that there had been a sudden drop in the water table in the gully floor in response to drought. This would explain why trees in the gully and not the dry ridges were most affected. A survey of the area in 1974 showed that the disorder had stabilised, with very few new deaths occurring and healthy epicormic shoots appearing on partially affected trees (Palzer 1981).

Calder dieback

Detailed investigations of this dieback of *E. obliqua* in north-western Tasmania were carried out by Chris Palzer, with help from Neil McCormick, between 1975 and 1980, although the disorder had also been reported some 30 years before:

> *On a small area in the Calder River Valley in the North-West Division an unidentified disease killed tall eucalypt saplings some years past. Similar deaths have been observed at Oldina. The areas are kept under observation and it is reported that there is no indication that it has been spreading in the last two years. The area concerned is a wet creek flat.* [Forestry Commission 1949, p. 11]

In the 1970s, the dieback was most prominent in the Calder and Inglis Valleys south of Wynyard. The investigations involved regular sampling of shoots and leaves high in the crowns of affected trees using permanently attached ladders, isolation of root-rotting fungi, and analysis of climatic data. Although these investigations began after the dieback was well established, the leaf sampling showed that the leaf spot disease *Aulographina eucalypti* was a consistent and sometimes severe leaf pathogen often causing premature leaf drop. Some trees which produced healthy epicormic shoots after apparently overcoming the initial loss of leaves then died suddenly. Inspection of the roots of these trees revealed a consistent association with the root-rotting fungus *Armillaria luteobubalina*.

The conclusion from these studies was that the dieback appeared to have been caused by unusually humid weather conditions, promoted by stagnant air in the valleys, which favoured the extensive development of the leaf spot disease *Aulographina eucalypti.* This disease defoliated the primary crowns of the eucalypts, with some subsequent secondary attack by the root-rotting fungus *Armillaria*. An episode of similar dieback and mortality of valley-floor eucalypts was recorded in north-western Tasmania soon after the very wet summer of 1988–89.

Valley fog in the Calder Valley, north-western Tasmania. The stagnant air lying in the valleys produced a very humid environment favourable for rapid development of leaf-spotting fungi which caused defoliation and death of many trees, an episodic phenomenon known as Calder dieback.

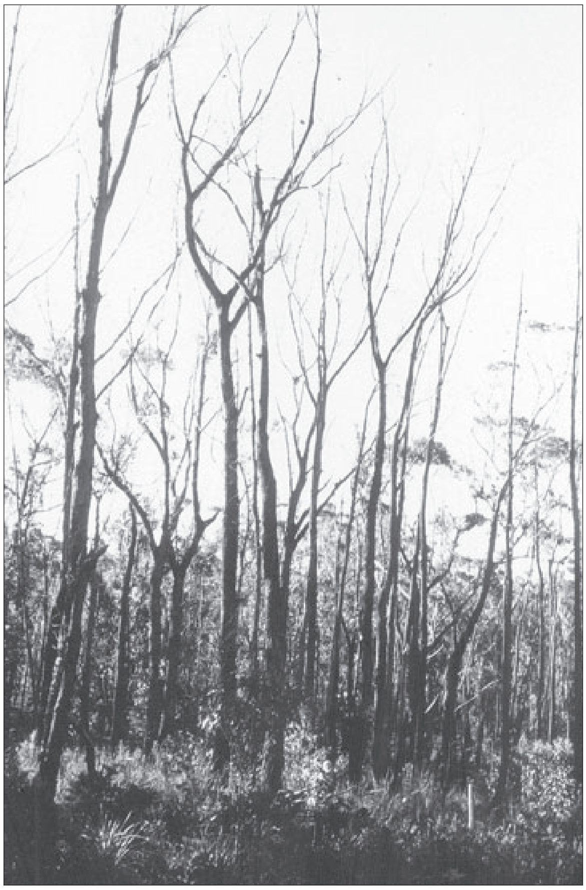
East coast dieback

East coast dieback was the term given to the decline and death of eucalypts in a mixed species stand of *E. globulus*, *E. obliqua*, *E. ovata*, *E. sieberi* and *E. viminalis* in the presence of the fungal pathogen *Phytophthora cinnamomi* in the Chain of Lagoons area on Tasmania's east coast. The wet summers in the early 1970s, followed by severe drought, triggered extensive dieback of *E. obliqua* and *E. sieberi* growing on flat, wet sites. In this area, soil temperatures reach the 15–30°C range required for aggressive development of *P. cinnamomi*, and its severe effects on susceptible understorey species as well as the eucalypts were obvious. Chris Palzer and later Tim Wardlaw monitored the health of dominant overstorey eucalypts and regeneration at Chain of Lagoons for several years. It was first thought that the greater susceptibility of *E. sieberi* and *E. obliqua* to *P. cinnamomi* would lead to a regrowth stand dominated by eucalypts tolerant of *P. cinnamomi* field-infection (*E. globulus, E. viminalis, E. ovata*). In fact, both *E. sieberi* and *E. obliqua* had higher growth rates than these tolerant eucalypt species and maintained reasonable health in the presence of the pathogen (Wardlaw and Palzer 1988).

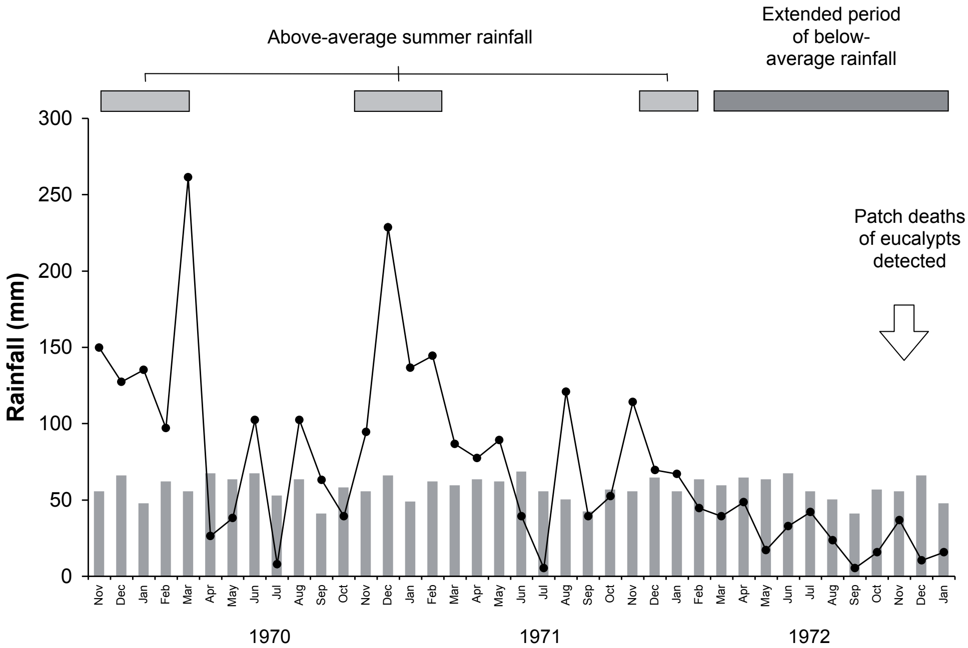
A greater understanding of the role of *P. cinnamomi* generally in Tasmanian forests resulted from the work at this site; eucalypts are relatively resistant to the disease but on some sites it can have a major influence on understorey species. It should be noted that the choice of this site for long-term monitoring on Tasmania's sunny east coast adjacent to beautiful white beaches with rolling surf was always treated with much cynicism by the pathologists' colleagues in the Forestry Commission!

Rural dieback

Dead and dying trees in the Midlands pastoral region have aroused public concern for several decades. Their impact on the aesthetics of the region is clearly visible from the main highway from Hobart to Launceston, which passes through some seriously affected areas. In addition, the tree deaths reduced shelter for stock. Forestry Commission staff carried out research on causes of the problem in the 1970s and 1980s, in co-operation with the Commission's Private Forestry Division and local landowners. It was recognised at the time that the problem required a multi-disciplinary approach due to the wide range of factors involved. However, the debate about where responsibility for this work lay and where the large amount of funding required would be sourced, remained unresolved. The Forestry Commission concentrated its efforts on providing advice, and testing methods of establishing trees in affected areas (see Chapter 7).



Dead and dying eucalypts infected with the root-rot fungus *Phytophthora cinnamomi* near Chain of Lagoons, eastern Tasmania, 1974.



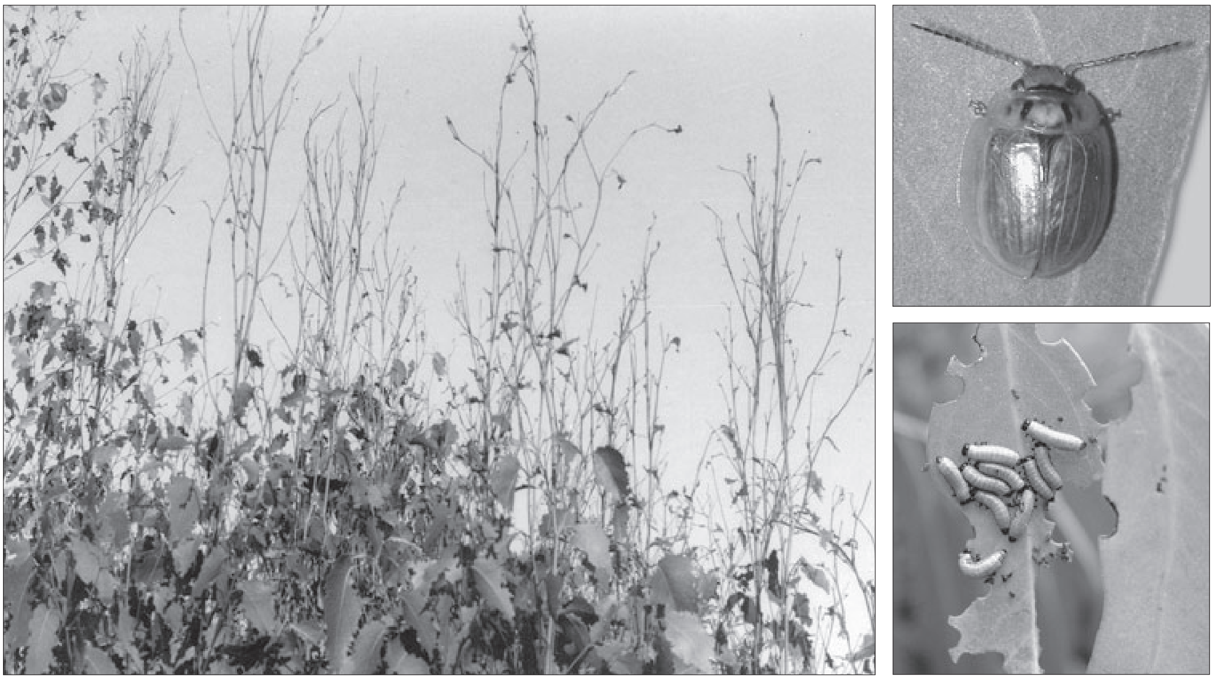
The relationship between rainfall patterns in the early 1970s and the occurrence of dieback of eucalypts in east coast forests. The line graph shows actual monthly rainfall over the study period; the vertical bars along the x-axis are the long-term monthly rainfall averages. (Adapted from Wardlaw and Palzer 1988.)

In the 1980s, Humphrey Elliott and Dick Bashford experimented with sustained watering of large dying trees and showed that some could recover remarkably quickly, putting out numerous epicormic branches. They also investigated the defoliation of shoots which commonly occurred on drought-stressed trees and found that the main culprit was the eucalyptus weevil, *Gonipterus scutellatus* (Elliott 1990). Subsequently, possums were implicated as a major factor in the dieback, and staff from the Department of Primary Industries, Water and Environment confirmed that possums could have an important role. From this work, many trees in affected areas were clad in sheet-metal bands to deter possums from climbing the trees to reach the foliage.

In the mid 1990s, the National Landcare Program funded a review of factors implicated in rural tree decline and management actions to arrest it. This project was conducted by Mark Neyland and supervised by a panel of representatives from the Department of Primary Industries and Fisheries, Forestry Tasmania, the Tasmanian Farmers and Graziers Association, Greening Australia, and Private Forests Tasmania. It was concluded that the cause of the decline was a combination of drought, possum browsing, insect attack and changes in the local environment through land clearing and farm management practices. Fencing of remnant forests to enable regeneration to establish and control of browsing animals were the principal recommendations put forward to alleviate the problem of rural tree decline (Neyland 1996).

Developing management strategies for leaf beetles

Defoliation of eucalypts in Tasmania by leaf beetles (Chrysomelidae) had been observed by forestry staff for many years, but it was not until Ron Greaves was awarded an Australian Newsprint Mills (ANM) post-graduate scholar-



Defoliation of young *Eucalyptus regnans* shoots in the Florentine Valley, 1966. Larval leaf beetles (bottom, right) and adults (top, right), mainly *Chrysophtharta bimaculata,* are responsible for the damage, which can have a significant impact on growth rates and tree form.

ship in the early 1960s that any research on this important problem was done. Ron's research provided information on the biology of the main leaf-beetle pest, *Chrysophtharta bimaculata*, and its impact on the growth of eucalypt regeneration in what was then the ANM Concession forest in the Florentine Valley (Greaves 1966). This initial work was followed in the 1970s and early 1980s by detailed studies of the pest's biology by David de Little in the north-west, firstly as a post-graduate student and then with Associated Pulp and Paper Mills (APPM) (de Little 1979, 1983).

Although the work done by Ron Greaves clearly established the serious impact that *C. bimaculata* could have on eucalypt growth, no management strategy was developed following the completion of his studies. It was not until the 1980s when David de Little (APPM) and Humphrey Elliott worked together to quantify the natural biological control that occurred at each stage of the beetle's life cycle (de Little *et al.* 1990) that the groundwork was laid for a control strategy. Their work showed that some 80% of *C. bimaculata* eggs were eaten by ladybirds (*Cleobora mellyi* and *Harmonia conformis*), soldier beetles (*Chauleognathus lugubris*) and other insect predators. Over the leaf beetle's life cycle, the total natural control exceeded 90% at the study sites in the Florentine Valley in the south and Surrey Hills in the north-west. Experiments in the Florentine Valley by Humphrey Elliott, Dick Bashford and Anna Greener then established a correlation between the numbers of eggs and young larvae present on individual trees prior to significant defoliation occurring and the level of defoliation that would ultimately result. This work established a threshold level for eggs and young larvae which, if allowed to remain, would result in economically significant defoliation.

The impact of leaf beetles on the growth of *Eucalyptus regnans* in the Florentine Valley was quantified. One-year-old trees attacked by *C. bimaculata* lost approximately half of their potential height increment and basal area increment over a two-year period compared with similar trees protected with insecticide (Elliott *et al*. 1993). Using data from these and other trials, the impact of *C. bimaculata* on *E. regnans* was modelled by Steve Candy, who showed that defoliation typically seen in the forest could reduce growth over a 15-year rotation by 40% (Candy *et al*. 1992). Such high impacts of leaf beetles on eucalypt growth prompted significant funding for further research into the problem.

Based on this information and work by Greaves on foliage consumption by the different larval stages, the Forestry Commission's entomological staff developed an integrated pest management strategy (IPMS) for the larvae of *C. bimaculata* attacking eucalypt plantations (Elliott *et al*. 1992). The key to the strategy was regular monitoring to determine population size. The first stage involved allowing the eggs and early larval stages to be subjected to the consistently high levels of natural predation. Then, if frequent monitoring showed that the populations of *C. bimaculata* were still above the predetermined population threshold by the time the larvae reached their later stages (which cause most of the defoliation), insecticide could be applied to the pest population. As part of the IPMS development, synthetic pyrethroid insecticides were tested in order to obtain registration for use against leaf beetles.

The main benefits of the strategy were that frequent monitoring often showed that many populations which initially looked very damaging were reduced by the predators to such an extent that pesticide use was unnecessary, and it also established a scientific basis for any application of pesticide. The IPM system for leaf beetles became part of normal forestry operations in the late 1980s, but continuing research has guided several refinements as discussed below.

During the 1990s, Jane Elek, Anna Greener, Steve Candy and Dick Bashford refined the control strategy for leaf beetles attacking *E. nitens* and *E. globulus* plantations. The population threshold which indicated that application of insecticide would be beneficial was progressively lowered, and improved aerial spraying techniques were developed. Much of their research was aimed at finding a more environmentally benign insecticide than the synthetic pyrethroid, α-cypermethrin (Dominex®), which was very effective against the pest but also killed non-target insects, including the all-important predators.

The leaf-beetle work under the Intensive Forest Management Program (IFMP, see Chapter 5) was directed at the management of leaf beetles in eucalypt plantations being established for solid wood production. Entomological research under the IFMP was conducted by Jane Elek, with assistance from several staff, including Natasha Beveridge, Caroline Ringrose, Sue Baker and Nita Ramsden. Their studies further quantified the impacts of defoliation, particularly on the main plantation eucalypt *E. nitens,* and led to the development by Steve Candy of an impacts model for the beetles on plantation eucalypts. This model was incorporated into the Farm Forestry Toolbox (Private Forests Tasmania 2000) and allows beetle population thresholds to be assessed based on plantation age and growth rate and current costs and benefits. Potential management approaches were also investigated, including the use of trap trees (tree species attractive to the beetles which can be injected

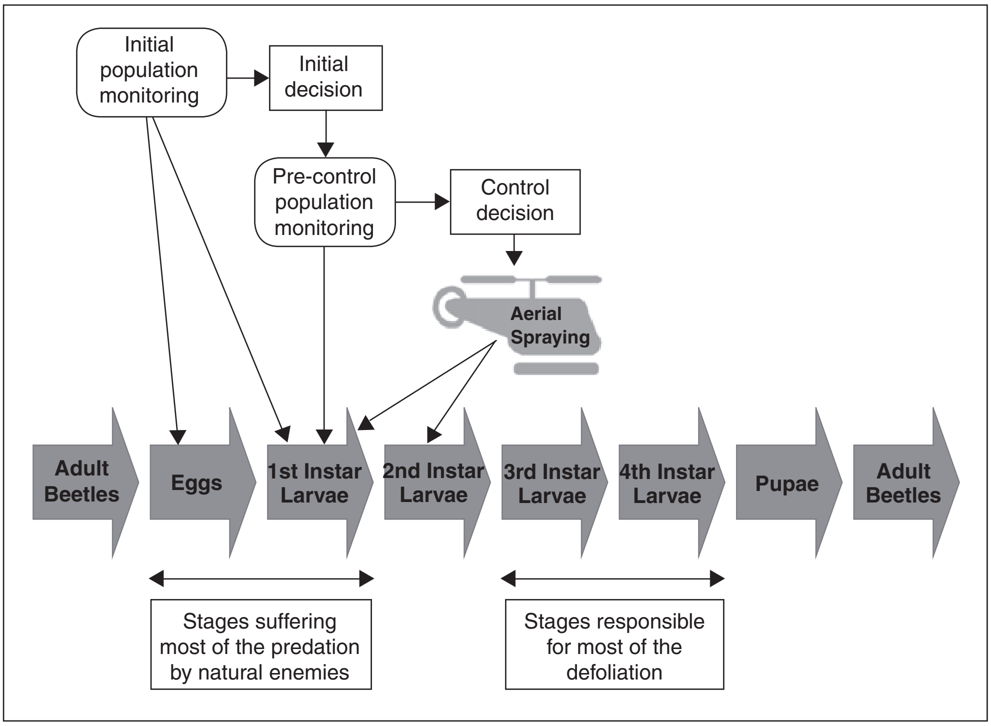
Rearing eucalypt leaf beetles in the laboratory for trials associated with the leaf beetle integrated pest management program. (Jane Elek pictured.)

with systemic insecticide or used for population monitoring) and use of the biological insecticide *Bacillus thuringiensis tenebrionis (Btt)* (Elek 1997). Research was also conducted at this time on another leaf-beetle species, *Chrysophtharta agricola*, which can cause significant defoliation of the juvenile foliage of *E. nitens* and *E. globulus* (Ramsden and Elek 1998).

Bacillus insecticides are effectively used in North America and Europe against lepidopterous pests. *Btt* shows activity against coleopterous (beetle) pests and a formulation used against the Colorado potato beetle in the United States of America was tested against leaf beetles in Tasmania. It initially showed some promise and appropriate dosage rates and methods of application were developed (Elek and Beveridge 1999). However, the small demand for a formulation specifically for use against leaf beetles inhibited investment in such a product by chemical manufacturing companies. *Bacillus* has since been shown to give variable results and is also expensive, so its widespread use against *C. bimaculata* in Tasmania is unlikely. More recently, Spinosad®, a more environmentally benign alternative pesticide to the synthetic pyrethroid α-cypermethrin, produced good results when tested against *C. bimaculata* and *C. agricola,* particularly in terms of preserving the complex of natural enemies of leaf-beetle larvae (Elek *et al.* 2004). Based on these tests, two formulations of Spinosad® (Success®

A pole-pruner being used by Jane Elek to collect shoots so that the number of beetle eggs and larvae per leaf can be determined.

The leaf-beetle team in the mid 1990s. From left: Dick Bashford, Sue Baker, Nita Ramsden, Bill Brown, Carolyn Ringrose, Natasha Beveridge, Jane Elek. Inset: Steve Candy and Humphrey Elliott.



The integrated pest management strategy for leaf beetles. Regular monitoring of leaf beetles and their predators and accurate timing of any control measures are critical components of the strategy. (From Elliott *et al.* 1992.)

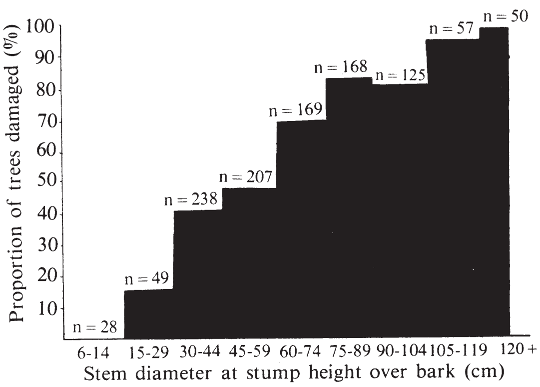
and Entrust®) have now been registered for use against leaf beetles and may replace α-cypermethrin for use in the IPM system.

The current control methods are directed against the larval stages of *C. bimaculata* but the adult beetles also attack eucalypt foliage and can cause severe damage, particularly in the late summer and autumn when the beetles feed before hibernating. Recent work by Jane Elek has quantified the damage caused by adult beetles and this information will be incorporated into a further refinement of the IPM system (Elek and Beveridge 2006).

The development of the leaf-beetle IPM and its incorporation into operational practice by Forestry Tasmania was an important initiative. It was the first time that a large-scale forest pest management program based on regular monitoring, population thresholds and impact models had been adopted by a major forest manager in Australia.

Termite damage in dry eucalypt forests

Unlike the mainland States, Tasmania does not have a serious problem with termites attacking timbers in houses and other wooden structures. However, investigations of low sawlog recovery in eastern Tasmanian forests in the early 1980s



Incidence of damage caused by the dampwood termite, *Porotermes adamsoni*, in various diameter classes of eucalypts harvested in Elephant Block, eastern Tasmania. (From Elliott and Bashford 1984.)

showed that the dampwood termite, *Porotermes adamsoni*, was responsible for major damage.

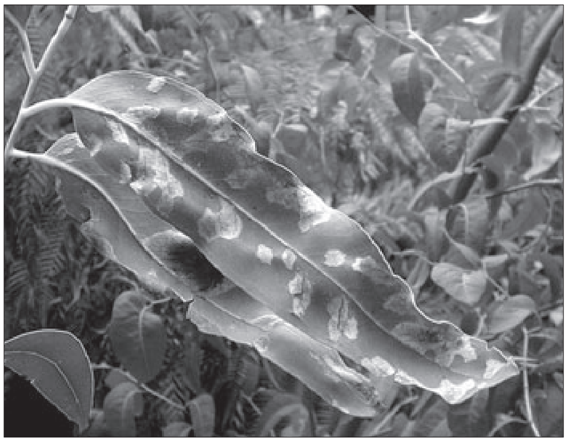
For several years, sawlog volumes actually recovered from these forests were far less than the volumes assessed before logging. Surveys showed that 60% of assessed sawlogs were rejected after cutting due to excessive defect caused mainly by *Porotermes*, and 43% of all potential pulpwood logs were graded as optional pulpwood; that is, they were not required to be taken due to excessive damage (Elliott and Bashford 1984).

The results of this work led to reductions in pre-logging assessed sawlog volumes due to termite damage, particularly in forests which had significant levels of fire damage, a factor known to promote termite access into standing trees.

Leaf blight

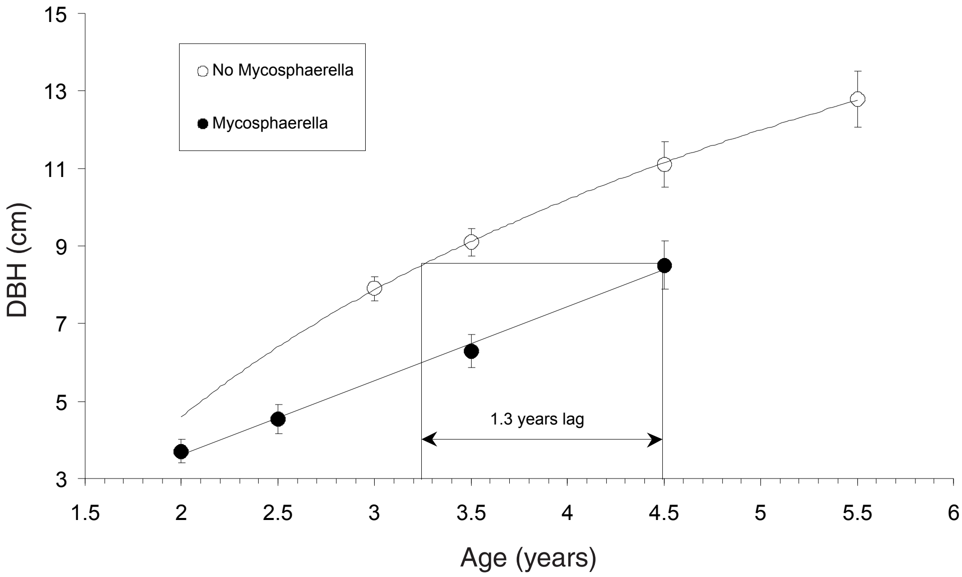
The warmer and wetter forest areas of the State, such as the far north-west, regularly produce ideal conditions for fungal leaf diseases. *Aulographina eucalypti* was mentioned earlier as a major factor causing Calder dieback. Another fungal leaf pathogen, *Mycosphaerella nubilosa*, emerged as a very serious defoliator of eucalypt plantations in the 1990s. This disease has had a major impact on *E. globulus* plantations near Smithton, so much so that planting of this species in areas prone to *Mycosphaerella* infection was suspended.

The effect of *Mycosphaerella* infection on growth was evaluated in the early 2000s by comparison of the growth of an *E. globulus* plantation which suffered severe defoliation from *Mycosphaerella*



Above: Eucalypt leaves damaged by the fungal leaf pathogen *Mycosphaerella cryptica.*

Defoliation of *Eucalyptus globulus* by the leaf-blight fungus *Mycosphaerella nubilosa* in north-western Tasmania.



Diameter growth in young plantations of *Eucalyptus globulus* defoliated by leaf blight, *Mycosphaerella* spp., in north-western Tasmania. This defoliation caused the loss of over one year's growth compared with undamaged trees. (From Wardlaw 2004.)

with that of an adjacent undamaged plantation. The results showed that the growth of the defoliated plantation had been set back by 12–18 months (Wardlaw 2004). Tim Wardlaw has been collaborating with Caroline Mohammed and Libby Pinkard from the CRC for Sustainable Production Forestry and the University of Tasmania on a range of research projects into this disease. Fungicidal control of the disease by foliar spraying in winter/spring was not found to be practical in the affected areas because of frequent windy conditions. Fertiliser applications (N and P) have produced some accelerated recovery of affected trees. Recently, Dean Williams has collaborated with Brad Potts (University of Tasmania) to establish a large genetic trial to screen elite *E. globulus* selections for their resistance to *Mycosphaerella*.

Decisions on future plantings in *Mycosphaerella*-prone areas will rest on a choice between *E. globulus* and *E. nitens*. *Eucalyptus globulus* has advantages in pulp yield, density and strength, but each species carries a forest health risk—*E. globulus* from *Mycosphaerella* and *E. nitens* from defoliating leaf beetles. A comparative evaluation of these risks will be needed for each proposed plantation where *Mycosphaerella* is a potential problem.

Stem decay in thinned eucalypt regrowth

Thinning of eucalypt regrowth has been practised from the earliest days of the Forestry Department (see Chapter 2). In recent years, the Forests and Forest Industry Strategy (FFIC 1990) identified thinning of eucalypt forests as one of the measures needed to optimise the sustainable supply of timber products from the reduced area of forests available for wood production. The Strategy recommended that the first priority for thinning to promote sawlog growth would be commercial thinning of the most highly productive regrowth forests which did not have a high risk of damage from fire, insects or diseases.

One of the main risks in thinning such forests is the retention of trees to grow on for future sawlogs that already have internal stem decay.

Assessing decay levels in timber sawn from trees from thinned and unthinned regrowth eucalypt forests. (From left: Tim Wardlaw, John Hickey, Bernard Plumpton.)

Studies by CSIRO researchers Don White and Glen Kile during the Young Eucalypt Program (see Chapter 2) demonstrated the importance of minimising damage during thinning operations to avoid decay from wounds. Following this work, John Cunningham developed operational thinning methods that had a low risk of stem damage.

As part of the Intensive Forest Management Program conducted in the 1990s, Tim Wardlaw, Milton Savva and Andrew Walsh began a program to sample trees which met the criteria for retention as final crop trees in coupes scheduled for thinning (Wardlaw *et al.* 1997). Their challenge was to identify a set of external tree features indicating internal decay which could be used when assessing trees to be retained. The program lasted 10 years, during which time over 1000 trees were dissected and assessed for stem decay within the basal 12 m of the stem.

The assessments indicated that 15% of the merchantable sawlog volume expected to be produced from retained trees would be downgraded to pulpwood because of stem decay, with further discounting for appearance-grade products. Incorporation into existing selection criteria of external stem features such as abundance of dead and live branches in the basal 12 m of stem could reduce by 20–30% the losses due to downgrading of sawlogs because of stem decay (Wardlaw *et al*. 1997; Forestry Tasmania 2003b). There was also a significant relationship between stocking and decay levels, stands with lower stocking having decay in a greater proportion of stem volume and a higher proportion of trees containing severe decay. Also, the usefulness of using external stem features to predict trees with decay declined as stocking decreased.

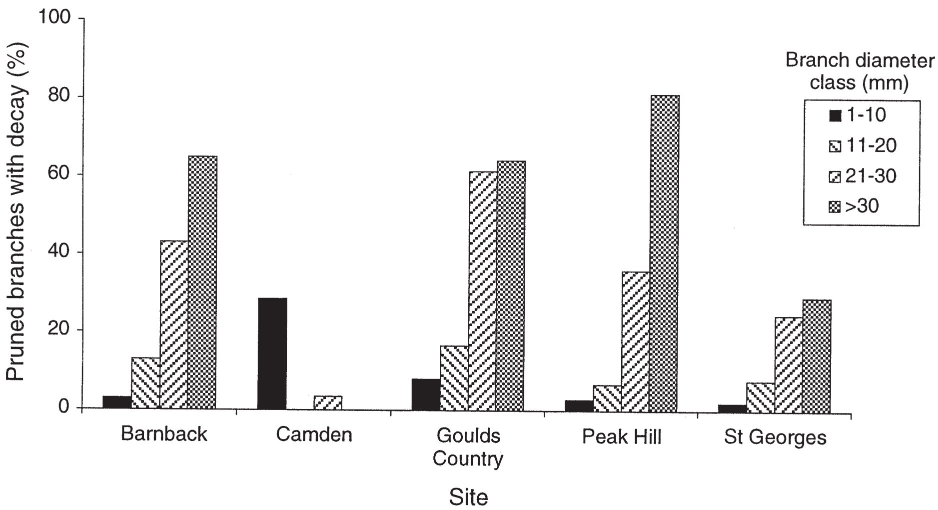
Overall, this research validated the existing criteria for tree retention. Selection of retained trees using the criteria with a bias towards preferential retention of larger trees could reduce the proportion of severely decayed final-crop trees by 29% in lowland *E. obliqua* forests and 65% in other wet eucalypt forests. These figures represented an additional 5000 m^3/yr of sawlog from a 300 ha/yr commercial thinning program.

Decay in pruned eucalypt plantations

The two main species, *E. nitens* and *E. globulus*, being used in Forestry Tasmania's eucalypt plantation program to produce solid wood products require pruning of the lower stem to limit the size of the knotty core and maximise the amount of high-grade clearwood available for processing. Although relatively small, the stem wounds produced by pruning are potential entry sites for fungi which can cause stem decay. The effect of pruning on growth and form was an important part of the research in the late 1990s to the early 2000s associated with the development of management systems for eucalypt plantations growing solid wood (see Chapter 5). Part of this research examined the incidence of decay in pruned final-crop trees.

The incidence of decay in *E. nitens* associated with pruning scars was initially investigated by Tim Wardlaw and Bill Neilsen using trees from 12–16-year-old plantations from five locations across Tasmania. They found that a high proportion of pruned branches were associated with decay spreading from branch traces into the stem, although there were significant differences in decay risk across sites. Pruning of larger branches produced a much higher risk of decay, a result which guided future prescriptions for maximum pruned branch size in plantations grown for solid wood products (Wardlaw and Neilsen 1999). This work triggered a major research program at the CRC for Sustainable Production Forestry supervised by Caroline Mohammed. An important finding from this research was that, on the most productive sites, pruning of eucalypt plantations at any time of the year may result in increased levels of stem decay originating from pruning wounds.

Libby Pinkard, working with Forestry Tasmania and the CRC for Sustainable Production Forestry, imposed different intensities of pruning on *E. globulus* to determine effects on growth response and decay. The experiments showed decay was a significant problem only when pruning removed 70% or more of the length of the crown, a level of crown depletion much higher than that used operationally. This decay problem was correlated with a higher incidence of live branches removed (Forestry Tasmania 2001c). Form pruning of *E. nitens* was also investigated as an option for reducing the number of large live branches in



The proportion of pruned branches associated with spreading columns of decay in *Eucalyptus nitens* plantations at five sites across Tasmania. (From Wardlaw and Neilsen 1999.)

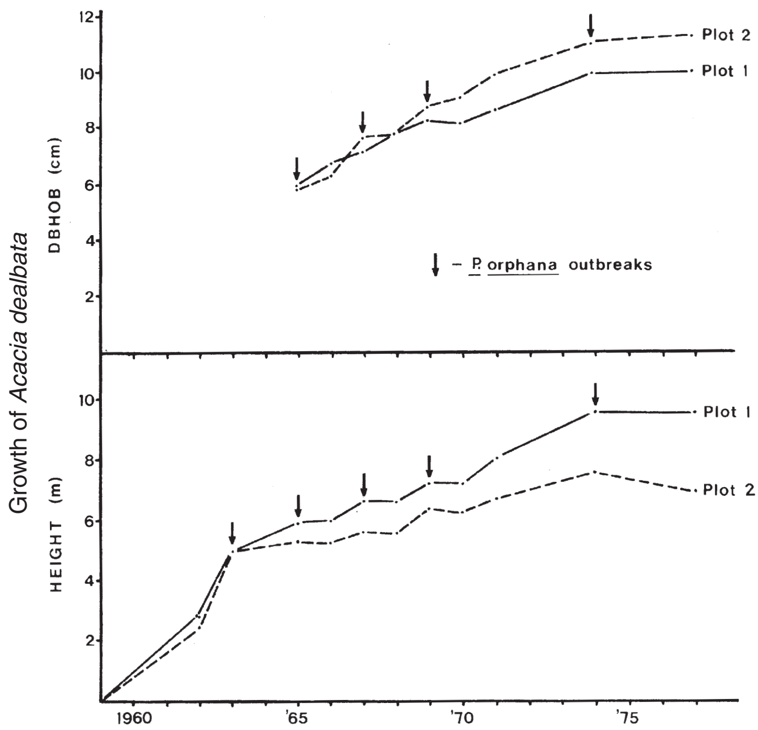
Left: Typical method of pruning young eucalypt plantations, using shears. Top right: A section through a pruned dead branch of *Eucalyptus nitens* showing a kino trace defect. Bottom right: The cambium below this pruned branch was damaged (arrow) during pruning, causing a decay column to develop.

that part of the crown retained at the time of first lift pruning. However, because removal of large branches increases the risk of infection by decay-causing organisms, careful timing to ensure branches were removed before they exceeded the threshold size was considered the best method of minimising the potential decay problem (Forestry Tasmania 2000c). More recent investigations of stem decay in older plantations (age 26 years) gives some confidence that *E. nitens* may be able to limit decay to within the knotty core.

Pests of Wattles

Silver and black wattle (*Acacia dealbata* and *A. mearnsii* respectively) were commercially important in Tasmania until the mid 1900s for the tanning properties of their bark. More recently, silver wattle has been shown to have high pulp yields and is also sawn in small quantities for furniture and craftwood.

The fireblight beetle, *Acacicola orphana*, is the only commercially significant pest of *Acacia*



History of *P. orphana* damage in *A. dealbata* plots.

1959	Slash burn and sowing of wattle.
1962	Young wattles growing vigorously.
1963	First defoliation by *P. orphana* larvae - Mean defoliation 80%.
1964	Wattles refoliating. Mean defoliation 60%.
1965	Severe *P. orphana* damage. 50% of plot trees completely defoliated.
1966	Wattles refoliating.
1967 (May)	Wattles completely refoliated after 1965 defoliation.
1967 (Dec.)	Severe *P. orphana* damage noted since May.
1969 (Feb.)	Wattles recovering but widespread shoot dieback evident.
1969 (Nov.)	*P. orphana* outbreak occurred during winter.
1974 -1977	Consistently high *P. orphana* populations. Wattles in a severely debilitated condition. Several trees dead and no growth recorded for remaining trees.

A history of defoliation of silver wattle, *Acacia dealbata*, by the fireblight beetle, *Acacicola orphana* (formerly *Pyrgoides orphana*) in the Florentine Valley. Note that 'sowing' refers to regeneration from ground-stored seed. (From Elliott 1978.)

species investigated by Forestry Tasmania. The larvae of this beetle cause very severe defoliation of silver and black wattles. Research was conducted on this pest because of its impact on the growth of a potential plantation species. There was also some possibility that the beetle might have potential as a biological control agent for wattles where they occurred as weeds in eucalypt and pine plantations.

The life history and impacts of the fireblight beetle on silver wattle in the Florentine Valley were investigated (Elliott 1978). Although natural populations of the beetle have caused extensive and timely defoliation of wattle in eucalypt and pine plantations in some areas over many years, attempts to introduce it into wattle-infested plantations where it was not naturally present were unsuccessful.

The potential risk of severe defoliation from the fireblight beetle on *Acacia* plantations is not currently an issue for Forestry Tasmania. Trial plantings of wattles were conducted during the Intensive Forest Management Program (see Chapter 5), but poor form of the young plantations was a major problem and no further plantings are planned.

Managing Browsing Mammals

Browsing of young eucalypt, pine and blackwood seedlings by native and introduced mammals has always been a concern for forest growers in Tasmania. The severe effects of browsing on pine plantations were noted in the 1940s:

> *Shortage of wire-netting has created many difficulties which have had to be overcome in order to reduce losses of young pines from attacks by rabbits and native game to a reasonable level. The worst case of damage during the year was at Kamona, where 65 acres of* Pinus radiata *were destroyed by kangaroo and wallaby.* [Forestry Commission 1948, p. 11]

At that time, strychnine was the common poison for rabbits in agricultural crops. However, it does not appear to have been used against native browsers. Sodium mono-fluoroacetate (1080) replaced strychnine in the early 1950s and was first used against native mammals in the early 1960s. It continued to be a major tool for reducing browsing of agricultural and forest crops for some five decades, but in 2005 the Tasmanian Government announced that its use in State forests would cease at the end of that year.

Much of the Forestry Commission's silvicultural research effort after 1950 was concentrated on the best way to establish fully stocked and fast-growing regeneration of the commercial eucalypt species. Consequently, the impact of browsing mammals on growth and particularly methods of restricting damage became very important components of these broader studies.

The earliest reported research on the browsing of young eucalypt seedlings by mammals was conducted by Bill Mollison working for Australian Newsprint Mills in the Florentine Valley in the late 1950s. He studied animal behaviour and control methods suited to the heavily forested country of the Florentine Valley, noting that:

> *… shooting and dogging are essentially open-country operations and cannot seriously be considered as control measures.* [Mollison 1960, p. xxiv]

Bill's studies included the usefulness of different baits containing 1080. He concluded that a bait of a dry bran-pollard mix was the most effective, and also tested large box traps to catch live animals that could then be killed and used for food.

A young *Eucalyptus nitens* plant defoliated by possums.

Caged eucalypt seedlings in the Florentine Valley, late 1950s, in one of the early research trials investigating the effects of browsing animals. (Max Gilbert pictured.)

Max Gilbert, as part of his ecological studies in the Florentine Valley, demonstrated the serious impact of browsing animals on establishment and growth of eucalypt regeneration (Gilbert 1961). Kurt Cremer (ANM Research Fellow and Forestry Commission) and Tony Mount (Forestry Commission) continued studies of this problem as part of broader investigations into the ecology of *Eucalyptus regnans* in south-central Tasmania (Cremer 1960, 1962, 1965, 1969; Mount 1964). These studies identified the main pest species as Bennett's wallaby (*Macropus rufogriseus*), brushtail possum (*Trichosurus vulpecula*) and red-bellied pademelon (*Thylogale billardierii*). Cremer's studies showed that recovery from browsing depended on season of defoliation, with autumn/winter attack having a much more severe impact on growth and survival than spring/summer attack.

Helen Fletcher was appointed in August 1977 to carry out research on the effects of 1080 poisoning. This work was supported by the 1080 Research Fund, initiated by the Forestry Commission. The Fund changed its name to the Browsing Animals Research Fund in 1980 to reflect the broadening of the research to include studies of the main pest species responsible for the browsing damage. The 1080 Fund also supported post-graduate studies at the University of Tasmania by Greg Hocking, who conducted research into the ecology and behaviour of the brushtail possum, *Trichosurus vulpecula* (also see Chapter 7). The Fund was financed by contributions from the Forestry Commission and the major pulpwood and woodchip export companies operating in Tasmania at the time. The research funds were administered by a committee with representatives from the forestry companies, Forestry Commission, the Department of Agriculture, and the National Parks and Wildlife Service.

In 1983, the comprehensive research by Helen Statham (nee Fletcher) resulted in a review of the browsing problem and the effects of 1080 poison (Statham 1983). She pioneered work on the ecology of the main animal browsers, and her studies of browsing damage in different areas of the State showed that the main browsing mammal pests varied with crop and location. For example, Bennett's wallaby was the main pest of *Eucalyptus delegatensis* in the Mersey Valley study sites and of radiata pine in the Fingal sites. However, pademelons were the main browsers of young blackwood seedlings in the Smithton District. Helen concluded that 1080 was a valuable control tool and a safe poison if used at the concentration of 0.014% under the controlled distribution system. Carrot bait was preferable to apple in terms of lower levels of poisoning of non-target wildlife, and significant secondary poisoning of native carnivores feeding on poisoned carcasses was very unlikely because of the massive amounts that needed to be ingested.

Helen Statham also tested the theory that repellents applied to vulnerable plants would provide protection against browsing mammals. Her trials are thought to be the first test of repellents against forest mammals in Australia. Egg powder, blood and bone, thiram (a fungicide; active ingredient tetramethylthiuram disulphide), aluminium ammonium sulphate and quassia chips (from the wood of *Quassia amara*) were tested on radiata pine seedlings for effectiveness as browsing repellents. Only the egg powder and blood and bone treatments showed any repellent properties. But once new shoots formed, the repellent substances applied were left behind and the unprotected shoots were browsed. In a separate trial in an agroforestry situation in southern Tasmania, egg powder in various formulations significantly reduced the extent and severity of damage to pines by sheep, probably because of the rotten egg gas smell of the treatment!

The information gathered by Helen Statham was condensed in 1986 into the Forestry Commission's first detailed advice on managing the browsing problem (Forestry Commission 1986). Management prescriptions included the use of sacrificial plots of seedlings and fenced indicator plots which enabled staff to monitor browsing activity in regenerated coupes (see also Chapter 2).

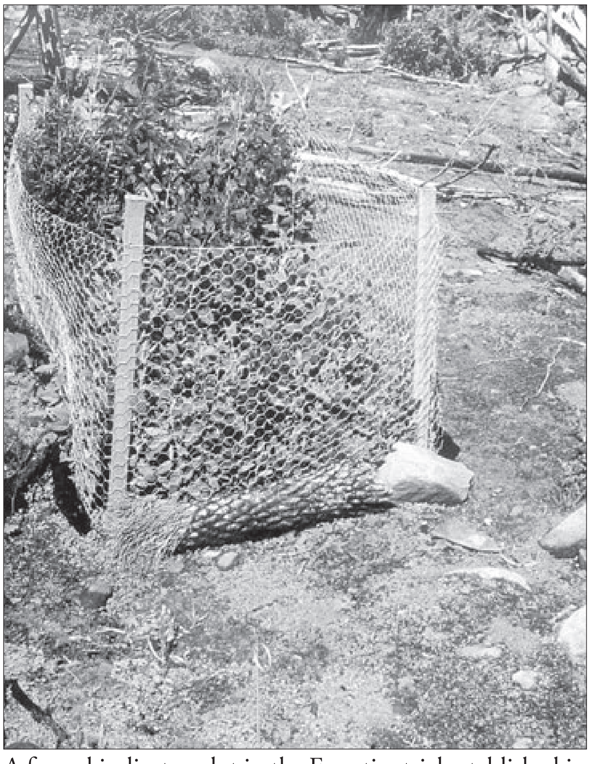
Most browsing studies from the 1960s to the 1980s were conducted on eucalypts in regeneration areas, but browsing was also of considerable concern in some radiata pine plantations. Bill Neilsen conducted simulated browsing trials in the late 1970s, in which clipping treatments (tip removal, 50% plant removed, plant removed down to 25 mm from ground) were imposed on radiata pine seedlings at different times after planting. These trials established that unless browsing was severe and repeated it did not significantly reduce growth rates or response to fertilizer in radiata pine plantations (Neilsen 1981).

The next major browsing trials were conducted by the Forestry Commission when a decision was made in the mid 1980s to establish significant areas of eucalypt plantations. Large trials of eucalypt species and silvicultural techniques were established by Bill Neilsen, Graham Wilkinson and other research staff at Goulds Country in the north-east. Simulated browsing studies were carried out as part of these trials to better understand the effects of browsing. Very pronounced effects on the growth and survival of young *Eucalyptus nitens* and *E. regnans* seedlings resulted from a range of 'clipping' treatments to simulate different levels of browsing. All treatments produced significant effects but the most severe treatment (complete shoot removal to within 25 mm of the ground) resulted in growth to age three years of treated seedlings being only 9% of that of untreated control seedlings (Neilsen and Pataczek 1991).

An evaluation of eucalypt plantations at Goulds Country by Bill Neilsen and Graham Wilkinson concluded that browsing could have severe long-term effects on the productivity of eucalypt forests. Their studies of 586 ha of *E. nitens* and *E. regnans* plantations showed that

63% of unprotected plantation areas had failed due to browsing, mainly by Bennett's wallaby, representing a loss of $387 000 on the $614 520 spent on establishing those plantations (Neilsen and Wilkinson 1995). Survival and growth were very low in unprotected areas subjected to heavy browsing, mean annual increment (MAI) averaging 7.9 m^3/ha and 14.6 m^3/ha for heavily browsed and protected areas of *E. nitens* plantation respectively.

Artificial defoliation of *E. nitens* seedlings was also used by Graham Wilkinson in the eucalypt plantation trials at Goulds Country to simulate the effects of browsing at different times and intensities on survival and growth. His work showed that the level (severity) of defoliation produced greater effects on survival and growth than the time of year that treatments were imposed. The impacts of different levels of defoliation and timing were quantified and the results confirmed that it was essential for eucalypt plantations to be protected against browsing mammals if their full growth potential was to be realised (Wilkinson and Neilsen 1995).



A fenced indicator plot in the Forestier trial established in the late 1980s in south-eastern Tasmania. It shows clearly how protection from browsing marsupials and rabbits can benefit survival and growth of eucalypt seedlings.

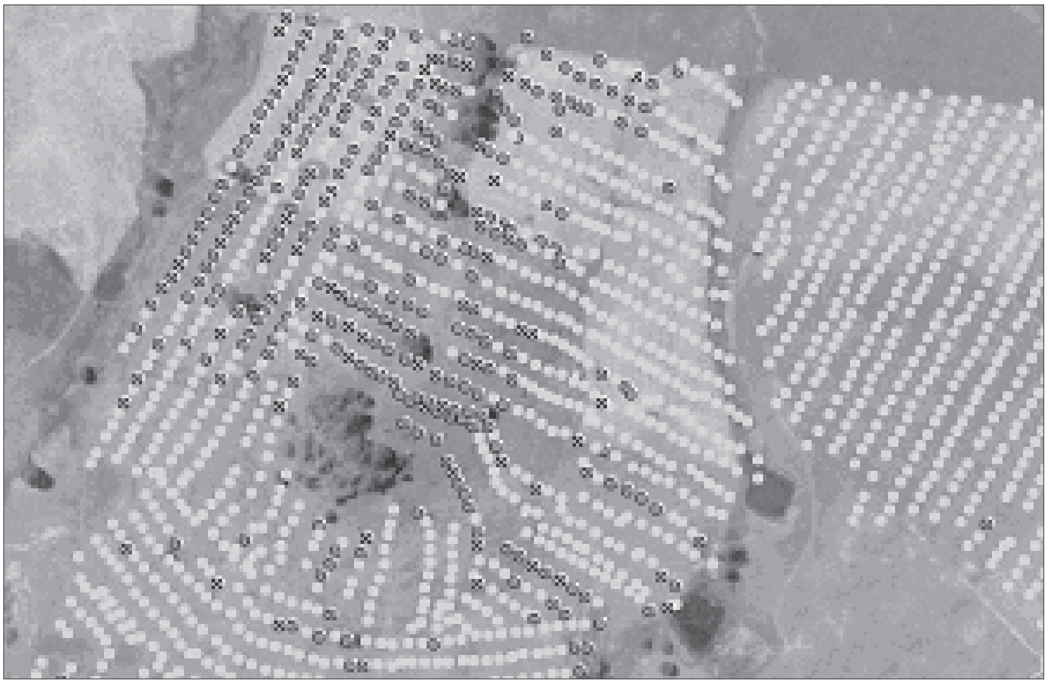
The behavioural ecology of browsing mammals, alternatives to 1080 poison such as repellents, and silvicultural techniques were investigated by Sue Parsons as part of the Intensive Forest Management Program associated with the implementation of the Forests and Forest Industry Strategy (FFIC 1990). The main results were that wallabies did not exhibit any strong territorial tendencies. Areas of forest, particularly those adjacent to cleared areas such as farmland, supported a reservoir of animals that could quickly move into young plantations and recolonise after control measures had been applied. The work on repellents added some more bizarre substances such as synthetic predator odours (big cats, foxes and coyotes) and oils from distasteful native plants such as *Zieria arborescens* (stinkwood) to the list of those tested in previous years. Although the substances had some repellent properties, they proved little more effective than those used in earlier trials and the problem remained of new growth extending beyond where repellent had been applied to the seedlings (Parsons *et al.* 1997).

Forestry Tasmania's eucalypt plantation program expanded considerably with the signing of the Regional Forestry Agreement in 1997 (RFA 1997), which included a commitment to plant some 20 000 ha of new plantation. A priority use for increased research funds in Forestry Tasmania resulting from the RFA was a concerted effort on the browsing problem. To this end, Nadia Marsh and Angela Jenni, and later Andrew Walsh and Tamara Kincaid, were appointed as the browsing research team. Their initial tasks were to consider the long history of research and operational developments related to the browsing problem and the varied operational controls in use, and to review practices for monitoring and controlling browsing damage within Forestry Tasmania Districts (Marsh

2000). This review highlighted several aspects of browsing management where improvements could be made, including bait laying and clean-up procedures for baits and carcasses, risk assessment of coupes prior to planting or sowing, and consistency of monitoring procedures across the Districts.

Concurrent with the research work described above were the continuing studies of browsing in native forests. During the 1990s, Leigh Edwards, Graham Wilkinson, Sue Jennings and other Native Forests research staff quantified growth losses to browsing animals using fenced and unfenced plots established in eucalypt and blackwood regeneration areas. The cause of regeneration losses and complete failures was not always obvious in native forest coupes; these trials and other similar investigations were used to emphasise the operational need to establish indicator plots and browsing transects within all native forest regeneration areas so that the incidence of browsing could be easily detected and monitored. This work on browsing in native forests was used to formulate management prescriptions and general information for District staff which was incorporated into several of the Native Forest Technical Bulletins (Forestry Commission 1991a, 1992a, 1994a; Forestry Tasmania 1999).

An effective browsing management system that does not include the use of 1080 was needed for plantations and native forests following the Tasmanian Government's ban on the use of that poison in State forests from 2006. Over recent years, Andrew Walsh and Tamara Kincaid have conducted detailed investigations into the spatial pattern of browsing in selected 'sacrificial coupes' where no control operations took place. This work showed that many plantations which were expected to have a high risk of browsing damage, in terms of the rate of browsing, varied widely in the actual damage that occurred. If the



A plot of the location of browsed seedlings in a eucalypt plantation two weeks after planting. The dark dots are heavily browsed seedlings and the lighter dots represent seedlings with little or no damage. Severely damaged trees are clustered around refugia such as large trees or piles of rock. (From Forestry Tasmania 2002b.)

Right and above: A eucalypt seedling treated with the repellent WR1. This tactile repellent, developed in Victoria, contains a sticker and grit. Research at Forestry Tasmania has shown that treatment of large seedlings with WR1 can be a useful method of reducing browsing damage in areas having a high risk of browsing, particularly where pademelons are the main culprit.

The Mersey Box Trap — a very effective trap for catching browsing animals, developed by Mersey District staff.

rate of damage is low, then seedlings can grow to a height beyond which they are not susceptible to browsing damage. From this work, risk factors are being identified which will enable better prediction of browsing risk so that coupe and plantation location and other operational factors can be assessed against these.

An initial integrated pest management strategy (IPMS) for browsing animals is being developed based on applying management strategies tailored to the assessed risk to individual plantations and native forest coupes. These strategies include the use of nursery seedlings with low susceptibility to browsing, creating ideal conditions for establishment and growth of seedlings, using repellents to slow down the rate of browsing and, when necessary, shooting (Walsh and Kincade 2005). Recently, effective trapping methods have been developed by staff in the Mersey District. District and research staff collaborated to provide scientific evidence showing the trapping methods were humane, and they have since been approved by the Animal Welfare Advisory Committee. Research to better understand the behaviour of browsing animals in commercial forest areas is also being conducted to assist the further development of the IPMS.

A feature of the browsing research has been the excellent co-operation between Forestry Tasmania, the forestry companies, and the CRC for Sustainable Production Forestry. The CRC, in particular, through the efforts of Clare McArthur and several post-graduate students, has contributed greatly to the understanding of browsing animal behaviour, feeding preferences, and other aspects of this major forest health issue.

Myrtle Wilt Disease

The orange-brown wilted foliage that indicates the death of myrtle, *Nothofagus cunninghamii*, has long been observed in rainforest and mixed forest in Tasmania and Victoria. Aerial photographs from the 1940s and 1950s indicate that myrtle wilt was present at the time in several major rainforest areas. The problem was first outlined in the scientific literature by Truda Howard in 1973, working in Associated Forest Holding's Concession Area south of Burnie (Howard 1973). She reported the death of large groups of myrtle and the presence of many tunnels of the ambrosia beetle, *Platypus* sp., in the dead trees, together with a mycelial felt in the tunnels. Knowing that many species of ambrosia beetles cultivate fungi as food for their larvae, she suggested that a pathogenic fungus was carried from tree to tree by the beetles, often killing the tree while at the same time feeding the beetle larvae.

The involvement of the Forestry Commission in research on this problem began in the late 1970s when Humphrey Elliott and Dick Bashford collaborated with CSIRO staff Glen Kile and Malcom Hall to study the cause of myrtle wilt. When wilting trees were closely examined, their most obvious symptom, apart from the dying leaves, was the large amount of frass (wood dust and insect excrement) on the trunk emanating from 1–2 mm pinholes. These were the tunnel entrances of the ambrosia beetle, which was subsequently identified as the mountain pinhole borer, *Platypus subgranosus*. Consequently, the main areas of research were the biology and behaviour of this insect and, as ambrosia beetles are associated with fungi, the nature of any fungal associates in myrtle trees attacked by the beetle.

Some initial experiments were set up to see if beetle attack could be induced on healthy myrtles. In an attempt to attract beetles, large cotton-wool pads were attached to the trunks of healthy myrtles and kept charged with ethanol from a five-litre drum strapped to the tree. This experiment simulated the release of volatile chemicals which occurs in sick or dying trees, many well-known species of ambrosia beetles

Dead and dying myrtles, *Nothofagus cunninghamii*, infected with the fungal pathogen, *Chalara australis*. A small beetle called the mountain pinhole borer, *Platypus subgranosus*, is attracted to infected trees and the wood dust from the beetles' tunnels covers the lower stems.

In early trials, logs infested with the mountain pinhole borer were caged around healthy myrtles to test whether beetles would emerge from the logs and attack the tree. The beetles were later found to be secondary pests which only attacked after trees were infected with the fungal pathogen, *Chalara australis*. This trial, near Sumac Road in Circular Head in the late1970s, was known by locals as the 'cemetery plot' for obvious reasons.

being attracted to trees in this condition. It was successful in attracting beetles to healthy trees and artificially modifying the beetles' behaviour in that they actually bored into trees which were not in a physiological state attractive to them (Elliott *et al.* 1983). Similarly, myrtle logs submerged in a dam for two weeks and then placed in the forest were heavily attacked by beetles relative to non-soaked (control) logs, presumably because of the volatiles released from the anaerobic fermentation in the soaked logs. Although these trials helped to understand beetle behaviour, they did not explain why some trees were susceptible to myrtle wilt or identify the actual cause of death.

To investigate what made myrtles susceptible to attack, trees were subjected to a range of stress treatments. In one experiment, individual trees in the Sumac rainforests near Smithton had beetle-infested logs piled round the trunk and these were caged in flowing white muslin to a height of about 5 m to try to force emerging beetles to attack the caged tree. This experiment became known locally as the cemetery plot as the large white shrouds looked quite eerie, particularly at dusk! To investigate the theory that beetle attack on myrtles in disturbed forests might be caused by physiological changes, a small patch of forest was cleared except for a few healthy myrtles which then had thermocouples inserted into their stems to determine any changes in temperature resulting from the greater exposure. These trees were christened 'heart machine trees' by one of the local foresters because of the apparatus protruding from their trunks. In a rainforest off the Gordon Road in southern Tasmania, the effects of drought were simulated by covering the ground around the trunks of myrtles out to the drip zone with plastic sheeting to prevent direct precipitation on the root zone. Another group of myrtles in the Florentine Valley had large amounts of soil piled up around their stems to simulate road-building disturbance. These trials were hard work but they all failed to induce myrtle wilt.

Eventually a fungal pathogen, *Chalara australis,* a relative of the oak wilt fungus, *Chalara quercina*, was found to be the cause of myrtle wilt (Kile and Walker 1987). Kile and Hall (1988) showed that wounds provided a direct infection site for the pathogenic fungus; it was not dependent on *Platypus* tunnels for entry into the trees and infection occurred prior to attack by the beetles. The invasion by the fungus resulted in dark brown radial streaks in the wood of infected trees and, when the bark was removed from these trees after beetle attack, the exposed beetle entry holes were found to be strongly concentrated in the stained areas.

Young myrtle regeneration in a rainforest gap, north-western Tasmania. Death of myrtles from myrtle wilt disease is a common mechanism for gap regeneration.

In addition to this research, a large survey of the incidence of myrtle wilt in a range of rainforest types in Tasmania was undertaken. This involved some 30 km of transects in undisturbed rainforest to determine the proportion of myrtle trees attacked and the health categories of these trees. This survey found that, on average, 24.6% of standing myrtles were dead or dying from the disease and, on the assumption that trees with brown foliage took one year to die, 1.6% of live myrtles were being killed by the disease each year (Elliott *et al.* 1987).

When the National Rainforest Conservation Program (see Chapter 7) began in 1988, Jill Packham was employed to conduct further studies on myrtle wilt. Jill found that the mortality rate should be revised downwards to 0.6% per annum because myrtles took longer to die than previously estimated. This was a great comfort to forest managers in terms of management of the disease. Jill also set up rate-of-spread plots in several rainforest types to monitor the progress of the disease over the long term. These plots have been measured periodically over some 20 years and show that in most areas there has been only a slight increase in the number of myrtles killed. Jill also established that functional root grafts occurred between closely spaced myrtles, thus facilitating the tree-to-tree spread of *Chalara* and resulting in the commonly observed clumping of attacked trees. She concluded that if current mortality rates continued it was unlikely that the disease would lead to any permanent change in forest structure; in undisturbed forest, myrtle wilt acts as a stand-regenerating mechanism (Packham 1991, 1994).

Monitoring of myrtle health for some 20 years following a range of selective logging treatments has shown that, after an initial increase in myrtle wilt in the treated areas, the disease stabilised at background levels reported for undisturbed forest. These results indicated that harvesting operations which retain at least 50% of the canopy will maintain an ongoing multi-aged structure provided damage to retained stems is low (Elliott *et al.* 2005).

Nursery Diseases

The loss of seedlings was a constant problem in the many early nurseries that were used to raise plantation stock after 1921, and the main diseases and pests responsible have been mentioned earlier in this chapter. In some cases, outside help to solve nursery pest problems was sought by the Department but, in those early years, it is probably a safe assumption that quite high losses, particularly from damping off diseases, were accepted as part of the process of raising seedlings.

With the arrival of Chris Palzer in the early 1970s, the incidence of *Phytophthora cinnamomi* in Branxholm and Perth nurseries was investigated. Infection of radiata pine seedlings at the Branxholm nursery near Scottsdale became so serious that it finally had to be closed and Perth became the only Forestry Commission nursery where pines were grown. There was some *P. cinnamomi* infection at Perth, but when land free of the fungus was purchased in 1978 at Native Point adjacent to the existing nursery, the opportunity was taken to upgrade hygiene measures, particularly against *P. cinnamomi*. The nursery extension was fenced, and all vehicle and foot traffic entering the nursery had to pass through anti-fungal baths; a steam-cleaning unit for vehicles was also installed. Finally, seedling production in the original infected land ceased. These measures provided effective protection of nursery stock from diseases.

Phytophthora, *Pythium* and *Fusarium* were recorded causing stem rot of eucalypt seedlings in the nursery (Wardlaw and Palzer 1985). These fungi were isolated from the river water which supplied the nursery, and installation of a micropore filter (5 µm) in the water line dramatically reduced damping-off problems (Palzer 1980).

Another major problem in areas where eucalypt seedlings were grown at Perth nursery was the fungus *Botrytis cinerea* or grey mould. Management prescriptions for grey mould were developed in the 1980s; these included improving ventilation around seedlings, appropriate timing of watering to reduce the time that wet foliage was present, and avoiding excessive lush foliage by adjusting the type and dosage of fertilisers (Wardlaw and Phillips 1990). The grey mould problem was further alleviated by the construction of several new shadehouses at Perth in the 1980s and 1990s with sides which could be opened to increase airflow, thus lowering the humidity and helping to reduce the spread of this fungus.

Forest Health Surveillance

In 1997, Forestry Tasmania introduced the first formal, structured forest health surveillance (FHS) surveys in Tasmania. Prior to this time, forest health problems were reported by District staff, members of the public and by specialists in the course of their research programs. The FHS initiative arose mainly as a result of the dramatic expansion in the establishment of plantations during the 1990s, particularly the hardwood plantations established under the Intensive Forest Management Program. By the 1990s, the proportion of actual and potential total wood volume coming from plantations had increased significantly and their relatively high cost of establishment and management compared with native forests warranted more systematic monitoring to detect health problems. In addition, Forestry Tasmania's eucalypt plantations were being managed for sawlog production, a regime requiring much higher cost inputs than for pulpwood production, thus raising the importance of risk factors such as pests and diseases.

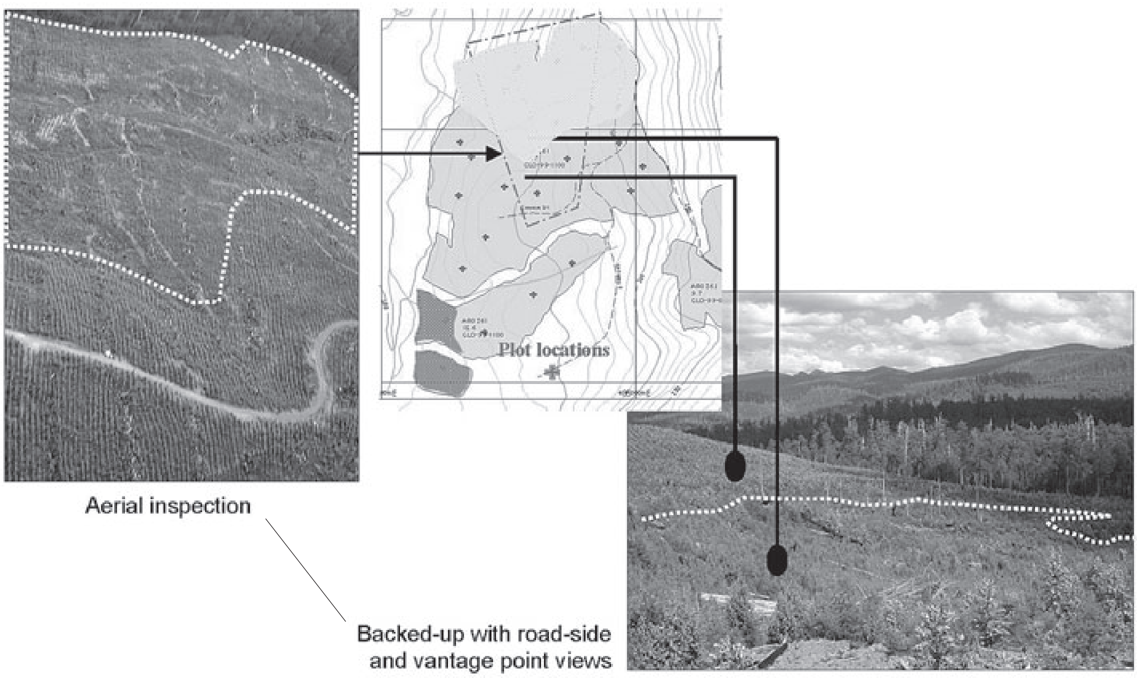
Forest Health Surveillance initially used a mix of survey techniques (aerial, drive-through, walk-through) to detect, assess and map forest areas with health problems. Monitoring and recording systems for FHS were developed by Tim Wardlaw and other staff of the Biology and Conservation Branch. The specific purposes of these surveys were as follows (Wardlaw 2005):

- Detect new incursions of exotic pests or pathogens;
- Identify emerging pest or pathogen threats;
- Trigger operational responses to detected health problems;
- Evaluate the effectiveness of control operations against particular pests and pathogens;
- Manage the risk of unacceptable losses from pests and diseases;
- Demonstrate sustainable forest management.

Karl Wotherspoon and Robyn Doyle were initially appointed to carry out the surveys. Sue Jennings and Nita Ramsden were later also involved in the FHS program.

The commencement of health surveillance on State forest in Tasmania coincided with a period when pruning began in the eucalypt sawlog plantations established during 1992–96, the first wave of plantation expansion following the Helsham Inquiry. The early guidelines for these plantations had strict specifications for attributes such as growth rate, stocking and size of branches on trees suitable for pruning. Operational decisions on when and where to prune were critical to the sawlog regime but monitoring systems to assist managers in decision-making were still evolving (Wardlaw 2005).

To satisfy this need, health status surveys were conducted in all eucalypt and pine plantations



A map showing the forest health condition of a eucalypt plantation area. These maps are produced by Forest Health Surveillance teams and are an invaluable aid to District staff for scheduling remedial action against pest problems or the timing of pruning. (Figure supplied by Tim Wardlaw.)

A forest health surveillance team during aerial surveys of eucalypt plantations. (From left: Karl Wotherspoon, Sue Jennings and the pilot, unidentified.)

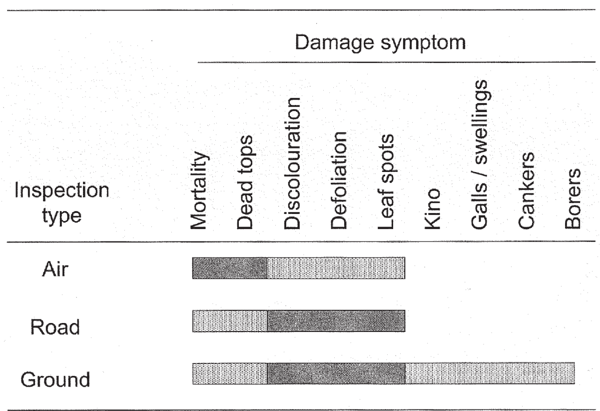
A sticky band trap being installed by Dick Bashford on a pine tree to monitor the occurrence of exotic pests in high-risk areas surrounding ports.

approaching the age when pruning decisions were made (18 months and three years respectively). These surveys provided detailed information about the growth and health of plantations. Maps were provided to managers showing the different performance in areas within each plantation.

District staff were very supportive of the new system as it provided detailed compartment-by-compartment information on health status, along with recommendations for any remedial actions. The system expanded to become a vital part of the overall silvicultural management of plantations. In addition to assisting with the timing of pruning, it also allowed informed decisions to be made on altering regimes such as bringing forward first pruning operations because of rapid growth, or changing to a pulpwood regime in poorly growing sections of some compartments.

A diseased eucalypt is inspected by Dick Bashford (left) and Tim Wardlaw during a ground survey.

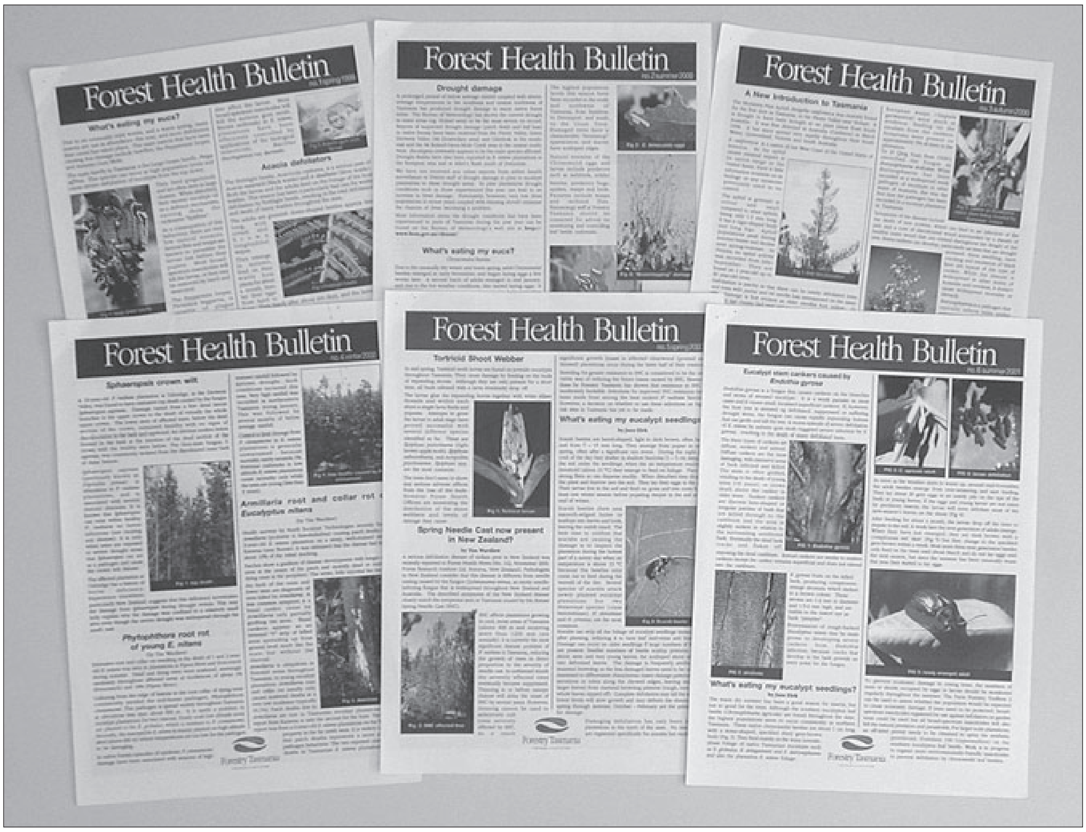
An intercept panel trap used to detect insect pests. The lure in the centre of the trap releases volatiles which attract the pests and they are captured in the container below the trap.



The effectiveness of different types of forest health survey techniques (air, road, ground) in detecting a range of damage symptoms. The darker shading indicates effective detection. (From Wardlaw *et al.* 2005.)

Recent analysis of the FHS system showed that the costly ground inspections were inefficient at detecting health problems when these occurred at a low incidence, aerial and roadside inspections being considered sufficient to detect pests and diseases that may warrant management intervention (Wardlaw *et al.* 2005).

Another recent development of the FHS has been the establishment of pheromone and other trapping systems in and around major ports of entry to detect new incursions. Pheromone trapping is being used for the Asian Gypsy Moth at Australian ports by the Office of the Chief Plant Protection Officer. A recent pilot study in Tasmania by Dick Bashford showed that the inclusion of funnel and panel static traps in a monitoring program around ports greatly expanded the range of pests intercepted and at low additional cost. This method has since been adopted by quarantine agencies as part of a national urban surveillance program.



Forest Health Bulletins – compiled by Forest Health Surveillance Officers to inform District staff about current pests, diseases and other disorders affecting tree health.

Forestry Tasmania's Current Forest Health Management Capability

From the 1920s to the present day, staff from Forestry Tasmania and other agencies have combined to gather basic information on a wide range of pests and diseases which damage forests. The Tasmanian Forest Insect Collection held by Forestry Tasmania is a nationally recognised source of information on forest insect biodiversity, pest species and their host plants. Detailed knowledge of the biology and behaviour of the main pests has accumulated from research and operational experience in plant health problems over many years.

Pests such as sirex wasp, leaf beetles, leaf blight fungus and browsing mammals are a constant threat to the economic viability of the State's forests. Sophisticated management systems have been developed for these and other pests from research into the biology of the pest and associated organisms, their impacts on tree growth and form, and control methods which are cost-effective and environmentally acceptable. These systems have been adopted operationally as a normal part of forest management and have also been used by other forest growers in Tasmania and elsewhere.

The Forest Health Surveillance system developed by Forestry Tasmania is regarded nationally as a model for effective detection and monitoring of plant health. It has also become an essential aid to decision-making by forest managers in the intensive management regimes for plantations.

Chapter 7

Forest Biology and Conservation

Introduction

There are many early references to the outstanding natural values of the forested lands of Tasmania. Excellent examples are contained in the narrative of the epic, pioneering journey of Sir John and Lady Franklin and party from Hobart Town through the western forests to Macquarie Harbour in 1842. The spectacular scenery in the vicinity of Frenchmans Cap made a particular impression on the party, poetically described thus:

> *It transcends the power of the most gifted pen; mine is wholly incompetent to convey the faintest idea of the scene that here meets the traveller's gaze. Its magnificent grandeur—its boundless extent—its infinite variety—its romantic loveliness—its pictorial wildness—the enchanting graces of its innumerable panoramic beauties, astound and delight, fresh subjects of admiration wooing the eye at every turn.* [Burn 1842, p. 16]

Though the magnificent scenery was a backdrop to the lives of the European settlers, it was not the preservation of wilderness and aesthetic values that was becoming the primary forest conservation issue through the nineteenth century. The major concern was the clearing of fine forests for settlement and agriculture, thus jeopardising the sustainable supply of timber. This problem was exacerbated by provisions in the *Waste Lands Act 1876* which required settlers to live for 14 years on their selected land and to improve it. Settlers naturally chose the most fertile sites and their 'improvements' usually entailed ringbarking and subsequent removal of highly productive forests. As the renowned nineteenth century priest, educator and scientist, Reverend Julian Tenison-Woods, commented after a visit to Tasmania:

> *The only way to prevent the wholesale destruction of the timber will be by proclaiming reserves or State forests, as they have done in Victoria … The matter is one which the Legislature should deal with promptly, or the forests of Tasmania, peerless and priceless as they once were, will soon be things of the past.* [Tenison-Woods 1878, p. 28]

Such was the concern that in 1881 provisions were added to the *Waste Lands Act* for setting aside areas of forest for 'preservation and growth of timber' (see Chapter 1). It was this Act that Sam Steane, Conservator of Forests from 1930 to 1947, considered the beginning of formal forest conservation efforts in Tasmania.

> *But it is the Waste Lands Act of 1881 which must be regarded as marking the birth of a State policy of forest conservation.* [Steane 1947, p. 3]

These early provisions were strengthened by the *State Forests Act 1885*, Section 3, which empowered the Governor in Council to make and issue regulations:

> *... for the care, protection and management of all state forests and public reserves and of all places of public recreation of which the care and control are not by law vested in some local authority, and for the preservation of good order and decency therein.*

The first Conservator of Forests, George Perrin, was appointed in March 1886. After a short inspection of some of the State's forests, he expressed great concerns over widespread wasteful and illegal cutting of trees, noting the tendency of settlers and landowners, particularly in the Midlands, to destroy practically all tree growth on their properties. He strongly recommended retention of blocks and belts of trees for shelter (Steane 1947).

Further forest protection initiatives were gradually introduced. In 1896, a regulation under the *Crown Lands Act 1894* proclaimed:

> *… no tree shall be felled so as to obstruct any road or tracks, or into any river or stream.*

An extract from the Chief Forest Officer's report of 1906–07 states:

> *To further aid the process of natural reafforestation commenced last year, timber reserves have been created in favourable localities … On all these reserves a young and promising growth of indigenous timber trees of commercial value has already been established, and only requires to be protected to produce, in the course of years, valuable marketable timber.* [Lands and Surveys Department 1907, p. 25]

These early attempts to protect the State's forests from wasteful cutting and general degradation were greatly expanded by the progressive dedication of State forest after the creation of the Forestry Department. An initial target of 1 500 000 acres (600 000 ha) was prescribed in the *Forestry Act 1920* (see Chapter 1). This measure, together with the sustained efforts to protect forests from wildfires and to improve the standards of utilisation, was a major shift for forest conservation away from the waste and destruction that had occurred in earlier times. The Forestry Department's first full-year Annual Report in 1922 summarised the optimism for this new era of forest management:

> *It is anticipated that many of the old forests that have been destroyed on the Southern waterways and other easily accessible localities will eventually be restored, and then protected and worked in such a manner that they will never again reach a stage of exhaustion.* [Forestry Department 1922, p. 5]

Although the main aim of the dedication of State forests was the sustainable management of these forests for a continuing supply of timber, statements in the Department's early reports (e.g. Forestry Department 1924, p. 6) clearly identify a broader conservation strategy:

> *... it should be made clear that the permanent reservation of forest areas serves many purposes, including protection of forest for catchment areas, mountain slopes, river banks, &c., to prevent erosion and regulate and conserve water-supply, forests in or near settlement for providing local requirements only, and for many other purposes, in addition to the main economic factor of continuity of supply of commercial timbers.*

When the Forestry Commission was established in 1947, this inclusive forest policy was again emphasised by the Chief Commissioner, Alec Crane:

> *The minimum objectives of forest policy must be the maintenance of adequate timber supplies of all classes and at all times for the needs of the people and timber-using industries of the State,*

the protection of watersheds and the conservation of the rich forest estate with which Tasmania was endowed. [Forestry Commission 1947, p. 3]

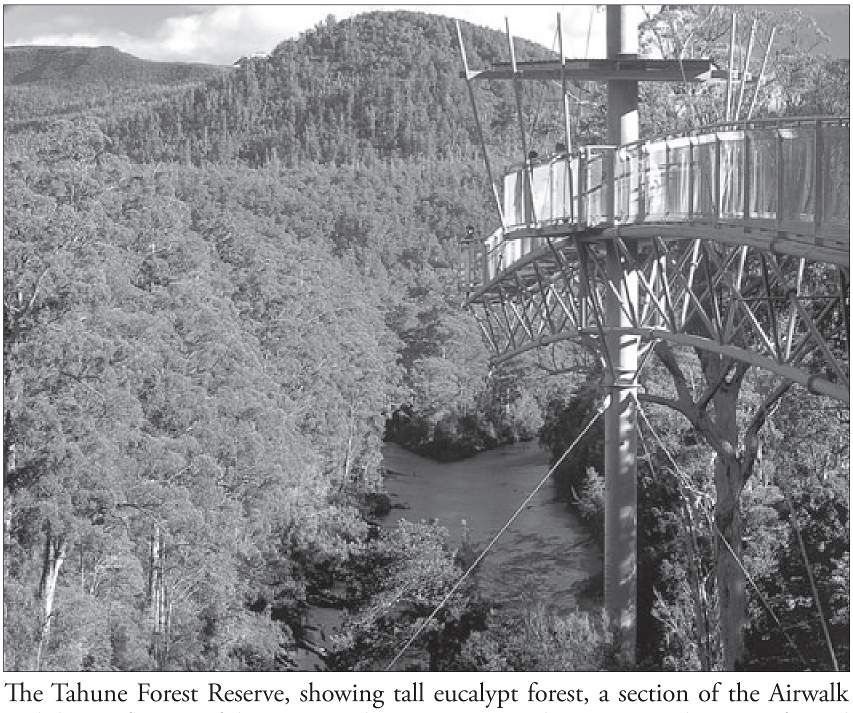
In the Commission's 1959–60 Annual Report, the concept of multiple use of the State's forests was discussed, together with the difficulties that are encountered when attempting to balance various uses. This report also articulated the Commission's landscape-level approach to forest conservation, a strategy still in place some 50 years later and still leading to conflicts at the local level:

Multiple use of the forests has kept pace in Tasmania with the impetus that integrated forest management is gaining in many parts of the world as the demands on these basic natural resources increase. It is the keynote of the recent agreements made in respect of the establishment of new wood-pulp and paper industries. It provides for recreational and watershed protection values of the forests also. As intensity of use increases, conflicts develop and multiple use becomes a major problem in practical application, to be resolved in the widest sense of public interest.

Basically, multiple use must deal with large areas of forest land. It does not, and cannot, mean that each small area and each tree are available for all uses and to all people. [Forestry Commission 1960, p. 3]

Favourite places were protected initially by informal methods, usually by field staff familiar with the special values of their local area. For example, the forest in what is now the Tahune Forest Reserve containing the Airwalk was taken out of wood production in 1967 by Jim Walker, the Divisional Forester based at Geeveston. During the 1970s, the Forestry Commission embarked on a program to establish Forest Reserves within State forest to provide facilities for recreation, or conservation of significant plant communities, or for aesthetic reasons.

The Forestry Act was amended in 1975 to allow Forest Reserves to be gazetted, if the Parliament



The Tahune Forest Reserve, showing tall eucalypt forest, a section of the Airwalk and the confluence of the Huon and Picton Rivers. This area was taken out of wood production in the 1960s, in recognition of its natural values, and has now become a major tourist attraction in the State, with well over 100 000 visitors annually.

agreed. The first forest reserves were opened at Oldina and Milkshakes Hills in the north-west in November 1975. Additional areas across all the major State forest regions were progressively gazetted over the next 20 years and, by 1994, there were 44 reserves totalling 20 384 ha, ranging in size from three to 3745 ha.

The disputes over dam construction for hydro-electricity production in the early 1970s, particularly the flooding of Lake Pedder, greatly increased public interest in the conservation of natural values generally in Tasmania. Forestry operations, being highly visible and widespread in the landscape, became a focus for comment and protest. Concerns were raised over many potential impacts, including loss of wilderness, effects on wildlife habitat, harmful effects of fires (including nutrient loss), use of pesticides, water quality, and spread of disease, especially the fungus *Phytophthora cinnamomi*. Many local forest conservation disputes arose (Bennett *et al*. 2006).

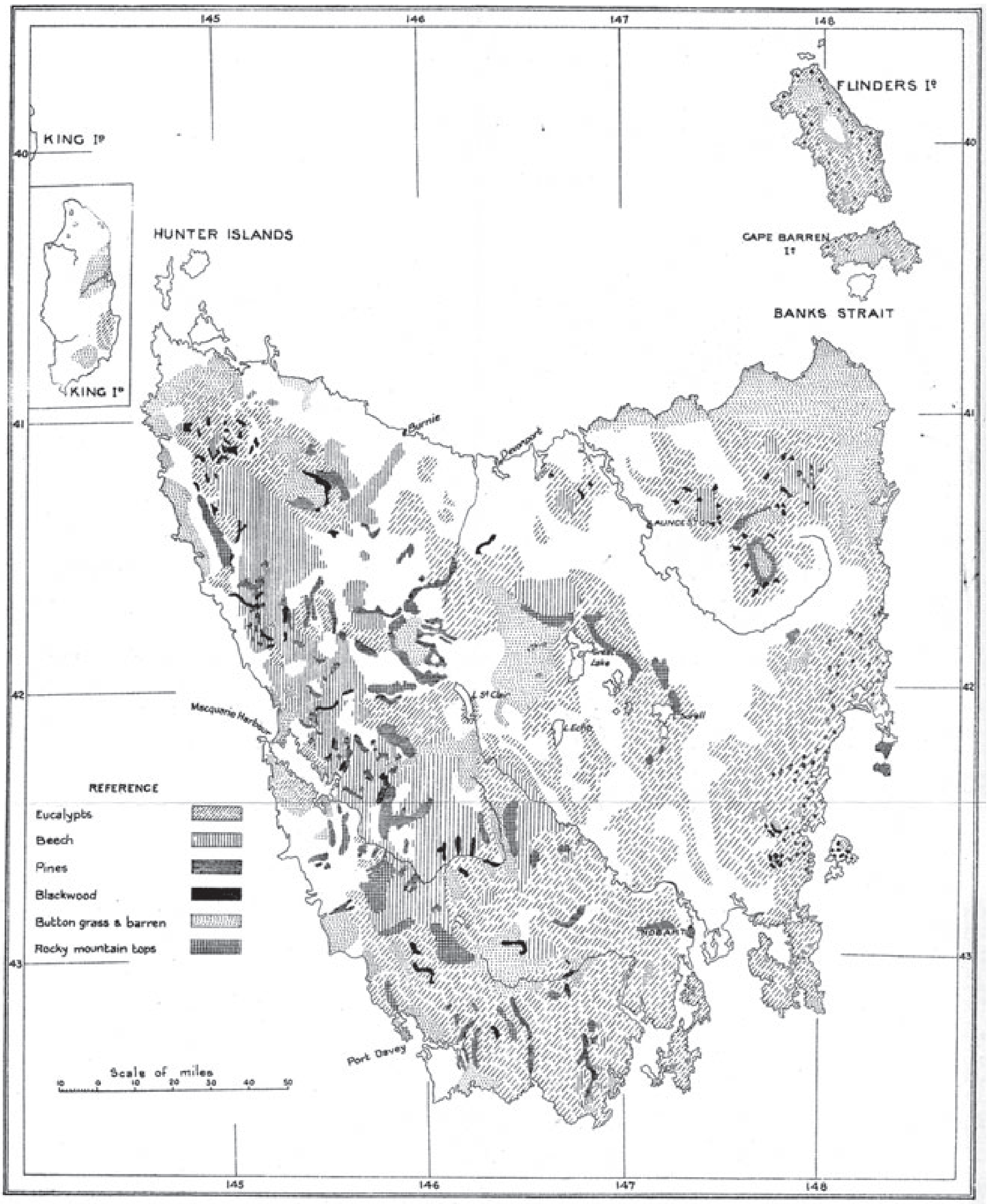
The Milkshakes Forest Reserve south of Smithton, established in 1975. It was one of the first two Forest Reserves to be opened. The other was opened the same year at Oldina, also in the north-west.

Concerns over the impacts of forestry activities on natural values led to a succession of inquiries resulting in several Commonwealth/State agreements which attempted to balance competing demands for production and preservation. A list of key inquiries/reports relevant to the conservation of natural values in Tasmanian forests is provided in Appendix 1. The data used in the analytical phases of the inquiries were mostly obtained from the research and inventory work of State agencies, particularly the Department of Primary Industries and Water, Forestry Tasmania, and the Forest Practices Authority (or their predecessors), the University of Tasmania, and private companies and individuals. This work was supplemented by results from projects on natural, economic and sociological values commissioned to fill knowledge gaps.

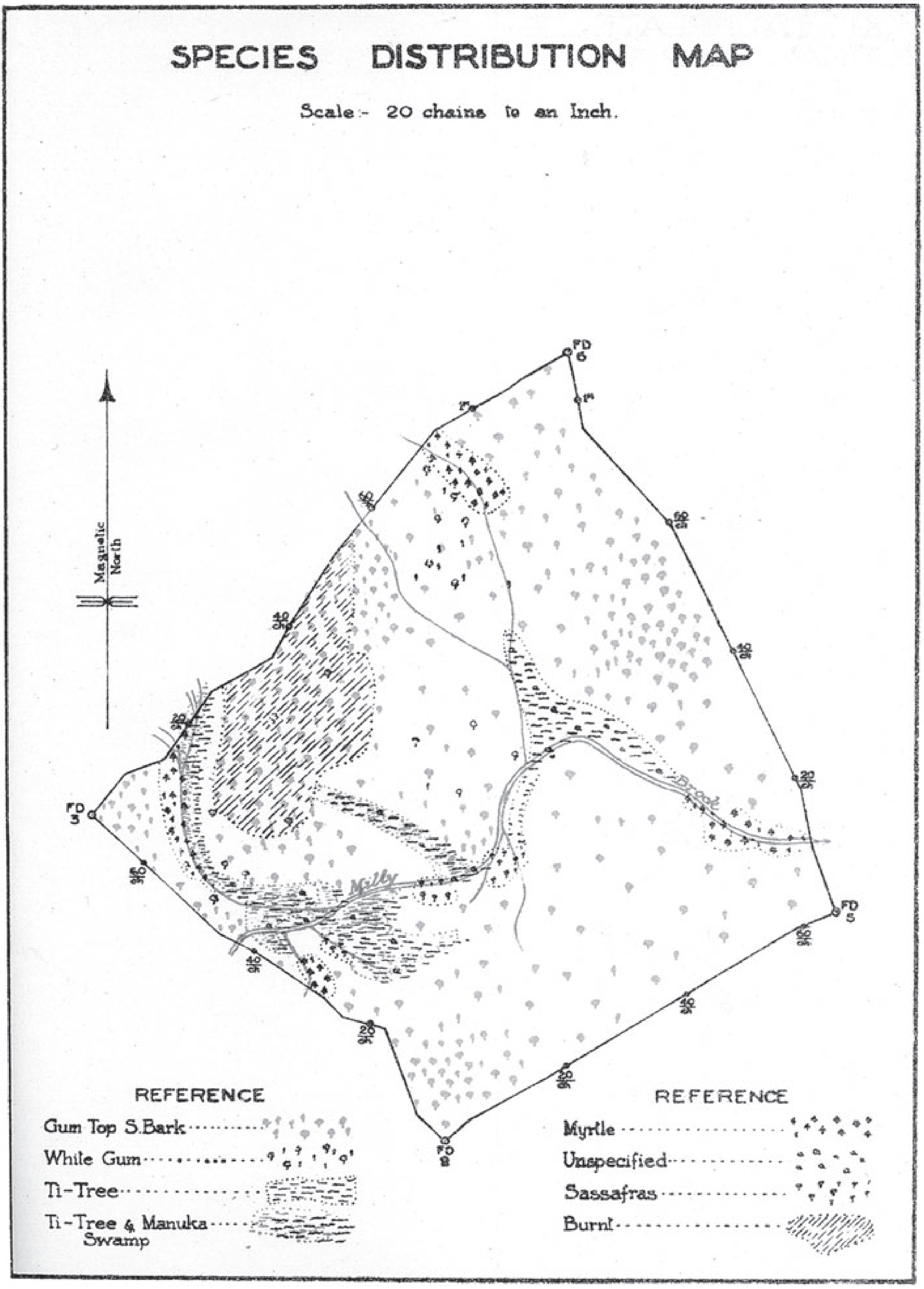
Forest biology and conservation research in Tasmania since European settlement can be grouped broadly into three phases. The first was a naturalist phase in which visiting naturalists gathered information on various forest values, mainly the identification of species of flora and fauna. In the second phase, the investigations evolved into more detailed research within each of the scientific disciplines. The third phase saw the integration of information on a range of values to provide a picture of the state of biological knowledge of the whole forest. The inquiries mentioned above were instrumental in providing such a picture, the first being the Environmental Impact Statement on Woodchip Exports in 1985, continuing through to the Regional Forest Agreement of 1997 and the Tasmanian Community Forest Agreement of 2005. Information on some of the main inquiries and Government agreements has been included within this chapter to provide a context for the conservation research associated with them.

Early In-House Research

The earliest specific research activities of the Forestry Commission in forest biology were inventories paralleling studies of wood resources (see Chapter 1). The forest type maps produced for those studies were very useful vegetation maps; the methods developed for their production became the basis for vegetation mapping in Tasmania, which has set the standard for such mapping nationally.



One of the earliest maps, possibly the first, of Tasmania's vegetation. It was published in 1928 in the *Forestry Handbook*, which was compiled by Thomas Stubbs, the Acting Conservator of Forests.



An example of an early map of the distribution of tree species in a specific area, compiled from assessment data. (From Lane 1937.)

The first reference collections of forest species began well before specialist conservation researchers were appointed. Tom Stevens established a small herbarium, probably in the late 1920s or early 1930s (Gilbert, undated), which was later expanded by Max Gilbert. Specimens were added by many staff, particularly Wally Pataczek, who curated the collection for many years. In the course of this work, Wally found a new *Acacia* species that was named in his honour (*A. pataczekii*) in 1974. The herbarium collection was widely used by forestry staff for research work and particularly for training of Technical Foresters. In 2003, it was absorbed into the Tasmanian Herbarium.

As with plants, the need for a reference collection of forest insects was also recognised. It was established by Humphrey Elliott in 1974, expanded, curated and catalogued by Dick Bashford (Bashford 1990), and later re-organised by Simon Grove. Known formally as the Tasmanian Forest Insect Collection, it remains a very significant collection in a national context.

The Forestry Commission commenced water sampling in 1971 in eastern Tasmania to monitor the effects of forest operations (mainly roading and harvesting) on water quality. The sampling was conducted by District staff who forwarded samples to the Government Analyst for laboratory analysis. This program was extended to cover all forest Districts in mid 1976. At the same time, assistance was provided in a co-operative study on the effects of forest practices on water quality with the Rivers and Water Supply Commission, the Department of the Environment, and the University of Tasmania. Potential water quality deterioration and erosion associated with harvesting operations were areas of concern in the mid to late 1970s, particularly with the large expansion in native forest logging occurring as a result of sourcing material for the export woodchip industry.

In order to monitor the effects of harvesting, roading and burning on water quality, Tony Mount selected a group of ten catchments on M Road in the east coast forests, which comprised some unlogged control catchments and the remainder in various stages of harvesting. These and other investigations of the effects of operations in native forest on soil and water values resulted in the Forestry Commission issuing *Guidelines for the Planning and Control of Logging in Native Forests* in 1976, a revised version being issued in 1981 (Forestry Commission 1981b).

The Tasmanian Forest Insect Collection, which was started in 1974, has become a significant scientific resource on a national scale. It currently houses over 100 000 databased specimens.

Support for External Research

From the 1970s, the Forestry Commission began funding forest biology research projects carried out by specialists in other agencies, particularly the National Parks and Wildlife Service and the University of Tasmania. Recognising that the in-house expertise needed to be supplemented, the Commission provided knowledge of the forests, funding, logistical support and forestry expertise to enable external specialists to work on mutually agreed projects. Most of this early co-operative research was directed at regional planning for vegetation conservation and determining the impacts of forest harvesting and regeneration practices on flora and fauna in particular areas.

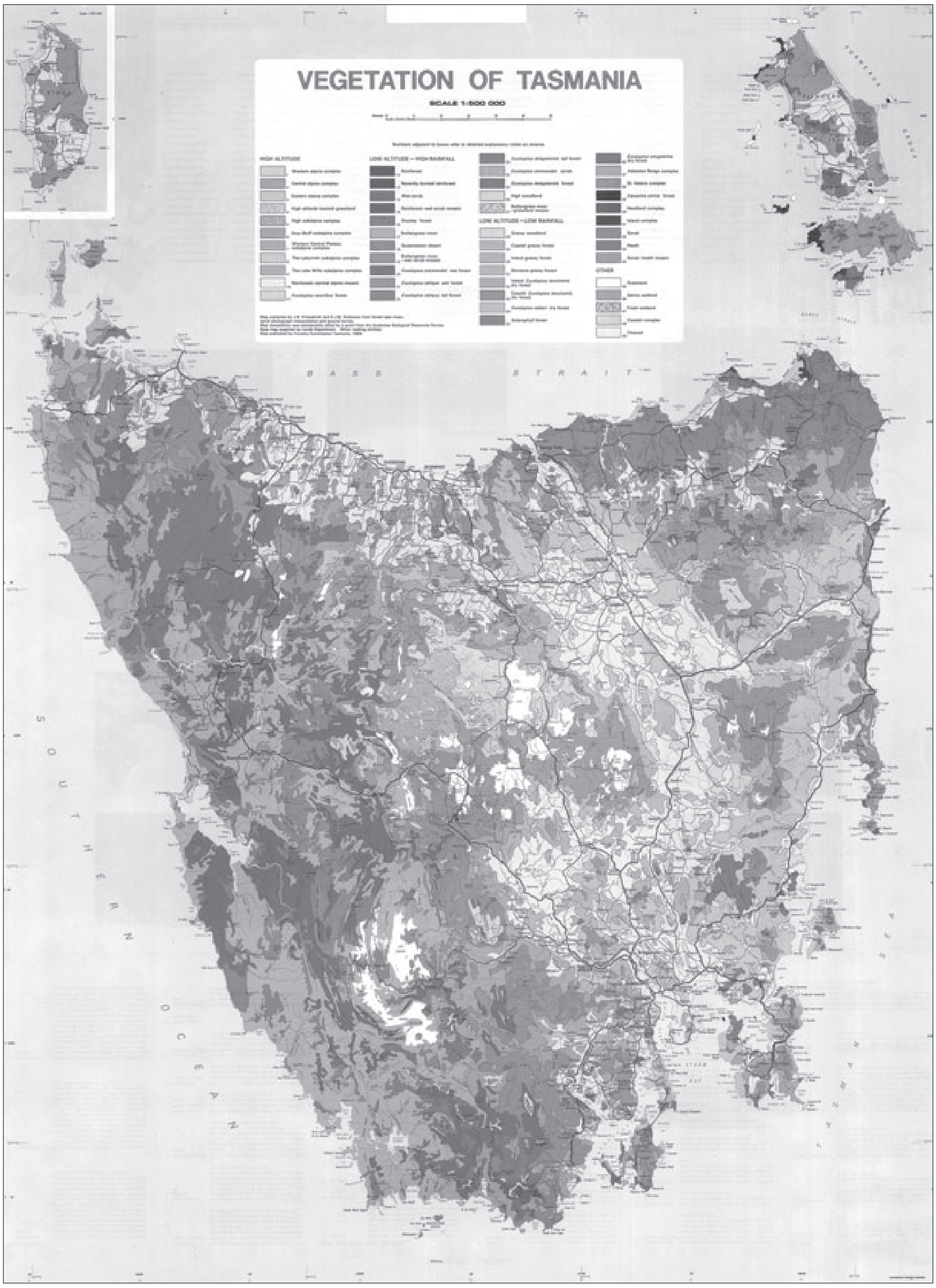
Bob Green from the Queen Victoria Museum in Launceston commenced a major, long-term study of a range of vertebrate and invertebrate fauna in the Maggs Mountain forests in 1974. He documented the fauna of the area and monitored the effects of harvesting and regeneration on this fauna (Green 1977, 1982). In the mid to late 1970s, the Commission funded a post-graduate scholarship at the University of Tasmania. Greg Hocking investigated the biology of the brush-tail possum, *Trichosurus vulpecula*, in regrowth forests and recently harvested and regenerated coupes in the Geeveston District and the Florentine Valley. This work produced new information on the ecology and behaviour of the possum by monitoring the colonisation, expansion and decline of populations paralleling habitat changes produced by forest operations (Hocking 1981).

Large harvesting units (coupes) of over 100 ha were commonly used in the 1970s and 1980s, and public concern was raised over the impact on forest fauna from clearfelling and burning practices in these large areas. John Madden, John Hickman, Alastair Richardson and Lionel Hill at the University of Tasmania studied the effects of forest operations on litter invertebrates, mainly in *Eucalyptus obliqua* mixed forest in the Salmon River area in north-western Tasmania. They concluded that clearfelling and burning may result in only short-term suppression of populations of most invertebrate groups sampled. Dispersal back into the harvested area of litter fauna occurred from moist refuges in the coupe provided by fallen logs and other debris on the forest floor, giving rapid recolonisation (Madden *et al*. 1976).

The advent of the export woodchip industry in the early 1970s prompted research into possible effects of pulpwood harvesting on flora and fauna in dry forests. The Forestry Commission provided support for important studies of bird succession in dry forests in the Swanport area and wet forests in the Florentine Valley by Vicky Pattemore from the National Parks and Wildlife Service (Pattemore 1980). Following this initial study, monitoring of bird populations was carried out for many years in logged and unlogged forests in the same area by the staff of the Triabunna District, beginning in 1977–78 (Taylor *et al*. 1997). These studies showed great variation in the responses of individual species to logging. The total numbers of bird species and individuals were highest in the mature forest, and higher in the younger regrowth than the older regrowth.

Support for botanical studies in rainforest was provided in the mid 1970s to early 1980s to post-graduate students at the University of Tasmania. Greg Rowberry conducted studies on the ecology of unlogged, lowland Tasmanian rainforest. Satwant Calais investigated the regeneration of King Billy pine, celery-top pine and myrtle in relation to soil conditions and post-logging burning. Much of the work of these students was conducted at the Smithton Research Station concurrent with the studies of rainforest silviculture (see Chapter 4). Other support for botanical research in the 1970s was provided to the Tasmanian Conservation Trust for studies of rare plants in the Eastern Tiers.

In the late 1970s and early 1980s, the Forestry Commission assisted several important botanical studies which have been widely used since to assist the development of strategies for flora conservation. Key examples of these studies were the production of the first detailed vegetation map for Tasmania (Kirkpatrick and Dickinson 1984) and *An Atlas of Tasmania's Endemic Flora* (Brown *et al.* 1983). Distribution maps of the iconic endemic species King Billy pine, Huon



The 1984 *Vegetation of Tasmania* map was compiled by Jamie Kirkpatrick and Kath Dickinson from the University of Tasmania. The cartography, undertaken by Tony Rainbird and other staff at the Forestry Commission, was a huge task in the days before the routine use of computers. The map has been an important resource for many studies and decisions on land use.

pine and deciduous beech were also published by the Commission, based on surveys by researchers in the Forestry Commission, the National Parks and Wildlife Service and the University of Tasmania (Forestry Commission 1991b).

The late 1970s saw considerable expansion of pine plantations, particularly in the north of the State. Separate Environmental Impact Statements had to be conducted for each new plantation project, with no requirements for a regional context. Ken Felton persuaded the Department of the Environment that a regional study would give more relevant information, and an area of Crown Forests immediately west of the Tamar River was selected for study since a considerable expansion of pine plantations was envisaged there. In a co-operative study between the Forestry Commission, the National Parks and Wildlife Service, and the Department of Environment, the range of habitats was identified and mapped. The results were used to provide a framework within which the regional effects of the conversion of native forests could be determined and plans to minimise impacts formulated (NPWS 1979). As a follow-up, the Forestry Commission issued *Environmental Guidelines for Plantation Establishment* in 1980, and the first Wildlife Policy was prepared to give direction to Commission staff on catering for wildlife conservation in forest management.

Kurt Cremer examining bryophyte recolonisation on burnt seedbeds in the Florentine Valley in the 1960s.

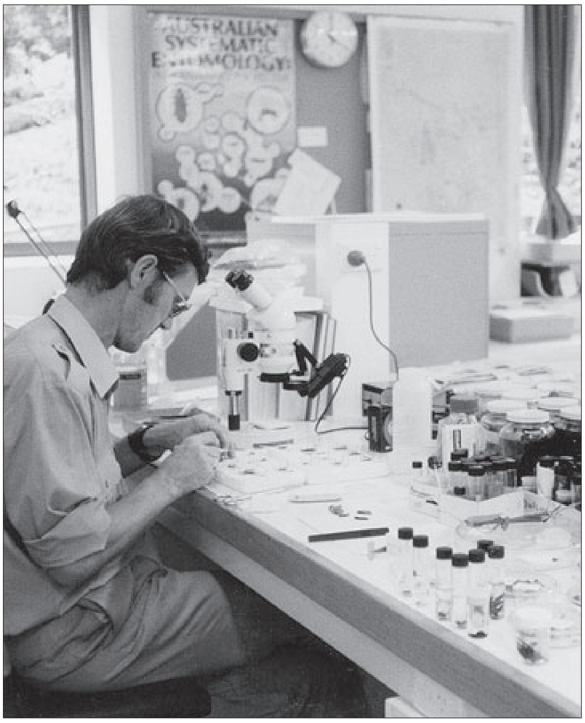
Research by In-House Specialists

The early research staff in the Commission's Silvicultural Branch concentrated their efforts on studying commercial forestry problems, which is not to say that they (and operational staff) did not gather important information on forest biology. Much of this information was never published, but some was. Max Gilbert's and Murray Cunningham's theses provided the firm theoretical base for understanding the natural regeneration processes of tall, wet eucalypt forest (see Chapter 2). When Tony Mount and Kurt Cremer were studying regeneration of wet eucalypt forests in the 1960s (Cremer and Mount 1965), they investigated the recolonisation of seedbeds after fire (see Chapter 2), examining both vascular and non-vascular plants. Their work on bryophyte succession was the first of its kind in Australia and it remains an essential basic reference for studies on recolonisation (e.g. Duncan and Dalton 1982; current studies being undertaken at the Warra LTER Site in southern Tasmania).

At the time of Chris Palzer's appointment as a forest pathologist in 1972, there was much anxiety about the possible effects of the root-rotting fungus, *Phytophthora cinnamomi,* on commercial forests. However, little information was available on its occurrence and effects in different vegetation types. In the course of work on managing this disease (see Chapter 6), Chris accumulated information on the susceptibility of native plant species to *P. cinnamomi,* which greatly assisted plant conservation strategies in both State forests and national parks.

The effects of forest operations associated with the woodchip industry on flora, fauna and other natural values became the subject of considerable public debate in the 1970s (Senate Standing Committee on Science and the Environment 1977). In 1977–78, in response to this concern, a series of plots in several dry eucalypt forests scheduled for harvesting in eastern Tasmania were established by Humphrey Elliott and Dick Bashford in co-operation with Keith Taylor (CSIRO). These plots were the basis of long-term studies of foliage insect and plant diversity. The foliage insect groups present in these forests were documented, along with the species composition of the eucalypts and understorey plants before and after harvesting and the growth and species composition of the eucalypt regeneration (Elliott *et al.* 1991, 2002, 2003; Neyland 1991b).

The dieback and death of trees and the lack of regeneration in the rural landscape, particularly the Midlands region, continues to be a matter of concern since it was first raised in the 1970s by the farming community, the media and in scientific meetings. The Private Forestry Division was part of the Forestry Commission from its beginning in 1977 until it became a separate Government Authority, Private Forests Tasmania, in 1994, and both have investigated the rural dieback problem. Beginning in 1984, the Forestry Commission studied the conservation and establishment of trees on rural properties in a rural tree regeneration program. Work began with collections of seed from Midlands' provenances of eucalypts and other species, followed by trials of broadcast sowing and spot and sheltered spot sowing on several Midlands and south-eastern properties. This work was started by Tim Geard, with strong co-operation from property owners, Greening Australia, and the Midlands Tree Committee. A successful application by the Forestry Commission to the National Soil Conservation Program resulted in the appointment of Libby Pinkard in March 1987 to work full time on the project.



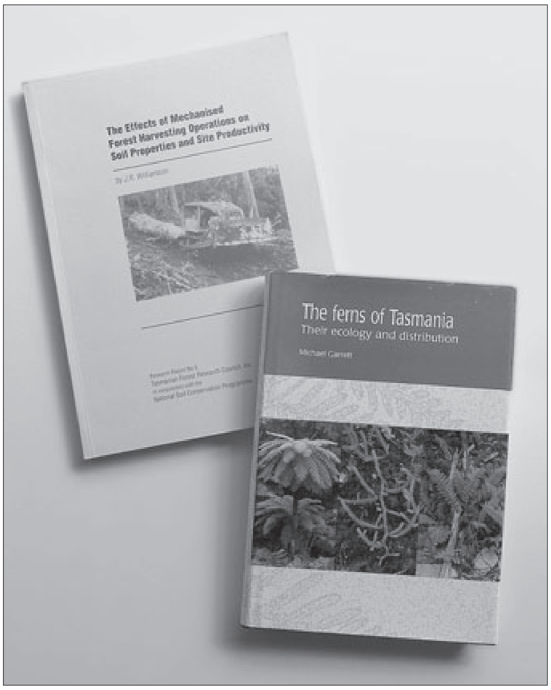
Dick Bashford sorting forest insect species in the Surrey House laboratories, 1984.

Tim Geard with capsules of Midlands eucalypt species in the glasshouse at Surrey House, 1984.

The provenance trial of Midlands eucalypt species established at Ross in 1990–91, shown here in 2006. The forest cover in parts of the Midlands has been severely depleted and this planting preserves the genes of eucalypt species native to the region for future plantings.

Following this appointment, four direct seeding trials were established in the Midlands. These trials tested various treatments, including pre- and post-seeding weed control, a range of sowing rates, and cultivation of the site before sowing. From this work, prescriptions were developed for species mixes and sowing rates for direct seeding at different sites in the Midlands, which were later refined by Private Forests Tasmania. In addition to the range of direct seeding trials, cost-effective planting methods were also investigated, mainly through a large planting trial at Lovely Banks in the southern Midlands encompassing several species of eucalypts and *Pinus radiata,* and different planting techniques. *Eucalyptus nitens* had the highest initial growth rates but *P. radiata* had the highest survival rate and was eventually the most successful species on this site. An important legacy of the rural tree regeneration project is the provenance trial established at Ross with co-operation between the Forestry Commission, Greening Australia, and the Tasmania Bank using seed collected by Alan Gray in an earlier National Soil Conservation Program project. This planting preserves the genes of Midland eucalypt species and is an important source of seed for any future sowing and planting projects.

In the early 1980s, some loss of tree ferns (manferns) in clearfelled and burnt coupes and indiscriminate harvesting by some fern cutters prompted the development of a Forestry Commission policy on the harvesting of tree ferns. However, little information was available at the time on the regeneration processes and requirements for tree ferns. Studies by Adrian Goodwin, a researcher with the Silvicultural Branch, resulted in recommendations that no *Cyathea* ferns should be harvested and that *Dicksonia antarctica* should be cut under licence by evenly thinning them within each coupe and retaining at least 25% as spore sources for regeneration. Soon after the release of the tree-fern policy, a study of tree-fern conservation and management was conducted by Mark Neyland, then of the National Parks and Wildlife Service, which provided the background information



Two of the publications resulting from projects funded by the Forest Ecology Research Fund.

for the production of a tree-fern management plan for Tasmania (Neyland 1986).

There was an expansion of conservation research in the early 1980s by the Forestry Commission and by other forest managers and research providers in Tasmania. This was largely due to the establishment of the Forest Ecology Research Fund (FERF, see Box 8). Beginning in the 1980s, FERF and its successor, the Tasmanian Forest Research Council (TFRC), funded several important conservation-related projects, including studies of nutrient cycling in north-eastern eucalypt forests (Adams and Attiwill 1988), effects of harvesting on forest soils (Williamson 1990), a floristic study of rainforest (Jarman *et al.* 1984), and an atlas of Tasmanian ferns (Garrett 1996). FERF also organised a workshop on rainforest in 1982, where results from several studies on flora, fauna and ecology were presented (FERF 1983).

Box 8

The Forest Ecology Research Fund.

Conservation research in Tasmania's forests received a major boost when the Forest Ecology Research Fund (FERF) was established in 1981; the initial grants were made in 1981–82. This fund was an initiative of Ken Felton, then the Head of the Silvicultural Branch. Funding was provided by the Forestry Commission and major timber companies and the initial annual income was $60 000 to be used to support studies of the effects of forest practices on the forest environment. Decisions on use of funds were made by a committee chaired by Dr Max Gilbert, with administrative support provided by the Forestry Commission. Murray Jessup was the initial secretary to FERF and Ron King filled the position from 1984.

In addition to the increased research resulting from the establishment of FERF, there were several other major benefits. Communication between researchers in the Forestry Commission and those in other agencies increased markedly, research became better directed to the problems of most concern to forest managers, and operational staff and funding organisations took much greater interest and responsibility for research projects. FERF was succeeded by the Tasmanian Forest Research Council in the late 1980s.

Environmental Impact Statement on Tasmanian Woodchip Exports beyond 1988

Conservation-related issues were the subject of several Commonwealth/State investigations and agreements. The first of these that led to significantly increased research was the requirement for an Environmental Impact Statement (EIS) for the continuation of the woodchip export industry.

The industry had been operating in Tasmania since 1971 but, in order for woodchip exports to continue beyond 1988, woodchip exporting companies had to comply with the provisions of the Commonwealth *Environment Protection (Impact of Proposals) Act 1974–1975*. Under this Act, the Commonwealth Government required proponents of any export-related activity which might affect the environment to prepare a draft EIS which was to be available for public comment before an export licence could be issued. The comments had to be taken into account in the preparation of a final EIS which had to be assessed by the Commonwealth. In addition, the Commonwealth Minister for Primary Industry (the licensing Minister) was required to consult the Minister for the Arts, Heritage and Environment on the environmental aspects of the proposal before a decision on licensing was made.

Consequently, in late 1983, the Tasmanian woodchip exporting companies (Associated Pulp and Paper Mills, Forest Resources, Tasmanian Pulp and Forest Holdings) and the Forestry Commission began the task of preparing a draft EIS. This was completed in January 1985 (Tasmanian Woodchip Export Study Group 1985).

The EIS marked an important point in the history of forestry research and development in Tasmania because the document included summaries of the state of knowledge at the time of major non-wood values and expert opinion on the likely impacts of the woodchip industry on these values. This integration of knowledge of forest biology and conservation was a very significant achievement. Natural values of Tasmanian forests covered in the document included geology, soils and soil nutrients, karst, water, fire, flora, fauna, diseases, and archaeology. The source documents used by the EIS Study Group for these summaries were a series of Working Papers prepared by specialists from the Forestry Commission and other institutions (Table 2).

Table 2. Working papers on environmental topics prepared by specialists for the EIS Study Group. Forestry Commission authors are marked by an asterisk.

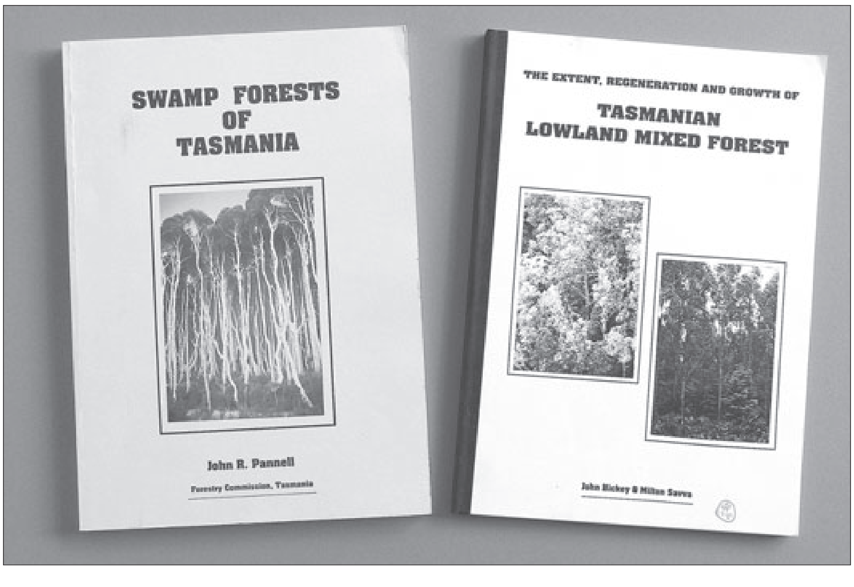
Working Paper	Publications
Environmental checklist and guidelines	Forest Resources (1982)
Fire	Ingles* (1985)
Silvicultural practices	Lockett* and Keenan* (1985)
Tasmanian forest soils	Neilsen* and Davis* (1985a)
Tasmanian water resources and effects of forestry practices on water values	King* (1985)
Tasmania's vegetation and its response to forest operations	Duncan (1985)
Invertebrate fauna	Elliott*, de Little and Reid (1985)
Vertebrates	Reid (1985)
Diseases and fungi	Palzer* (1985)

Based on the draft EIS, the information in public submissions and the response to these submissions, the Commonwealth Government approved the continuation of woodchip exports beyond 1988. In 1986, this approval was cemented via a Memorandum of Understanding (MOU) between the Commonwealth and Tasmania. Importantly for conservation research, the MOU contained provision for research on the effects of woodchip operations on natural values. This research was funded mainly by the woodchip exporting companies via a levy per tonne of woodchips exported, plus a substantial annual commitment from the Commonwealth Government, together with State Government support.

The research funding under the MOU was channelled through the Tasmanian Forest Research Council (TFRC), the successor to the Forest Ecology Research Fund which was disbanded in the late 1980s. The TFRC was set up with increased total funds and a broader funding base comprising Commonwealth, State and industry bodies. It distributed funds for research through three Sub-Committees: Ecology, Wood Production, and Harvesting and Processing. The sub-committees assessed the merit of applications and allocated funding, with funds for conservation research being administered by the Ecology Sub-Committee.

Many research projects received TFRC funding following the signing of the MOU. Examples involving Forestry Commission staff include modelling the occurrence of rare plant species (Orr 1994), the archaeology and physical history of Tasmania's timber industry (Kostoglou 1991), wildlife habitat strips (Taylor 1991b) and the Tasmanian karst atlas (Kiernan 1996). Some of these projects are summarised in the later section on Forest Practices.

In addition to funding available from the TFRC, the Commonwealth Department of Primary Industries (DPIE) provided funding for specific conservation projects from its internal budget. These included effects of steep country harvesting on vegetation (Peacock 1994), classification and conservation requirements of swamp forests (Pannell 1992; see 'Determining conservation needs for major vegetation types', p. 312), studies of the extent, regeneration and early growth of lowland mixed forests (Hickey and Savva 1992), and a floristic study of cryptogams in a range of eucalypt communities (Jarman and Kantvilas 1997).



Examples of publications resulting from conservation research funded by the Commonwealth and State Governments following the signing of the Memorandum of Understanding in 1986.

The Helsham Inquiry

Despite the MOU signed by the Commonwealth and Tasmania in 1986, the dispute over the use of forests in Tasmania escalated. Many areas, including the Lemonthyme and Southern Forests, had been placed on the Register of the National Estate after nomination by conservation groups and other parties. However, there were widely conflicting claims over the significance of the natural values in these areas.

In 1987, the Commonwealth Parliament passed the *Lemonthyme and Southern Forests (Commission of Inquiry) Act 1987* which required Commissioners (headed by Commissioner Helsham) appointed under the Act to inquire and determine whether there were any 'qualifying areas' within the Inquiry area (283 300 ha). Qualifying areas were defined as those areas which would meet the requirements of the World Heritage Convention, or areas which would contribute to these areas or to adjacent existing world heritage areas. The Helsham Inquiry concluded that a small proportion of the Inquiry area (10%) met the criteria. Subsequent political decisions resulted in some 275 000 ha being added to the existing World Heritage Area and thus being unavailable for commercial forestry.

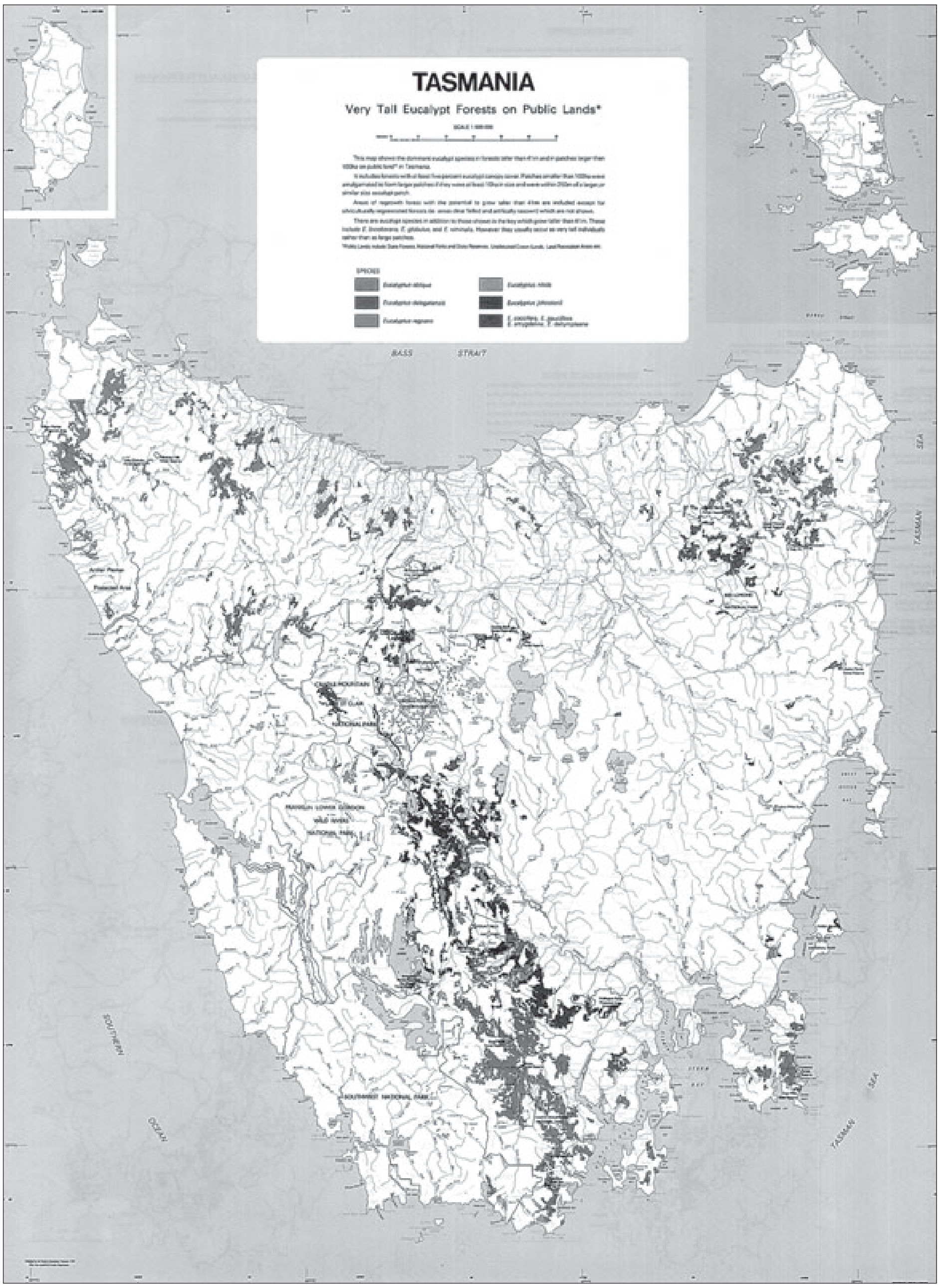
Research staff from the Forestry Commission and other agencies spent a considerable time gathering and processing data and presenting material to the Inquiry. The main work undertaken was a survey of many proposed coupes within the Inquiry area to study their natural values, particularly those associated with botany but also fauna, archaeology and geomorphology.

During the Helsham Inquiry in 1987–88, a Statewide inventory of tall eucalypt forest types and their conservation status was conducted by John Hickey, John Davies and others. This program was known as SWIFT (Statewide Inventory of Forest Trees) and involved the mapping of tall eucalypt forests 34–41m and

Aerial reconnaissance was used to assess dominant eucalypt species for mapping tall eucalypt forests in wilderness areas, as part of information gathering for the Helsham Inquiry in 1987. Project officers are shown here on Mount Weld. (From left: John Hickey, John Davies and the helicopter pilot, unidentified.)

greater than 41 m in height. A related program Species-SWIFT recorded dominant and secondary eucalypt species in the patches defined by the SWIFT program. John Davies collected and analysed the data for Species-SWIFT and Ben Smith manipulated it on the GIS. Mapping Branch prepared a 1:500 000 map of very tall eucalypt forests on public land from these data.

Following the Inquiry, the Commonwealth Government funded a package of measures to compensate for the loss of access by forest industry to commercially valuable forests in the area taken out of production. Most of this Helsham Package was directed at intensification of forest management, mainly through the establishment and management of eucalypt



Very Tall Eucalypt Forests on Public Lands, published in 1988, was a product of the SWIFT program (Statewide Inventory of Forest Trees) conducted during the Helsham Inquiry.

plantations for sawlog production. The research activities associated with this initiative are described in Chapter 5. Some research related to soil conservation was also included via a project on the characterisation and mapping of soils with reference to erodibility and sustainable forest management, and also to their suitability for plantations.

Determining Conservation Needs for Major Vegetation Types

In the late 1970s and 1980s, the Wildlife Division of the National Parks and Wildlife Service administered several significant botanical studies in a range of forest types assisted by the Forestry Commission and other agencies and individuals. Much of this research was initiated and supervised by Mick Brown, who later led conservation research in the Forestry Commission. These studies included a survey of Huon pine in the Pieman River State Reserve (Pedley *et al.* 1980, initiated by the Forestry Commission), conservation and management of Huon pine (Davies 1983; Gibson 1986), a floristic classification of rainforest (Jarman and Brown 1983; Jarman *et al.* 1984), and studies on the extent and conservation status of dry sclerophyll forest (Duncan and Brown 1985).

In 1984, the Tasmanian Government established a Working Group for Rainforest Conservation. This body subsequently became the Working Group for Forest Conservation (Box 9), with a primary aim of determining the conservation needs for the major forest types in Tasmania.

One of the outcomes of the Working Group for Rainforest Conservation was the production of an informative and extensively illustrated book,

Box 9

Working Group for Forest Conservation.

The Working Group for Forest Conservation (WGFC) comprised representatives from the Forestry Commission, Department of Parks, Wildlife and Heritage, and the Department of Resources and Energy. The permanent Forestry Commission representatives on the WGFC were Mick Brown (Chair) and John Hickey (Co-ordinator). Representatives from the member agencies changed over the Group's life (1984–90) and several specialist project officers were employed to obtain the data necessary for the WFGC to formulate its recommendations.

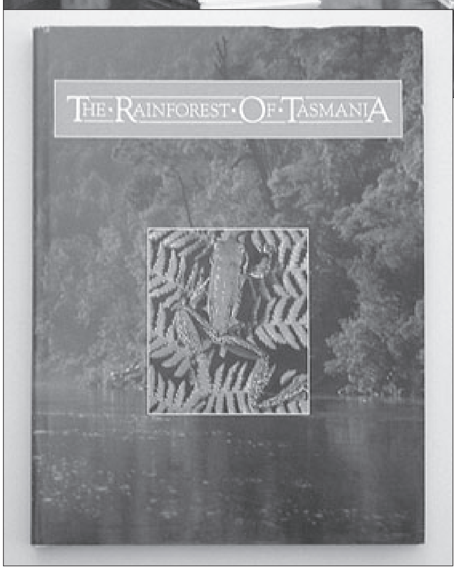
The role of the WGFC was initially to advise the Government on the conservation of rainforest but this task expanded after the signing of the Memorandum of Understanding in 1986 to include advice on the conservation of wet and dry sclerophyll forests. Specifically, the tasks of the WGFC were to:

- Assess the regional conservation status of rainforest, wet eucalypt forest and dry sclerophyll forest and identify Recommended Areas for Protection (RAPs), where necessary, so that adequate examples of all component communities would be protected in secure reserves;
- Recommend and oversee projects carried out under the National Rainforest Conservation Program (NRCP).

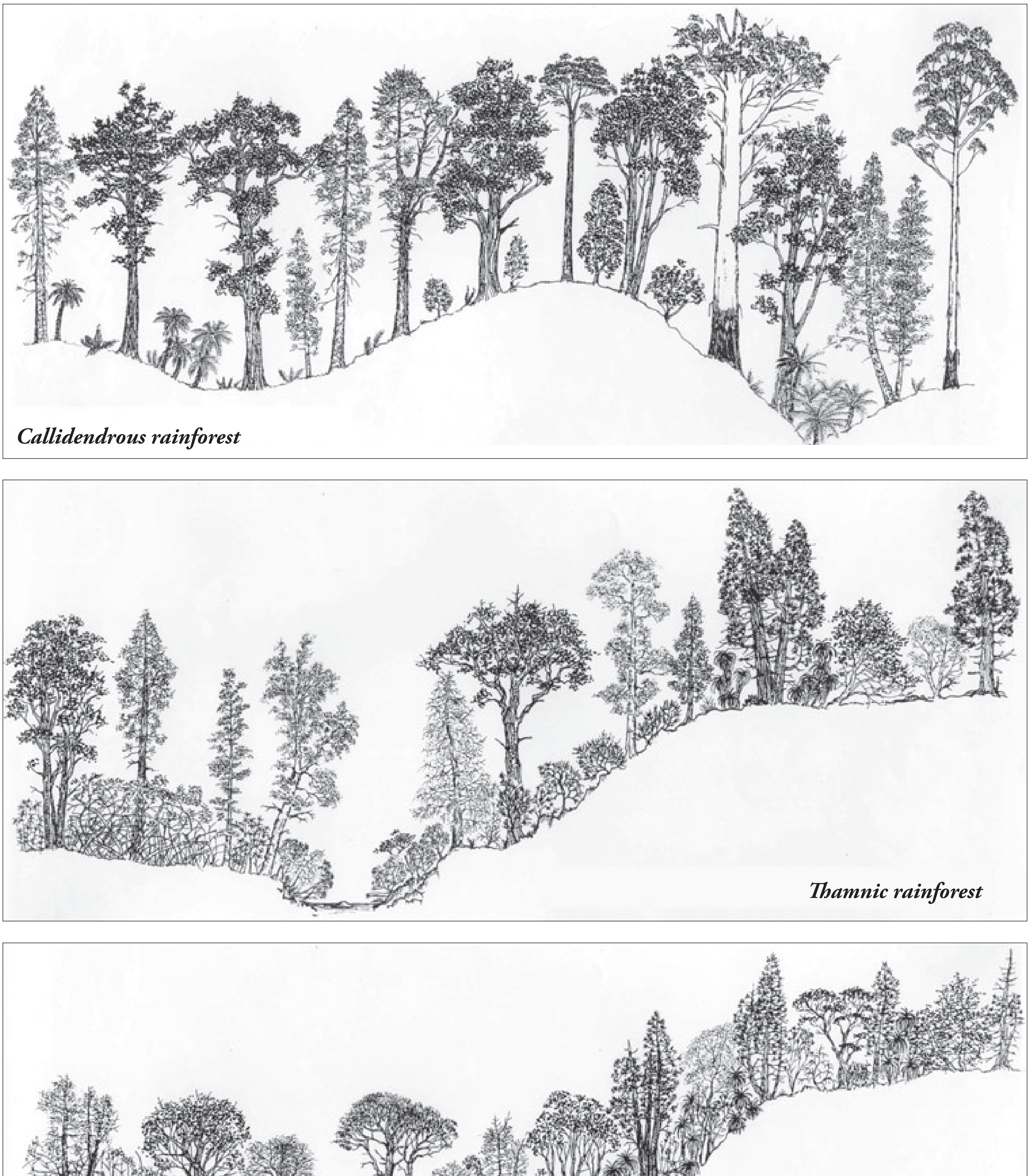
The work of the WGFC resulted in the recommendation for protection of 200 areas covering 229 210 ha across the three forest types (rainforest, wet eucalypt forest, dry sclerophyll forest) studied. This was later revised to 176 areas covering 215 000 ha (RAPs 1990).

The Rainforest of Tasmania, that highlighted the value and scientific significance of Tasmania's rainforests. It gave an account of the nature, evolution, distribution, commercial uses and management of rainforest in Tasmania and, while directed at the general reader, remains a comprehensive summary of many aspects of cool temperate rainforest. It was produced by an editorial team representing the Working Group for Rainforest Conservation, with the text written by John Hickey and Peter Boyer from the Forestry Commission (Working Group for Rainforest Conservation 1987).

In 1986, the Forestry Commission's main research unit, the Silvicultural Branch, was restructured to become the Division of Silvicultural Research and Development. The increased research on forest biology was formally recognised in the new Division by the creation of a Biology Branch (later Biology and Conservation Branch), with wood production research being undertaken by the Plantations and Native Forests Branches. Mick Brown moved from the National Parks and Wildlife Service to become the first head of the Biology Branch in mid 1986. He continued in this



Members of the panel associated with the preparation of *The Rainforest of Tasmania*, which was published in 1987. From left, standing, Bert Shepherd and Jamie Bayly-Stark (Department of Lands, Parks and Wildlife), Peter Boyer, Ken Felton, Paul Smith, Mark Stranger (Forestry Commission) and, seated, Mick Brown and John Hickey (Forestry Commission).



Profile diagrams of the three major groups in Tasmania's rainforest, drawn by Fred Duncan and taken from *The Rainforest of Tasmania* which was published in 1987. A fourth group, open montane rainforest, has also been described (and illustrated): it is relatively minor in terms of area occupied but very important for its biodiversity.

position until 1996, when he was succeeded by John Hickey. Mick and John played a major role in shaping the conservation policies for Tasmania's flora and, apart from their numerous direct contributions to the conservation debate (e.g. Hickey and Brown 1989; Brown and Hickey 1990; Kirkpatrick and Brown 1991, 1994; M. Brown 1996a), provided input into a great many projects that led to a better understanding of the conservation requirements of Tasmania's flora and fauna.

The first conservation research in the Biology Branch was mainly pre-logging botanical surveys in contentious areas such as Jackeys Marsh and the Lemonthyme, and plant surveys in forest reserves. Contract work was also funded to gain information on the fauna (Statham 1987) and flora (Williams 1987) of the Southern Forests to assist the preparation of the Forest Management Plan for that area. These were the most detailed fauna and flora inputs into Forest Management Plans up to that time, reflecting the increased attention being given to non-wood values in forests and the expanded range of technical expertise within the Forestry Commission.

However, the main work of the Biology Branch soon developed into conducting and supervising projects on the conservation of major forest types on behalf of the Working Group for Forest Conservation (WGFC). Comprehensive reports on the conservation status of each of the major forest types were commissioned by the WGFC in 1987:

- Rainforest (Hickey *et al.* 1988);
- Wet eucalypt forest (Wells 1989);
- Dry sclerophyll forest (Williams 1989).

The project officers for the rainforest and dry sclerophyll studies were John Hickey and Kristen Williams (assisted by John Grant) respectively. These two studies were partially funded by the Commonwealth Department of Primary Industries and Energy (DPIE) and supervised by the Biology Branch. Penny Wells was appointed to study the conservation of wet sclerophyll forests in a joint program administered by the State Department of Lands, Parks and Wildlife and funded by the National Parks and Wildlife Service. Ben Smith (State funded) and Tom Kelley (DPIE funded) provided GIS technical support for the eucalypt and dry sclerophyll projects.

The authors of each report used the eleven Nature Conservation Regions (NCRs) of Tasmania which had been identified at that time to study regional representation of each of the forest types. The existing reservation status of the different vegetation types within each NCR was assessed against parameters of geology and altitude. Recommendations for reservation were then based on the assumption that regional reservation of adequate samples of all those geology/altitude classes supporting each forest type would achieve the conservation of component species and communities (RAPs 1990). The Recommended Areas for Protection (RAPs) for each forest type were identified by overlaying maps of forest type, NCR, geology, altitude and tenure. The minimum reservation for the wet and dry eucalypt forest types was set at 5% in accordance with the then current guidelines of the International Union for the Conservation of Nature (IUCN), and 30% for rainforest to reflect the greater sensitivity of this type to fire and other disturbance.

The WGFC also used research on the distribution and conservation of King Billy pine (Brown 1988) and Huon pine (Peterson 1990) in the final selection of rainforest reserves. This research also assisted the Forestry Commission in the development of policy statements on these two species.

The processes adopted by the WGFC to determine conservation needs were a landmark in the history of forest conservation in Tasmania and nationally. This was the first time that a systematic scientific approach had been used to determine where appropriate reserves for particular vegetation types should be located.

Many other vegetation studies around this time led to a better understanding of the conservation needs of plant species and communities in Tasmania. The frequent burning of buttongrass plains for forest protection and habitat maintenance prompted studies funded by the TFRC of their floristic composition and structure in order to better understand the effects of burning regimes (Jarman *et al.* 1988a, b). Vegetation change, including the role of fire, and concern over the susceptibility of native species to the root-rot fungus *Phytophthora* were the focus of several studies. Mick Brown was involved in many of these studies, working co-operatively with researchers from other organisations (e.g. Podger and Brown 1989; Podger *et al.* 1989; Podger *et al.* 1990b; Jackson and Brown 1999; Brown *et al.* 2002). The classification and conservation requirements of the swamp forests were the subject of a major study by John Pannell, jointly funded by the Commonwealth Department of Primary Industries and Energy and the Forestry Commission (Pannell 1992). Conservation research was directed at individual species, for example, Huon pine (Brown 1988), King Billy pine (Peterson 1990) and deciduous beech (Robertson and Duncan 1991), as well as communities. The reservation status of each documented plant commmunity was assessed in a co-operative study with input from several organisations, including Forestry Tasmania, and published by the Tasmanian National Parks and Wildlife Service (Kirkpatrick *et al.* 1995). Regional studies included assessments of the flora of the north-east (M. Brown 1996b) and south-east (Forestier Peninsula; Brown and Duncan 1989). Experience gained over the years from the many surveys provided a sound basis for examining the best approaches to, and problems associated with, managing and protecting Tasmania's flora (e.g. Brown *et al.* 1994; Brown and Podger 1999).

A plant survey of the Martins Hill Recommended Area for Protection in north-eastern Tasmania, 1997. (Karen Johnson pictured.)

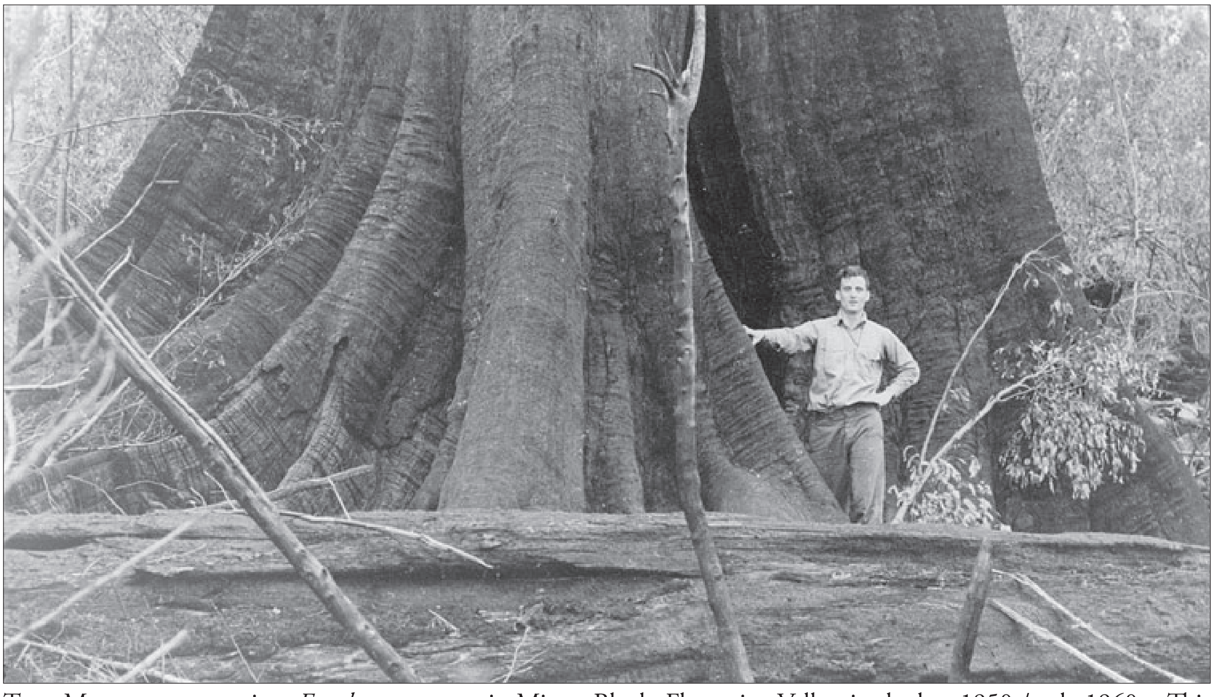
The Resource Assessment Commission

Under the *Resource Assessment Commission Act 1989*, a Forest and Timber Inquiry was initiated by the Prime Minister to examine options for the use of Australia's forest and timber resources. An important part of the Inquiry was the investigation of the conservation of native forests. Jamie Kirkpatrick (University of Tasmania) and Mick Brown were employed as consultants by the Resource Assessment Commission to report on regional conservation adequacy in Tasmania. Together with technical project staff, they used biological distribution data (vegetation mapping units, endemic species, rare and threatened species, poorly reserved and unreserved species and communities) and environmental domains (determined by reference to geology, altitude, climate and solar radiation) to design a forest reserve system for higher plant communities and species for the State. Their studies indicated that reservation planning based on both biological data and environmental domains may produce better results than either technique used alone (Kirkpatrick and Brown 1991, 1994).

This process was nationally recognised in the report of the Resource Assessment Commission as a useful structural basis for determining future reservation priorities (RAC 1992). The analyses also supported the approach used earlier in the project that identified Recommended Areas for Protection (RAPs).

Conservation of Tall Eucalypt Forests

As Tasmania is the home of the world's tallest hardwood tree species, *Eucalyptus regnans*, and other very tall eucalypt species, the conservation of tall trees in State and private forests has been a research and inventory task in Forestry Tasmania for many years. Staff of Australian Newsprint Mills and the Forestry Commission identified very tall trees in the Styx Valley in the early 1960s (Mount 1960; Hickey *et al.* 2000).



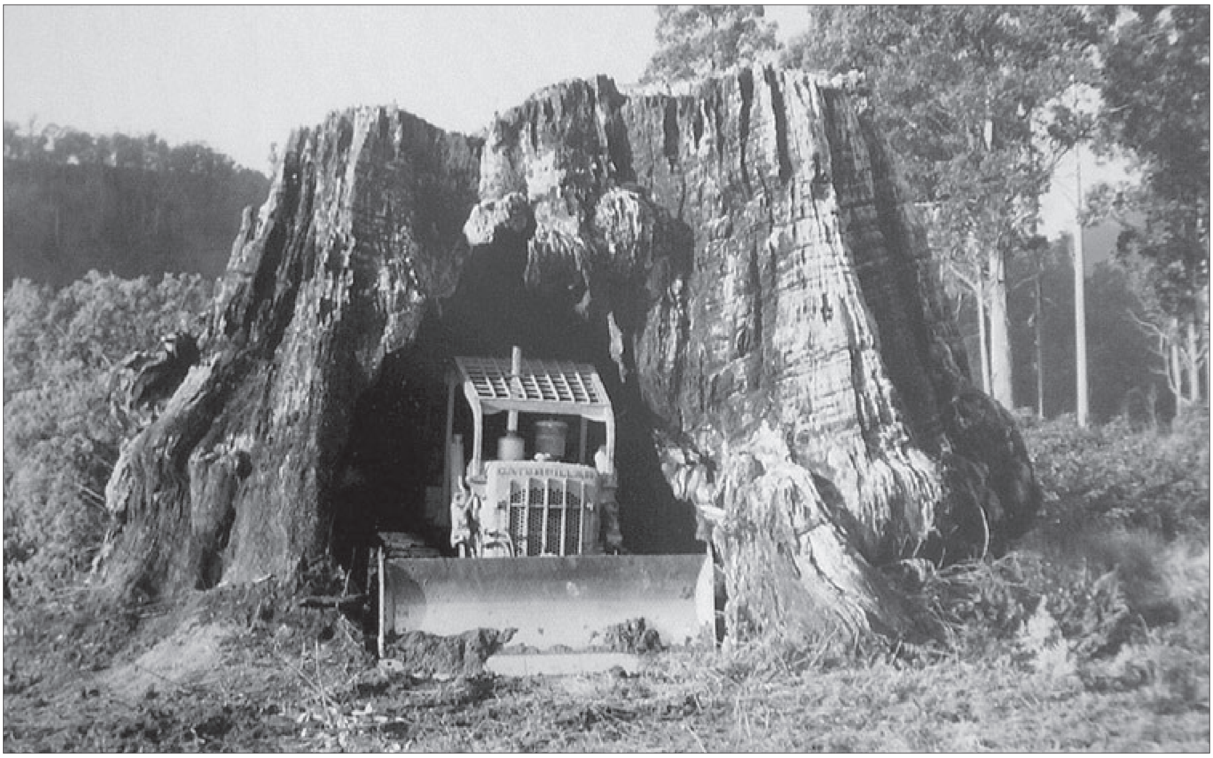
Tony Mount next to a giant *Eucalyptus regnans* in Misery Block, Florentine Valley, in the late 1950s/early 1960s. This tree had a girth of 62 feet (18.9 m) and was the biggest found in the Florentine Valley to that date.

During the Helsham Inquiry in 1987–88, an inventory of tall eucalypt forest types and their conservation status was undertaken across the State (the SWIFT project, see p. 310), resulting in a good understanding of the distribution and extent of very tall eucalypts in Tasmania.

In 1987, the Forestry Commission decided to establish several Tall Tree Management Zones around the State to ensure that areas of existing and potential tall trees were reserved as part of a tall tree conservation program. There was an emphasis on identifying stands that, because of their youth, were not yet 'tall' but would grow into that state. After a statewide survey, several areas were selected and subsequently reserved for this purpose. A workshop on the reservation and management of tall eucalypt forests was held in September 1987 and the recommendations from this workshop formed the basis for tall tree conservation management (Brown *et al.* 1987).

Several years later, Parry Kostoglou prepared a report for Forestry Tasmania on a survey of very tall trees in Southern Tasmania (Kostoglou 2000). It contained a review of information on tall trees, height measurements, and a preliminary register of Tasmania's tallest trees. Subsequently, the results were formally published in *Tasforests*, and the findings examined in the context of tree and stand growth.

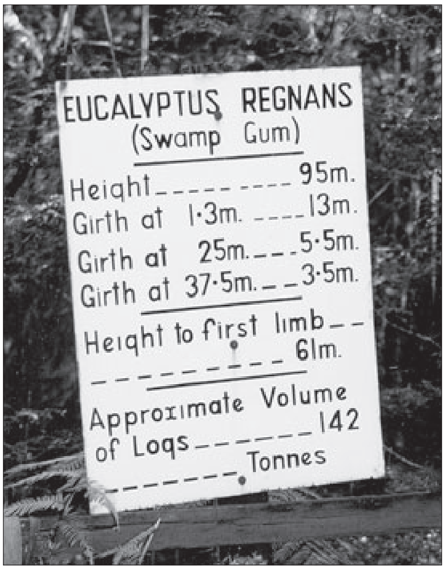
A Giant Trees Policy was established by Forestry Tasmania in 2003. It prescribed regular searching for and protecting trees 85 m high and taller or at least 280 m^3 in volume. At the end of 2005, 69 trees were on the register, mostly *E. regnans*, with some *E. delegatensis*, *E. globulus*, *E. obliqua* and *E. viminalis* (www.gianttrees.com.au).



A 10 ton D4D bulldozer in 1975 nestled in the stump of a giant *Eucalyptus regnans* in Junee Paddocks, an area cleared for pasture, probably in the early 1900s, with the logs going to a sawmill at Tyenna (K. Creak, pers. comm.). The Australian Newsprint Mills Forest Concession Area, a little to the west of this site, contained similar trees which supplied sawlogs to local sawmills and resource for the Boyer Newsprint Mill for many decades after operations began there in 1941.

An 88 m high *Eucalyptus regnans* in the Andromeda stand, Styx Valley, thought to have originated about 1710.

A climber (Tom Greenwood) on the 87 m high Arve Big Tree, the most massive of the tallest recorded trees.



The sign erected by Australian Newsprint Mills that stood beside the 'Big Tree' in the Styx Valley for many years.

The National Rainforest Conservation Program

In 1988, the Commonwealth Government and those States with areas of rainforest began the National Rainforest Conservation Program (NRCP). The aim of the program was to identify, promote, protect and conserve Australia's rainforests by funding research and other activities to supplement existing programs in the States and Territories (Jarman and Hickey 1996).

The Tasmanian component of the NRCP was relatively large on a national scale, not only because the State has jurisdiction over most of Australia's cool temperate rainforest but also because it was very active in submitting many worthwhile proposals for research, inventory, planning, education and visitor facilities. The Tasmanian component of the program was administered by the Working Group for Forest Conservation (WGFC), which vetted proposals which, if funded by the Commonwealth, were then implemented by three State agencies: the Department of Environment and Land Management, the Forestry Commission, and Tasmania Development and Resources. Mick Brown and John Hickey, as the Chair and Co-ordinator respectively of the WGFC, were again the principal managers of this important conservation program.

The NRCP ran in Tasmania from 1988 to 1996 and during this time some 38 rainforest projects were conducted covering research (16 projects); inventory (5 projects); planning (5 projects); education through books, maps, posters and a seminar (8 projects); and provision of visitor facilities and site works (4 projects). The Tasmanian component of the program has been summarised by Jarman and Hickey (1996), and resulted in over 100 scientific and technical publications, books, articles, maps and higher

The best representation of cool temperate rainforest in Australia occurs in Tasmania, with the north-west having the largest uninterrupted patches. The forest shown here is from the Savage River area.

degree theses. Research results from some of the early projects were reported at a major conference in Hobart in 1990 (Hickey *et al.* 1990).

The Tasmanian NRCP research projects (see Table 3) covered studies of the ecology of major rainforest tree species and their relationships within forest communities, cryptogamic flora, relict rainforest patches, blackwood plantation trials, fire in rainforest, various invertebrate groups, and myrtle wilt disease. Information on blackwood plantations and myrtle wilt research is discussed in Chapters 5 and 6 respectively.

The results from this wide range of research projects greatly expanded the level of information available on rainforest in Tasmania, especially in relation to biodiversity and ecology. As part of the floristic project, the influence of soils and geology on plant communities was examined in a co-operative study with the Department of Resources and Energy. This demonstrated a clear relationship between the three main rainforest groups and the nature of their substrate. The projects on individual species (e.g. autecology of Huon pine) yielded much useful information for better management of these species, while the studies of particular groups such as the rainforest bryophytes and lichens (jointly with the Tasmanian Herbarium) and invertebrates provided a wealth of new information on the composition and ecology of these groups. The

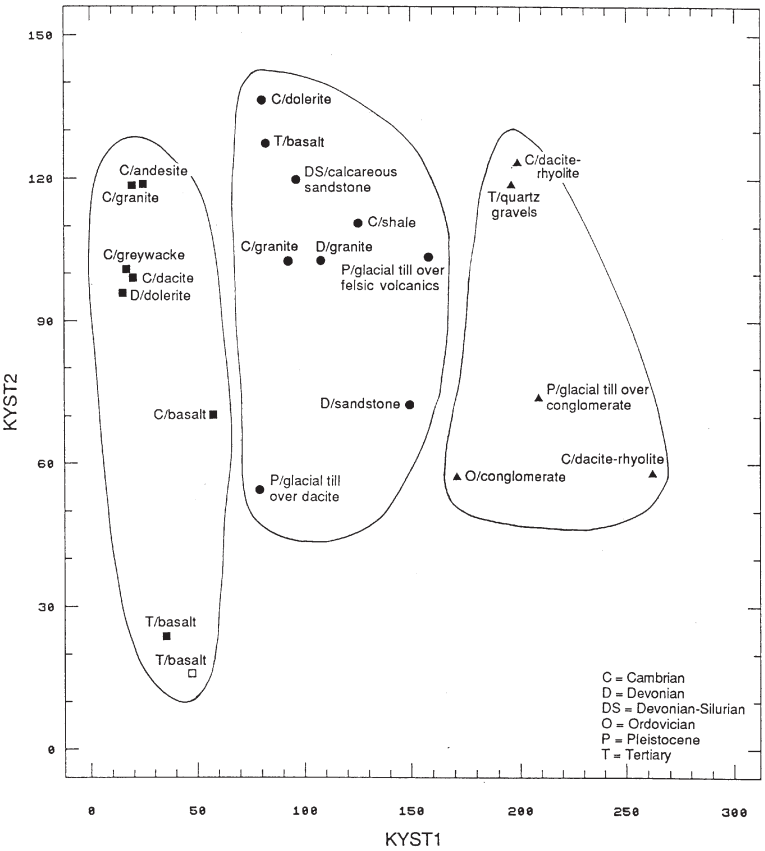
Table 3. Research projects undertaken in the National Rainforest Conservation Program.

Project	Reference
Vegetation	
Phytosociological analyses	Jarman *et al.* (1991)
(and a pilot study on soil, geology and flora interactions)	Brown *et al.* (1990)
Autecology of Huon pine	Shapcott (1991)
Relict rainforest	Neyland (1991a)
Autecology of *Phyllocladus* and *Anodopetalum*	Barker, P. (1992)
Blackwood plantation trials	Allen (1992)
Pattern in lowland temperate rainforest	Rowberry (1992)
Genetic variation in sassafras	Shapcott (1993)
Leatherwood floral phenology	Ettershank and Ettershank (1993)
Floristic studies on bryophytes and lichens	Jarman and Kantvilas (1995a)
Illustrated handbook of rainforest bryophytes	Jarman and Fuhrer (1995)
Illustrated handbook of rainforest lichens	Kantvilas and Jarman (1999)
Fire	
Fire ecology	Barker, M. (1991)
Effects on rainforest of repeated burning	–
Invertebrates	
Insects associated with leatherwood	Ettershank and Ettershank (1993)
Rainforest invertebrates	Coy *et al.* (1993)
Litter invertebrates in north-western Tasmania	Mesibov (1993)
Key insect groups	–
Fungi	
Myrtle wilt	Packham (1991)
Illustrated handbook of rainforest fungi	Fuhrer and Robinson (1992)

studies of relict rainforest and information on fire ecology and the effects of burning on rainforest provided immediate practical information for conservation management.

The inventory and planning projects produced accurate vegetation mapping of western Tasmania, botanical manuals for identification of key rainforest communities and information on their conservation significance, management plans for important Forest Reserves and a review of the Recommended Areas for Protection (RAPs) proposed by the WGFC. This latter review examined RAPs where there was a conflict of interest between conservation and resource use, and explored alternatives to resolve these conflicts. Importantly, the NRCP projects also provided training opportunities for several young researchers who later went on to gain further employment based on their achievements and experience in the program.

As part of the NRCP program, handbooks illustrated with high-quality colour photographs by Bruce Fuhrer were prepared and published. The first dealt with rainforest fungi (1992), the second with bryophytes (1995) and the final book in the series covered rainforest lichens (1999).



Ordination based on floristic data from 15 sites, made up of five from each of the three major rainforest groups in Tasmania. Rock type is superimposed over the sites. Mafic rocks are to the left; the more siliceous rock types are to the right. The rainforest groups are shown by the symbols ■ = callidenrous rainforest, ● = thamnic rainforest, ▲ = implicate rainforest, and □ = intermediate between callidendrous and thamnic rainforest. (From Brown *et al.* 1990.)

Thamnic rainforest. The narrow pointed crowns belong to horizontal (*Anodopetalum biglandulosum*).

High-altitude callidendrous rainforest—its vascular flora is simple but the cryptogamic flora is very rich in species.

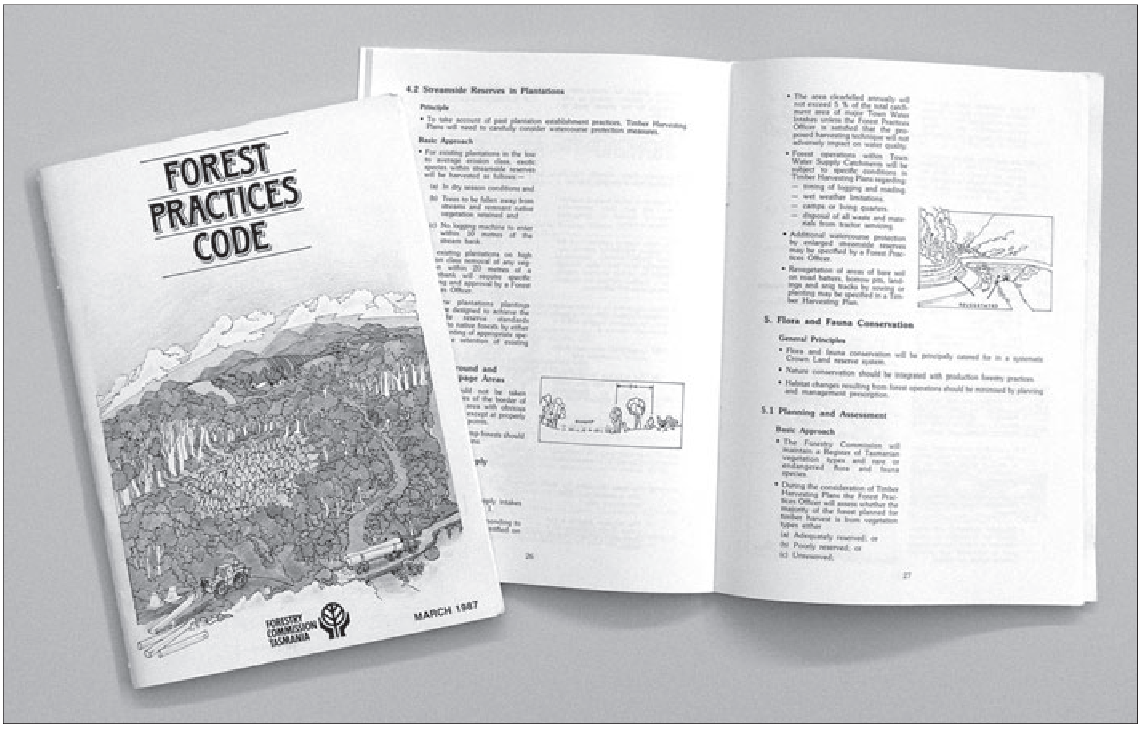
Sampling for insect pollinators on leatherwood flowers. (George Ettershank pictured.)

Forest Practices Research

The guidelines on planning and controlling logging, released by the Forestry Commission in 1976, marked the start of a formal process for continuous improvement in forest practices. A most important step was taken with the release of booklets on *A Forest Practices Concept for Tasmania* which outlined forest practices legislation and a code of practice (Forestry Commission 1980b).

In 1983, work commenced on the preparation of Forest Practices legislation and a Forest Practices Code, as required by the legislation. In May 1985, the *Forest Practices Act 1985* was proclaimed. This was the first legislation of its kind in Australia and it provided a mechanism for ensuring that sound forest practices occurred on both public and private land. It also provided for voluntary declaration by landowners of Private Timber Reserves. In 1987, the Forest Practices Code was published after receipt of public submissions (Forestry Commission 1987). With the adoption of the Code by Forestry Tasmania, training of field staff in all aspects of environmental protection covered by the Code became a high priority.

The *Forest Practices Act 1985* became fully operational in November 1987. The objectives of the Act were to promote the practice of sound forest management on all tenures and to set environmental standards for harvesting, reforestation and protection of forests. Forest Practices Officers (FPOs) are the backbone of the forest practices system—they are trained and authorised by the Forest Practices Authority (see p. 325) to plan, supervise and monitor forest operations to ensure compliance with the Act. Through their normal field work (e.g. surveys and assessments), FPOs gather essential information for continuous improvement of forest practices.



The *Forest Practices Code*, first edition (1987). The *Code* provides a set of standards to protect environmental values during forest operations in Tasmania, including how to deal with rare and threatened plants. It is now the responsibility of the Forest Practices Authority, but early editions were produced by the Foresty Commission.

The 'Gang of Four'

To achieve the aims of the *Forest Practices Act 1985*, specialist advice for FPOs was required in several subject areas. To meet this need, the Forestry Commission appointed four experienced specialists, one each in zoology, botany, archaeology and geomorphology. These first Forest Practices specialists were Rob Taylor, Fred Duncan, Anne McConnell and Kevin Kiernan respectively, christened the 'Gang of Four' by their co-workers. During the following years, they had a very positive influence that cannot be overstated on the Forestry Commission's and Tasmania's conservation science and forestry practices. In 1990, Mike Laffan, an experienced pedologist, was employed by the Forestry Commission and he transferred to the Forest Practices Board in 1994 to provide soil science expertise (see Soil Conservation section).

The initial task of the Forest Practices specialists was to assist FPOs with information and advice on the conservation of natural values. An important part of this assistance was the production of Resource Manuals for fauna (Taylor 1990), forest botany (Duncan 1991 and subsequently), archaeology (McConnell 1990) and geomorphology (Kiernan 1990). These manuals provided information on the key aspects of each subject and the procedures and guidelines necessary for managing wood production forests in a manner consistent with the conservation of natural values.

Although their role in providing advice and resources to FPOs and forestry field staff initially consumed most of their time, the four Forest Practices specialists also conducted their own research projects and very successfully sought external funding to employ project research staff. This research component was much needed as there was only limited knowledge at the time of some of the natural values in forestry areas, particularly geomorphology and archaeology.

The specialists initiated and conducted or supervised a very large number of research and inventory projects of great value to the conservation of natural values in Tasmania's forests. Examples of some of the main projects of the 'Gang of Four' and other specialists relevant to the work of Forest Practices Officers in implementing the Forest Practices Code are summarised in the sections below.

From 1 July 1994, a Forest Practices Board was appointed to administer the *Forest Practices Act 1985* on State and private forests. As a result, the Forest Practices specialists who had been working within the Division of Forest Research and Development in Forestry Tasmania then came under the direction of the independent Forest Practices Board. However, there was still very close co-operation on research projects and in scientific forums between these specialists and scientists in Forestry Tasmania and industry. In 1996, Rob Taylor moved back to Forestry Tasmania to become the Principal Research Officer in charge of the Biology and Conservation Branch.

In 2005, the executive arm of the Forest Practices Board was renamed the Forest Practices Authority, with the term 'Forest Practices Board' referring specifically to the Board of Directors of the Authority.

Fauna conservation

Wildlife habitat strips for fauna conservation in native forests

Rob Taylor initiated the provisions for 100 m wide wildlife corridors or wildlife habitat strips (WHSs) to be incorporated into forest planning. These strips maintained the connectivity between native forest areas for biodiversity conservation. Their value and appropriate width were the subject of a long-term research project, which commenced in 1989. The research was funded by the TFRC and the Forestry

Native eucalypt forest retained as a wildlife habitat strip in a radiata pine plantation at Fingal.

Commission. It compared the 100 m wide WHSs with 40 m wide streamside reserves in respect of how representative the reserved areas were of the whole coupe, and also examined the effects of logging the surrounding area on the fauna in the reserved strips.

This research was conducted in both wet and dry eucalypt forests. Peter Cale began sampling fauna in dry sclerophyll forests at Pioneer in north-eastern Tasmania in 1989 and Ray Brereton began a similar project in wet eucalypt forest at Tarraleah in 1991. Both sites were sampled for 12 months prior to logging, and then fauna surveys were conducted in the reserved areas 10 years after logging. Mammals, birds, amphibians, reptiles, and molluscs, beetles, moths and other invertebrate groups were sampled. To date, pre- and post-logging comparisons have been made for birds and carabid beetles. At the Pioneer site, many elements of the avifauna present in the mature native forest were retained in the strips and the streamside reserves. Considerable

A wildlife habitat strip extending through young eucalypts into the adjacent area being prepared for plantations.

temporal differences in bird data were found at the Tarraleah site, indicating the need for more frequent sampling (Forestry Tasmania 2004c). The assemblages of carabid beetles in the habitat strips and streamside reserves differed from those in the logged areas but were similar to those in the surrounding forest. The WHSs are retaining the carabid fauna typical of unlogged forest, but not all species (Forestry Tasmania 2002c).

Effects of partial harvesting systems on fauna

With the progressive introduction of partial harvesting silvicultural systems (non-clearfelling) in the 1980s and 1990s, the effects of these systems on fauna conservation became a research priority. Two projects funded by the Forestry Commission and the Commonwealth Department of Primary Industries and Energy were initiated in the early 1990s to address this topic. Murray Haseler and Rob Taylor compared the number of bird species in dry forests harvested by clearfelling and partial harvesting systems (advance growth retention, overstorey removal, shelterwood) with unlogged mature forest. Overall, partial harvesting had a lower impact on birds than clearfelling, with the number of bird species present in partially harvested forests being comparable with unlogged forest. As expected, the response of individual bird species to harvesting regimes varied but the overall conclusion from the study was that retention of older trees can ameliorate the impacts of harvesting.

In the second study, Anne Duncan sampled pygmy possums, bats and reptiles in 17-year-old regeneration established after clearfelling, in partially logged forest and in unlogged mature forest. Both wet and dry eucalypt forests were sampled. The general recommendations from the study were (Duncan 1995):

- In dry forest, partial logging should continue to be the silvicultural technique used as it was preferable to clearfelling in this forest type from a fauna perspective.
- It is important to maintain habitat diversity in wet forests where clearfelling is practised, this being achieved through coupe dispersal, streamside reserves, wildlife habitat strips and patches of forest which are too steep or too rocky to log.
- The provisions in the Forest Practices Code for fauna conservation are very important for long-term conservation of the animal groups studied.

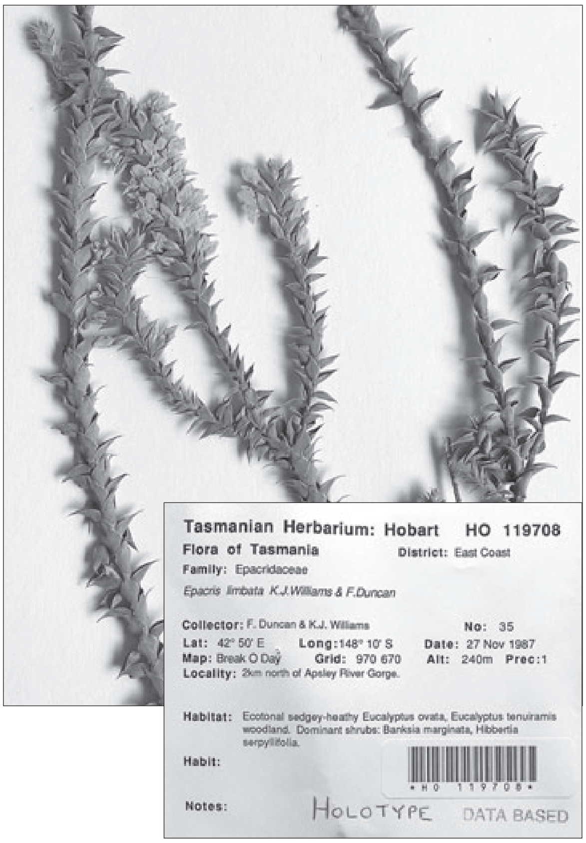
Fauna conservation in plantation areas

The value of WHSs for conservation of fauna within a matrix of pine and eucalypt plantations was studied in the late 1990s to the early 2000s, sampling points in plantations being paired with points in nearby extensive native forest. Species composition of birds in habitat strips within plantation areas was not significantly different from that in adjacent native forest, although strips on upper slopes and ridges had lower species richness and abundance than controls (MacDonald *et al.* 2002). Studies of ground-dwelling beetle fauna by Simon Grove showed that the habitat strips contained a beetle fauna intermediate between the native forests and the plantation, with the vast majority of beetle species of native forest being present in the WHS. Vegetation studies conducted concurrently with the fauna research are still being analysed but, overall, the research provided evidence of the effectiveness of these retained strips as a conservation measure for faunal groups and vegetation in production forests (Forestry Tasmania 2004c, 2005d). Other studies have investigated the value of retained vegetation in areas where plantations are established. Wildlife habitat strips in these areas were found to aid conservation of plant biodiversity but their value could be improved by managing issues such as weed invasion (Loofs *et al.* 2001).

Flora conservation

Vegetation surveys

Surveys in a wide range of vegetation types have been a core activity for the botanical research staff. These surveys have greatly increased existing knowledge of species and community distributions, which has been particularly important for management of rare species. Previously unknown locations were recorded for many rare species, including, for example, *Bossiaea obcordata, Eucalyptus cordata, Glycine latrobeana*, *Helichrysum lycopodioides,* and *Spyridium microphyllum*. New species were discovered, including *Epacris limbata* from the Douglas–Apsley area (Williams and Duncan 1991), and a species of *Allocasuarina* from the Snug Tiers. This species was subsequently named *A. duncanii* in honour of Fred Duncan who found it and recognised its uniqueness (Johnson and Morris 1994). In 1990, Fred instigated an unusual botanical survey aimed at documenting the epiphytes on a large, recently fallen, old Huon pine tree on the west coast. Over 140 species were recorded on the one tree, including 16 vascular species (mostly opportunistic ground species colonising pockets of organic soil accumulating on large branches), and 76 lichen, 39 liverwort and 16 moss species (Jarman and Kantvilas 1995b).



Part of the Holotype of *Epacris limbata*, a heath discovered and named by Kristen Williams and Fred Duncan.

The information gained from vegetation surveys has been used many times to modify planned forest operations in order to comply with the Forest Practices Code and, in some cases, harvesting of whole coupes has been abandoned based on survey results. The impact of vegetation surveys on operational plans was assessed in the mid 1990s by examining information from 160 coupe, roadline and other surveys conducted between 1986 and 1993. Changes to operational plans were recommended to comply with the Code guidelines for 34% of proposed operations, including abandonment of one coupe and two roadlines (Forestry Commission 1994b).

The findings of the numerous inquiries into the impacts of forest operations on non-wood values referred to earlier in the chapter have relied heavily on data from vegetation surveys.

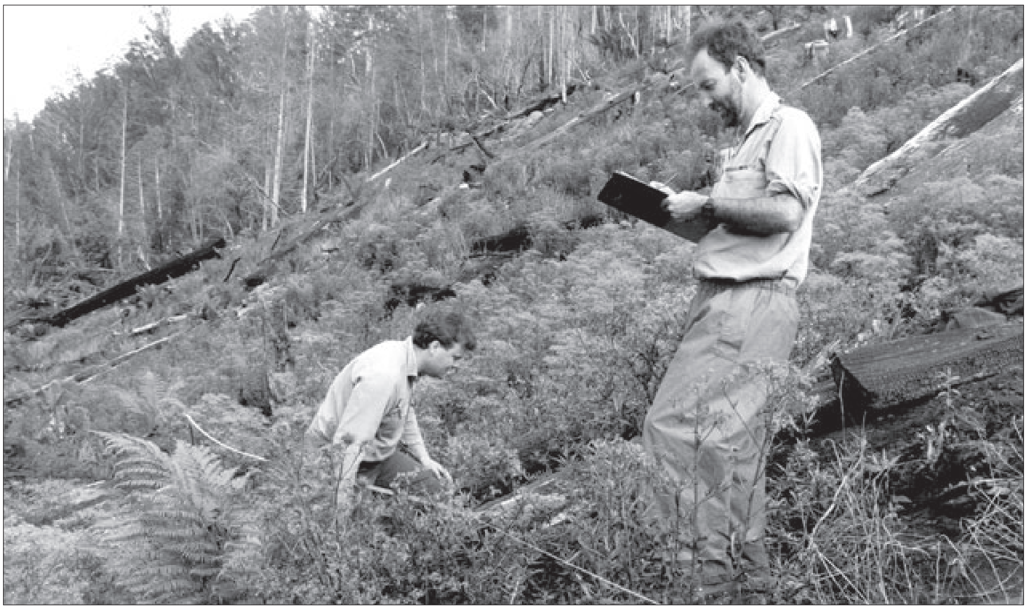
Kristen Williams surveying vegetation near the Crossing River in south-western Tasmania.

Fred Duncan next to *Allocasuarina duncanii*, a species named in his honour after he found it and recognised its uniqueness. It is known only from Snug Tiers in the south of the State.

Effects of steep-country harvesting on vegetation

An investigation of the effects of steep-country harvesting on native flora commenced in the early 1990s after some concerns were expressed that the impact of harvesting in steeper areas may be greater than in conventional (less steep) coupes. Much of this concern arose from the appearance of steep areas harvested using cable machines, in which all vegetation had been flattened. The project was funded by the Commonwealth Department of Primary Industries and Energy and the Forestry Commission. The research examined the pre- and post-harvesting flora in steep-country coupes and included studies of the effects on specific components of the flora, particularly relict rainforest patches, manferns and their epiphytes, and streamside reserves.

The research showed that the post-logging flora was similar in matched regrowth forests harvested by cable and by conventional ground-based techniques. The use of cable harvesting followed by burning in the steep-country coupes caused greater than 50% mortality of manferns



Recording post-harvest vegetation during the steep-country harvesting project in the early 1990s. (Ross Peacock, left, and John Hickey.)

but, 24 months after burning, numbers had stabilised at around 30% of the pre-logging figure. The only epiphytes present were herbs and immature wet forest shrubs and trees which had colonised the manfern trunks (Peacock 1994; Peacock and Duncan 1994).

The study results emphasised the need to maintain botanical values by minimising disturbance to streamside reserves from harvesting and burning and to adhere to the provisions of the Forest Practices Code which forbid logs being yarded through streamside reserves.

Management of threatened species

Following the advent of the *Threatened Species Protection Act 1995*, some 640 plant and animal species, many of which are forest dependent, have been listed as endangered, vulnerable or rare under the Act. Scientists from Forestry Tasmania, the Department of Primary Industries and Water and other agencies have been involved in developing prescriptions for the management of threatened species in areas subject to logging. Nominations for rare species are assessed by a Scientific Advisory Committee (of which Mick Brown was the inaugural Chair).

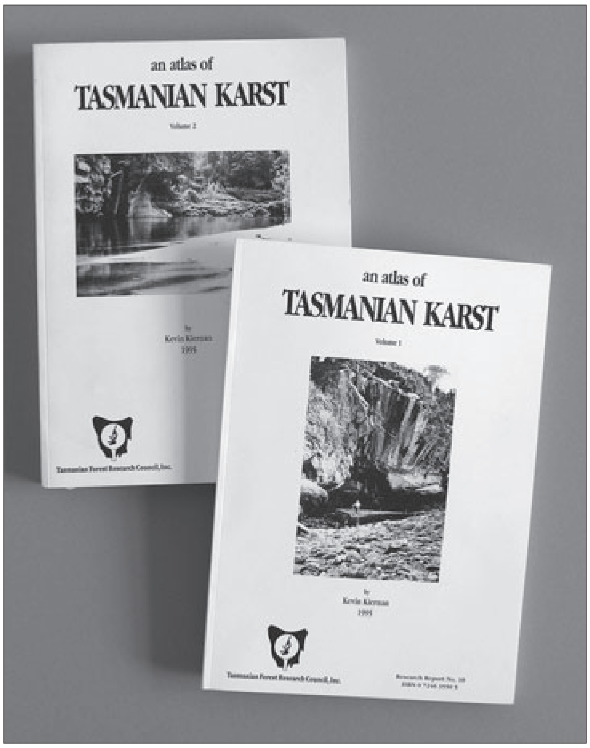
A project to develop management prescriptions for rare plant species was conducted by Phil Barker between 1994 and 1998, funded by the Australian Nature Conservation Agency, with support from Forestry Tasmania. The project had three components:

- Survey and monitoring of species threatened by *Phytophthora cinnamomi*;
- Selecting viable populations for conservation management;
- Management of threatened species in production forests.

Phytophthora cinnamomi was known as a lethal pathogen of several species of rare plants and the first stage of the project involved the selection of areas supporting susceptible species that could be protected from the spread of the fungus. Where all known populations of species were in *P. cinnamomi*-infected areas, new locations of these species were identified that could be protected by suitable management. Field trials to determine the effect of *P. cinnamomi* on infected populations of some plant species were established. Plots were also located at uninfected sites to monitor natural fluctuations in the populations of certain rare plant species (Barker and Wardlaw 1995; Barker *et al.* 1996).

A method was developed for assessing the viability of populations of rare species. It involved identification of the key population parameters from floristic, habitat and seed production variables. The final stage of the research examined the conservation status of species occurring in areas potentially available for harvest. Management prescriptions were developed for these species and a management manual produced as an adjunct to the Forest Practices Code.

Landscape-level prescriptions for the management of rare and threatened species have been developed using population viability analysis (PVA). In a co-operative project between the University of Melbourne, Forestry Tasmania and the University of Tasmania, a population model was developed for the land snail, *Tasmaphena lamproides*, in north-western Tasmania, using data on the species' biology, dispersal, predator-prey dynamics, and habitat. This model enables a range of management options for the snail to be tested (Regan *et al.* 1989). Similarly, population viability models were developed for eleven forest-dependent species of fauna and flora, which clearly showed the sensitivities of expected minimum population sizes to various management options (Fox *et al.* 2004). These PVA techniques are an important advance in the management of groups of species by Forestry Tasmania as they link the key aspects of the species' ecology at the landscape level to broadscale forest management.



An Atlas of Tasmanian Karst by Kevin Kiernan was published in two volumes in 1995.

Geomorphology

Atlas of Tasmanian Karst

A priority for geomorphological research relating to forest practices was to document the occurrence of karst areas so that Timber Harvesting Plans (now Forest Practices Plans) could take account of this very sensitive and important landform. Karst areas are the result of high solubility of the bedrock in natural waters, limestone caves being the best known components of karst. Tasmania has a high proportion of the karst area in Australia, much of it occurring in wood production areas.

In a research project supported by the TFRC, karst areas were progressively documented between 1988 and 1995, with some three hundred karst localities identified and marked on 1:100 000 maps. An inventory of karst features was compiled in areas with major and complex karsts such as Mole Creek and Junee–Florentine. The karst atlas (Kiernan 1996) has become an essential planning tool for Forest Practices Officers when developing conservation measures for geomorphological features in production forests.

Kevin Kiernan at the entrance to a limestone cave, the Welcome Stranger, during the Junee River Karst Inventory project.

Effects of logging on limestone caves

At the time of the introduction of the Forest Practices Code in 1987, little was known of the impacts, if any, of logging in the vicinity of karst systems. In order to more fully understand the factors influencing karst systems and how logging may affect them, Kevin Kiernan initiated a long-term study of hydrological and meteorological patterns within the Little Trimmer Cave at Mole Creek in 1989. The study was partially funded by the Australian National Parks and Wildlife Service, and was managed by Rolan Eberhard (Eberhard and Kiernan 1991).

Rainfall, surface temperature, cave temperatures, stream regime, seepage water regime and humidity in the cave were continuously monitored. Instantaneous monitoring was conducted for soil carbon dioxide, cave air carbon dioxide, groundwater acidity, stream water quality, cave winds and water-borne sediment flux. Over five years of data from Little Trimmer Cave in unlogged forest and comparison with data from karst areas which were logged provided a good understanding of the cave environment and the climatic and hydrologic parameters that need to be monitored to effectively detect any impacts of logging on cave systems.

Archaeology

Historic sites inventory project

Between 1988 and 1992, the number of documented historic sites in wood production forests increased from eight to over 1200. This was achieved through an inventory project initiated by Anne McConnell, partially funded by the National Estate Grants Program, and conducted by Lindy Scripps, Denise Gaughwin and David Parham. Local knowledge of Forest Practices Officers and other Forestry Commission staff was a very important source of information for the project. Historic sites resulting from activities such as convict-based construction, early harvesting, and mining were recorded in each major region (north-west, north-east and south-east).

The knowledge gained from the inventory was, and still is, an essential planning reference for Forest Practices Officers.

Archaeology and physical history of Tasmania's timber industry

This project recorded and documented historic sites relating to the Tasmanian timber industry, with an emphasis on sites located in current production forests. The Project Officer, Parry Kostoglou, produced a series of reports on this topic, mainly from studies in various parts of the Southern Forests, Wielangta in the south-east, and Mount Horror and the Sideling in the north-east (e.g. Kostoglou 1991, 1992, 1996).

An abandoned shepherd's hut in the southern Central Highlands, one of the sites recorded in the Historic Sites Inventory Project in the 1990s.

The remains of a tramway used to move logs from the forest in early logging operations on Tasman Peninsula.

Archaeological sensitivity zoning project

In 1995, Anne McConnell initiated a project aimed at zoning and mapping forest areas in each District on the basis of their potential for containing Aboriginal archaeological sites. In conjunction with District staff, forest areas were classified for archaeological sensitivity into high, medium, low, very low and unknown zones based on availability of archaeological data, local knowledge and particular environmental features such as sandstone shelters and sources of stone. Under the zoning system, the number of coupes that required surveying before logging was greater in forest areas classified as having high archaeological sensitivity than in forests classified as having low sensitivity.

The reliability of the zoning system was tested by Robin Sim and Denise Gaughwin some two years after its introduction. This testing showed that areas of dry forest zoned as high consistently had greater densities of archaeological remains than medium and low zones. In wet forests, there were low densities of archaeological remains in all zones, reduced visibility in such forests being one cause. It was concluded that the system was a useful guide for surveys for Aboriginal archaeology in dry forests although only high and low categories were required. The review recommended that wet forest where karst or stone suitable for tools was present should be zoned as high, with all other areas zoned as low.

The maps of archaeological-potential zones developed by this research project and its subsequent review provide a key reference used when implementing Forest Practices Code requirements for planning and assessment of Aboriginal heritage.

Soil conservation research

The effects of harvesting operations on soils have long been a cause of concern and were a major reason why the guidelines for logging operations were introduced. Soil damage was particularly noticeable in the high productivity, wet eucalypt coupes in the Southern Forests and the far north-west, where deep rutting and profile disturbance occurred. There was little information available in the late 1970s to early 1980s on the long-term effects of this soil damage, both on the soil itself and on the productivity of the site in terms of plant growth. Research on the effects on soils of another major operational practice, the use of fire for regeneration establishment and fuel reduction, is discussed in Chapter 3.

Effects of forest harvesting on soils

John Williamson was appointed in 1985 to work on the effects of mechanised harvesting on the physical and chemical properties of soils. This project was developed and supervised by Gordon Davis, Ron King and Bill Neilsen, and funded by the National Soil Conservation Fund, the Forest Ecology Research Fund and its successor, the Tasmanian Forest Research Council. A sampling method was developed which enabled a quantitative assessment to be made of soil damage on snig tracks using a grid line intercept method which classified soil damage on a scale of three levels of damage as a proportion of snig-track length. The effects on soils of repeated passes of wheeled and caterpillar-tracked snigging machines were compared to obtain data on compaction, profile disturbance and other soil damage. Comparisons of growth of regeneration on and off snig tracks were also

Snigging large logs on wet soils. Studies of the effects of harvesting on such soils by John Williamson in the 1980s provided the basis for revised soil-care provisions in the Forest Practices Code.

made, including on rutted soils and soils in the middle of the tracks.

These studies showed that the initial damage to snig tracks was soil compaction. This decreased water movement in the soil, leading to a reduction in plant growth on the tracks but with more revegetation occurring with time. Even one pass of a machine in dry conditions could cause compaction, indicating that it was better to concentrate logging on a planned minimum number of tracks rather than use numerous dispersed tracks. High trafficking of wet soils can cause profile disturbance, a more serious form of soil damage from which, it was estimated, soils can take tens to hundreds of years to recover. Profile disturbance involves the mixing and inversion of soil horizons and removal of the vitally important organic layer and topsoil from disturbed areas, thus decreasing nutrient levels available for growth. The results of the studies (Williamson 1990) were an important input into the development and subsequent revisions of the Forest Practices Code.

Capability classification of forest soils

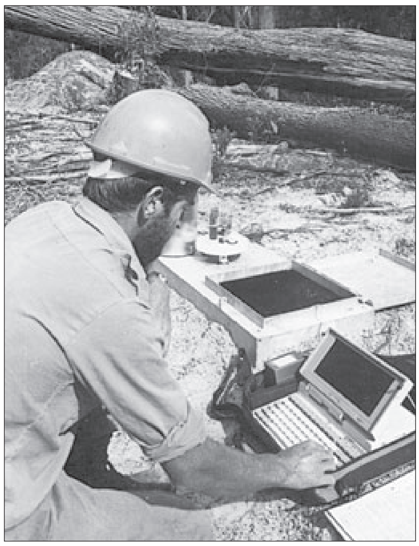
Mike Laffan, an experienced soil scientist, was appointed to the Plantations Branch in 1990 to work on a capability classification of Tasmanian forest soils—a project funded under the Intensive Forest Management Program and the National Landcare Program. This project is described in Chapter 5. Although principally aimed at plantation establishment, the work had significant benefits for soil conservation through the classification of erodibility, land-slide hazard and trafficability for a wide range of soil types. The results of the research were also used to improve the prescriptions in the Forest Practices Code. The detailed soils classification produced by Mike and other staff on the project (see Chapter 5) allowed Forest Practices Officers to recognise specific soil types, their erosion hazard and other characteristics. When the Forest Practices Board was established in 1994, Mike Laffan moved to the position of Senior Soil Scientist with that agency. However, he continued to have close involvement with Forestry Tasmania's soils research.

Erosion of granite soils in the north-east

In the mid 1980s, harvesting operations on some granite soils in north-eastern Tasmania produced severe erosion problems. Research on this problem is discussed in the water quality section below as the erosion was closely linked with hydrologic flows.

Water quality research

Sampling of streams to evaluate the effects of current forestry operations on water quality commenced in Triabunna District in 1971 and was later extended to all Districts. The sampling focussed on local issues and was not a structured research program. In the mid 1980s, the Forest Ecology Research Fund (FERF) and the Forestry Commission funded a detailed study of the effects of logging on water values.



Collecting hydrological data from trials investigating the impact of logging on granite soils in north-eastern Tasmania. (Graham Brown pictured.)

This study was conducted by Ron King, who was originally appointed to the Silvicultural Branch in 1985 as laboratory manager but was an experienced hydrology researcher. A study area was selected near the Tahune Reserve in the Southern Forests and, in 1986, Tom Lynch was appointed to assist with these studies. Six sampling sites on three streams flowing into the Huon River were established to obtain baseline data on turbidity, conductivity, colour, pH, temperature and stream fauna.

In 1987–88, FERF requested a review of the possibilities for future hydrology research in Tasmania. Many sites, particularly those which might be suitable for paired catchment hydrology research, were inspected by Emmett O'Loughlin (CSIRO), with assistance from Ron King, who prepared a report for the Forestry Commission with recommendations on directions for hydrological research.

In 1988–89, three weirs were established on the streams which had been studied since 1986 in the Warra Block. However, hydrology research at this site was halted when the study area was included in the forest taken out of production following the Helsham Inquiry and subsequent political decisions. Some years later, in the mid 1990s, these weirs were again used in hydrology research when the Warra LTER Site was established (see later in this chapter).

The St Helens granite trial

In the late 1980s, severe erosion occurred following harvesting operations in some areas of unconsolidated granite soils near St Helens in north-eastern Tasmania. An estimated 60 000 ha of forest in the region occurs on granite soils susceptible to erosion. A survey of the north-eastern granites was undertaken by John Davies, John Grant and Bill Neilsen to identify, map and describe erodible soils in the region. The project was funded by the National Soil Conservation Fund, Associated Pulp and Paper Mills and the Forestry Commission, with input from local logging contractors (Davies and Nielsen 1987). Tom Lynch supervised the establishment of minimum impact logging trials on highly erodible granite soils until Graham Brown was appointed as Project Officer in 1989. John Diggle was appointed as the Project Officer

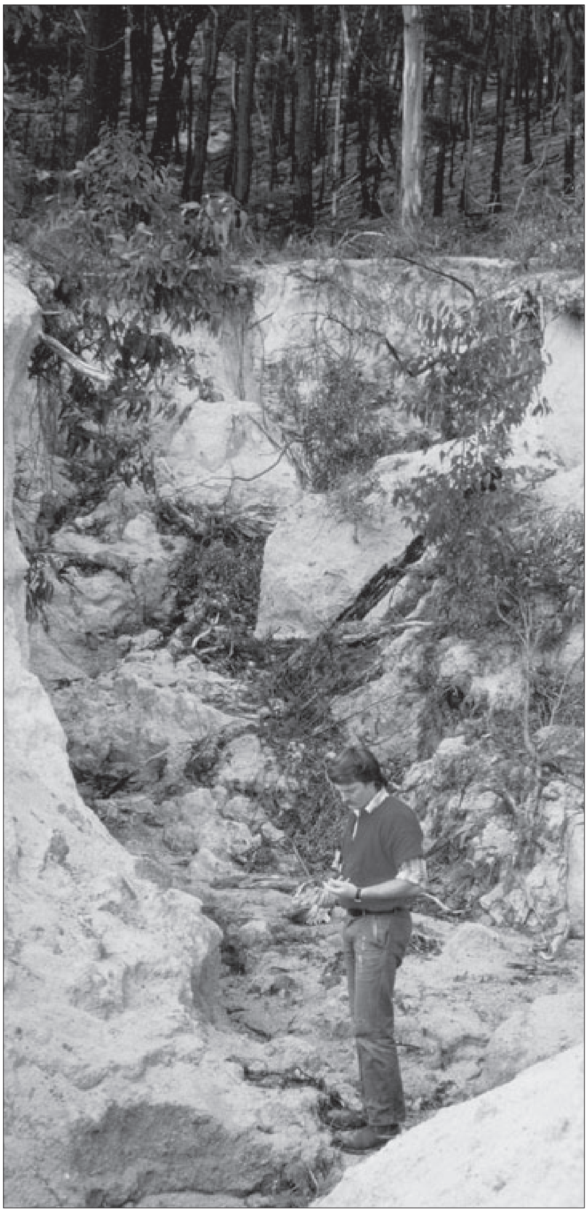
Simulating high rainfall in an experiment in the north-east to assess its effects on granite soils.

in 1991 and he was succeeded by Michael Blake in 1994. Alternative logging methods such as contour snigging and the use of wide-tyred snigging machines were tested. Techniques for logging these soils were developed, including placing limitations on the steepness of slopes that could be harvested, use of ridge-top tracks, and uphill snigging, and these were incorporated into the Forest Practices Code.

Because even light disturbance of unconsolidated granite soils near watercourses often led to erosion problems, monitoring the hydrologic parameters of the streams was considered the most appropriate way to test the environmental effectiveness of different logging techniques. Monitoring stations were set up at the top and bottom of each of two small catchments (Gentle Annie Creek and Deacons Creek) to record turbidity, conductivity, pH and nutrient loads before and after logging.

As the study became focussed on hydrology research, the Australian Centre for Catchment Hydrology began a supervisory role in 1991 and conducted supplementary studies which included determining the effects of simulated rainfall events on logged, unlogged, burnt and unburnt plots. Erosion pins were used to obtain data on the depth of soil erosion occurring in the study sites. Logging of the Gentle Annie catchment was completed in 1991 and four years of post-logging hydrologic data were collected. Logging in the Deacons Creek catchment was completed in 1994 using cable machines, thus allowing a comparison of the effects of this technique with the conventional logging (ground-based) used at Gentle Annie. The research showed that ground-based methods were successful in preventing deterioration of water quality. Cable logging was not suitable for these erodible soils because of the tracking which developed across the contours, leading to erosion.

These studies showed that there was little erosion where soil was protected by slash compared with control sites, but that erosion increased by an order of magnitude where soil was exposed. To identify the sites with the highest potential for erosion, the catchment was modelled using the TOPOG model developed by the CRC for Catchment Hydrology. This model created maps showing erosion potential, which assisted the planning of harvesting operations in the susceptible areas. Several areas of granite soils were subsequently taken out of production.



Severe erosion of unconsolidated granite soils in north-eastern Tasmania. (John Grant pictured.)

John Grant using a truck-mounted hydraulic auger to sample granite soils in the survey site near St Helens.

Musselboro Creek trial

During the 1980s and 1990s, there was much public discussion on the effects of various land management practices on water quality. Forest operations were often mentioned as the cause of local stream turbidity and other water quality degradation, but there were no reliable data available to test these assertions. In 1990, the Forestry Commission, in conjunction with the Australian Centre for Catchment Hydrology and with some funding from the Tasmanian Forest Research Council, established a trial at Musselboro Creek in the north-east. It evaluated the impact of a typical logging operation (conducted under normal Forest Practices Code requirements) on water quality, and compared these effects with those arising from farming activities. Three weirs were established and instrumented by Tom Lynch on the main branch of Musselboro Creek. They were located to monitor water quality in the stream after it left unlogged forest (the control), after leaving an area where two coupes had been harvested, and after leaving an area of agricultural land. Stream discharge, rainfall and water quality parameters were monitored at each weir for about 18 months in order to gain information on stream behaviour, including during and after several storm events. Monitoring then continued for four years following the logging.

Over the life of the trial, some 3905 samples were analysed for turbidity and conductivity and 800 samples analysed for nitrogen and phosphorus and a suite of ions. This trial showed clearly that streamside reserves retained under the Forest Practices Code effectively filtered sediment moving from the logged areas; there was no significant impact of logging on water quality recorded at the downstream weir. However, the clearing and livestock activity on the agricultural area produced high turbidity levels in the samples taken at the weir downstream of the area. This information was included in the Tasmanian State of the Environment Report for 1996 as a case study of research into the relationship between forestry operations and water quality (Sustainable Development Advisory Council 1996).

CASE STUDY 2: FORESTRY OPERATIONS AT MUSSELBORO CREEK

Musselboro Creek starts on the southern slopes of Mt. Barrow in north-east Tasmania. It drains about 1000 ha of State forest and about 1500 ha of mixed agricultural land before entering the North Esk river about 15 km upstream of the Chimney Saddle Reservoir water intake. In 1991 a research project was established by the CSIRO and Forestry Tasmania on this stream to quantify any impacts from a routine forest harvesting operation on water values (quantity, quality and biology) and to compare these impacts with the quality of the stream upon reaching the North Esk River.

Weirs were installed on the creek so as to measure streamflow; and storm-activated water samplers were fitted to the weirs to assess water quality during stormflow events. The weirs were located so that the first measures a control catchment, the second a logged catchment and the third the effects of agriculture. Baseflow water quality data was also collected from eight additional sites throughout the catchment.

Each site was monitored for a total of four years, during which a forest coupe was harvested in the treatment area upper catchment. A smaller coupe on a tributary stream was monitored for further comparison. These coupes were logged as per the guidelines established in the *Forest Practices Code*. After the harvesting operations all sampling sites were monitored for a further two years.

STORMFLOW RESULTS

Over the life of the study 60–70 storms affected the Musselboro Creek area, and about 1200 samples were collected from each autosampler. The average turbidity for each site is given in Table 2. Turbidity is normally greatest during storm flows, but, on average, the storm water run-off from these forest areas was within the guidelines for potable water (5 NTU). In comparison, turbidity downstream from the agricultural areas was great enough to require treatment prior to human consumption. However, the levels are still quite adequate for most other purposes. The differences between the data for the pre-logging, logging and post-logging periods are not statistically significant given the sample size. Also, some downstream increase in turbidity is not unusual, even in natural catchments.

BASEFLOW SURVEY

Baseflow data collected from the additional sample sites point to other features of the land use of the area contributing to instream turbidity (Figure 5). The flow into Musselboro Creek from the partly-logged areas above weir 330 was partly diluted by the unaffected water coming from weir 331. In comparison weir 743 (tributary catchment B) sampled the run-off from a completely cleared (other than the stipulated buffers) area; but still the water was very clear. Tributary catchment B is an old logging area, but still produced relatively turbid water due to the less sustainable forest practices used in the past, and a different soil type. Again, the most turbid water was found draining from the agricultural areas of the catchment.

CONCLUSION

In this catchment, the use of streamside filter strips and careful planning of the harvesting operation—as prescribed by the *Forest Practices Code*—has controlled the impact of the logging operations on the aquatic environment. Within the uncertainty of the measurements, harvesting operations have not adversely impacted on the level of turbidity in this stream.

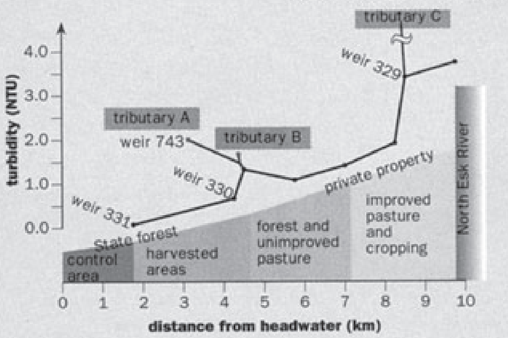
TABLE 2: AVERAGE STORMFLOW TURBIDITY IN MUSSELBORO CREEK

period	control area (weir 331)	harvested area (weir 330)	agricultural area (weir 329)
pre-logging	2.79	3.80	10.63
logging	0.77	1.46	8.40
post-logging	1.22	2.25	9.03

Source: FORESTRY TASMANIA

FIGURE 5: AVERAGE POST-LOGGING BASEFLOW TURBIDITY IN MUSSELBORO CREEK

Source: FORESTRY TASMANIA



Weir 331: catchment area 180 ha, all unlogged.
Weir 330: catchment area 600 ha, 180 ha logged.
Weir 329: catchment area 2800 ha.
Tributary A (weir 743): catchment area 30 ha, all logged.
Tributary B: catchment area 400 ha, 90 ha logged.
Tributary C (Wallaby Creek): catchment area 560 ha, forested private property and agricultural land. Turbidity at the confluence with Musselboro Creek averaged 21.25 NTU.

An extract from the Tasmanian State of the Forests report for 1996, summarising the results of Forestry Tasmania's hydrology study at Musselboro Creek.

Pampass grass (*Cortaderia* sp.), an environmental weed that spread to forests and other areas in the 1980s.

Environmental weeds

The pampas grass program

In the mid 1980s, the spread of the introduced pampas grass, *Cortaderia* species, was showing potential to cause problems for land managers, including the Forestry Commission. The account presented here is included as it is one of few examples of significant containment of an environmental weed in forest areas up to this time. Graham Wilkinson, the Principal Research Officer in the Native Forests Branch at the time, successfully presented a case for a strong Forestry Commission involvement in an eradication campaign. Tim Duckett was subsequently appointed as a project officer to work full time on this campaign in conjunction with several Government agencies, including the Department of Main Roads, Department of Environment and Land Management, the Hydro-Electric Commission and the Department of Agriculture.

The campaign involved the production and dissemination of 53 000 colour leaflets (Duckett and Wilkinson 1988), the appointment of Weed Inspectors in each Forest District to carry out the provisions of the *Noxious Weed Act 1964*, the control of some 23 separate incidences of pampas infestations in State forest, the control of approximately 6000 plants in and adjacent to the South-West World Heritage Area, and assistance to private landowners with control programs.

By the end of the two-year program, all pampas grass populations in State forest had been eradicated and the awareness of Tasmanian land managers of the need to control pampas was very high. Following the two-year program, Leigh Edwards and Sue Jennings (Native Forests Branch) and District staff continued the pampas monitoring and removal program. Although pampas grass is still present in the State, it occurs at low levels and is not a significant weed problem in State forests or National Parks, largely due to the effectiveness of the management program conducted in the late 1980s.

District Conservation Fund

Research into the conservation of natural values, particularly that directed at assisting Forest Practices Officers in implementing the requirements of the Forest Practices Code, was boosted in 1993 by the introduction of the District Conservation Fund (DCF). This fund was established internally by the Forestry Commission, and each District was required to allocate $10 000 from its annual budget to conservation research that had practical implications for management of non-wood values. Many projects across all the specialist research areas associated with the Forest Practices system were assisted by the DCF.

As well as increased research effort, a major benefit of the DCF was the greater involvement of District staff in conservation work through increased co-operation with Forest Practices specialists. The result was better management of natural values by combining specialist knowledge with the practical management approach required in Forest Districts.

The Regional Forest Agreement and Development of Sustainability Indicators

The Commonwealth and Tasmanian Governments signed the Regional Forest Agreement (RFA) in November 1997. The RFA provides for long-term sustainable management of Tasmania's forests; it applies for 20 years, with five-yearly reviews of performance. Some key outcomes of the Agreement were a substantial increase in the area of forests in reserves on both private and public lands, removal of Commonwealth controls on woodchip exports, maintenance of 300 000 m^3 of high-quality eucalypt sawlogs per year harvested from State forest, investment in intensive management of public forests through development of an expanded plantation estate and thinning of native forests to sustain the sawlog supply, and the continued improvement in Tasmania's forest management systems to deliver ecologically sustainable forest management.

During the development of the RFA, Forestry Tasmania staff provided essential information obtained through several major projects, particularly in the areas of forest inventory and conservation research, including:

- Assessments of the extent and conservation status of forest communities, threatened species, oldgrowth, and wilderness and heritage values;
- Mapping, modelling and evaluating reserve options and forest management strategies;
- Field review and finalisation of boundaries of areas proposed as comprehensive, adequate and representative (CAR) reserves;
- Reviews of wood resources to provide estimates of future wood supply under various management scenarios;
- Reviews of the knowledge, systems and research priorities that underpin ecologically sustainable forest management in Tasmania.

In the early 1990s, there were major initiatives at national and international levels involving sustainable forest management (SFM). These included the development of indicators for the main forest values (e.g. biodiversity, soil and water) against which performance of forest managers could be measured. The international moves for SFM began with the United Nations Conference on Environment and Development in Rio de Janiero in 1992 and a subsequent seminar in Montreal on development of sustainable management of boreal and temperate forests. In June 1994, a Working Group was formed which became known as the Montreal Process Working Group. It originally comprised representatives of twelve countries, including Australia, and it developed a framework of seven criteria and 67 indicators of SFM which received political endorsement in the Santiago Declaration of 1995.

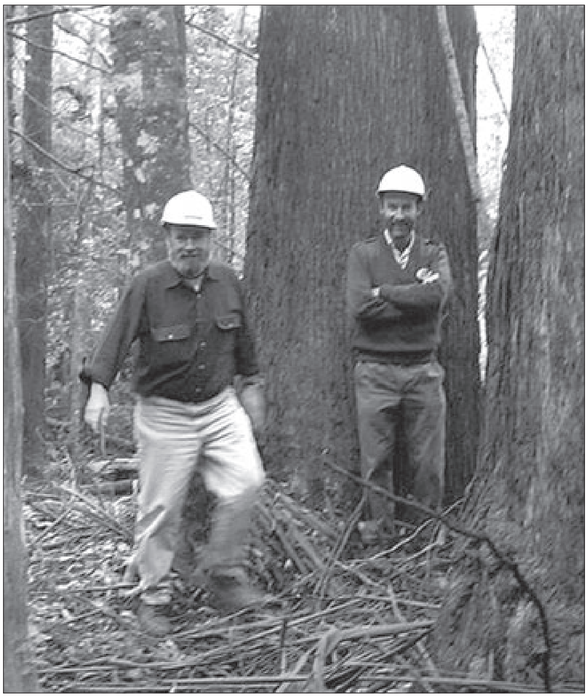
At the national level, Australia, in a co-operative Commonwealth/States process, reviewed these criteria and indicators in the Australian forestry context and produced a Framework of Regional (Sub-national) Level Criteria and Indicators of Sustainable Forest Management in 1998 (Commonwealth of Australia 1998).

The RFA increased the area of conservation reserves in the State and provided funding for increased intensification of forest management, as discussed in Chapter 5. Clause 91 of the RFA required a set of 'appropriate, practical and cost-effective sustainability indicators' to be developed and established in Tasmania by December 1999. A set of indicators was developed by Forestry Tasmania using the framework of regional (sub-national) level criteria and indicators in Australia mentioned above as a guide, modified where necessary to suit Forestry Tasmania's operational and reporting needs. This task was greatly assisted by information from conservation research that had been conducted over the years in Tasmania and advice from Forestry Tasmania staff. The set of Tasmanian SFM indicators included some which relied heavily on past and current Tasmanian research. For example, indicators of soil compaction used data from soils research (see p. 334), and indicators of water quality were the subject of research at the Warra LTER Site.

Typical wet sclerophyll forest at the Warra Site. *Eucalyptus obliqua,* about 60 m tall, overtops a layer, 20–25 m tall, of *Melaleuca, Leptospermum, Nematolepis* and *Acacia*.

The Warra Long-Term Ecological Research Site

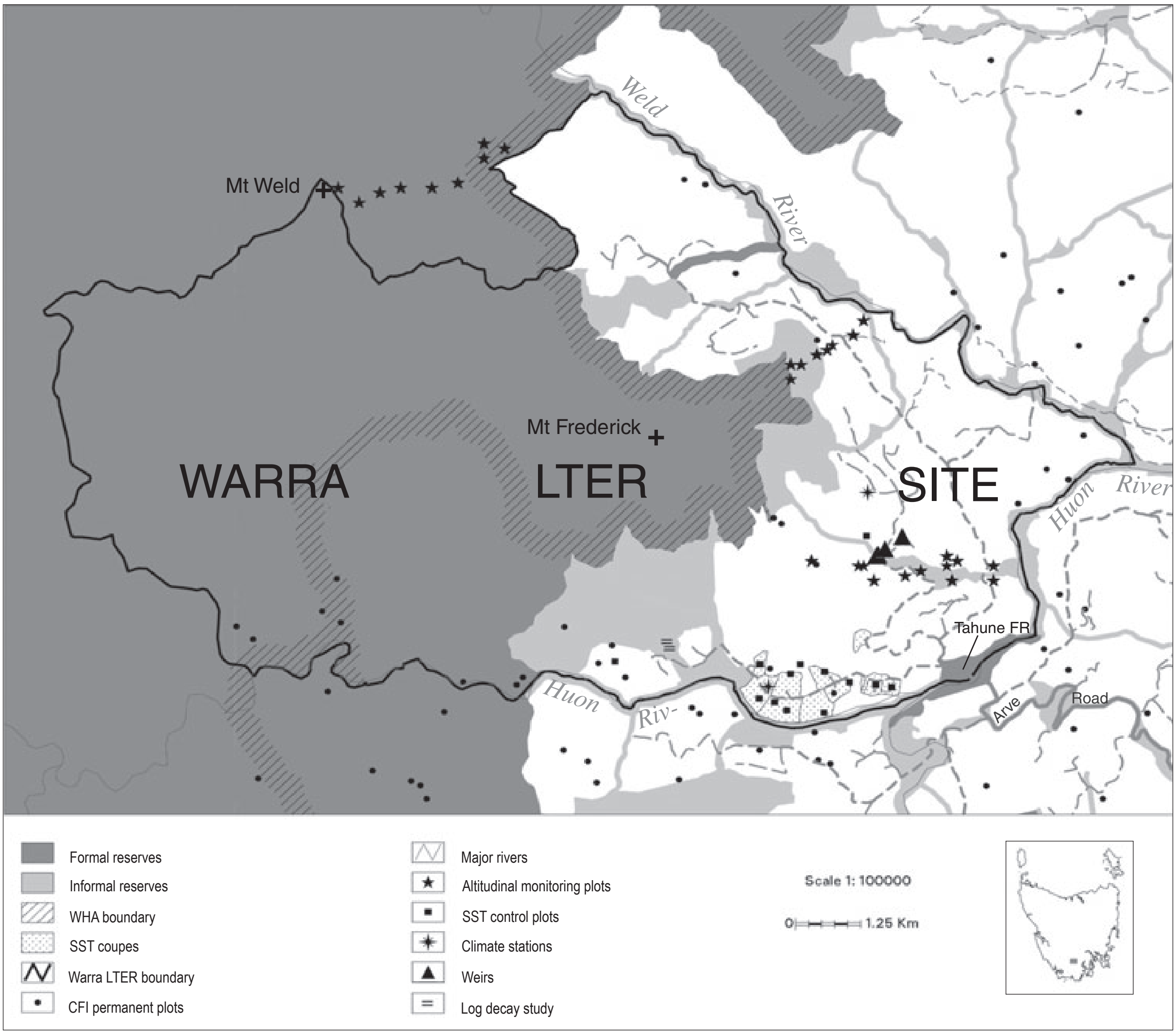
In parallel with the development of sustainability indicators at international, national and State levels, the Executive of Forestry Tasmania resolved to establish a major long-term ecological research (LTER) site where these indicators could be tested and wide-ranging ecological research directly applicable to Tasmanian forests could be conducted. The H.J. Andrews LTER Site in Oregon and the Hubbard Brook LTER Site in New Hampshire were visited by Mick Brown and Humphrey Elliott respectively to obtain information on the establishment and running of LTER sites.



Mick Brown (left) and John Hickey, with assistance from many others, led the development of ecological research in the early establishment of the Warra LTER Site.

A 14 790 ha area at Warra in southern Tasmania, lying between the Huon and Weld Rivers, was eventually chosen for Tasmania's LTER Site. The main reason for this choice was the presence of extensive areas of wet *Eucalyptus obliqua* forests representative of the State's wood production forests and also of large areas within the Western Tasmanian Wilderness World Heritage Area. Other factors were the wide altitudinal range within the site (37–1260 m), diversity of geology and vegetation types, the presence of multiple-use forestry operations, and reasonable proximity to research expertise and facilities in Forestry Tasmania and other institutions in Hobart. A description of the site and the information available on its natural values at the time it was established were compiled by Jill Packham (Packham 1995).

Warra is part of the International LTER Network and it also contributes to the Terrestrial Ecosystem Monitoring Sites database initiated by the Global Terrestrial Observing System (GTOS). The site is managed by a Policy Committee comprising representatives of the major State Government agencies involved in the research and the Commonwealth. There is also a committee which oversees the research



The Warra LTER Site, about 60 km west south-west of Hobart, showing reservation status and major long-term monitoring locations. (Adapted from Brown *et al.* 2001.)

being conducted at the site. Mick Brown and John Hickey, assisted by many others, have led the development of the site, the national and international links, and the scientific research program. A special edition of *Tasforests* (Volume 13, 2 parts, 2001) provided an overview of Warra and the research conducted up to that time.

The first research conducted at Warra was the establishment of the large alternative silviculture trial described in Chapter 2 which compares the standard clearfell, burn and sow treatment commonly used in wet eucalypt forests with a range of partial logging treatments. The treatments are also being used to test the impact of the silvicultural practices on flora, fauna, soils, water and other values.

Baseline studies of many natural values have also been established. The early research studies on the effects of forestry practices on natural values were part of the national project to test the suitability of the Montreal criteria and indicators under Australian conditions. Much of this work was partly funded by the Forest and Wood Products Research and Development Corporation. These projects began in 1996–97 and included:

- The effects of clearfelling and slash burning on soil properties;
- Soil surveys and impacts of silvicultural treatments on soils;
- Effects of silvicultural treatments on flora and fauna;
- Effects of forest operations on water flow and quality;
- Fire history of the Warra Site.

Since its establishment, there has been a very large number of projects conducted at Warra by Forestry Tasmania staff and individuals from other organisations. A fund providing small research grants has also been successful in attracting research students, and several postgraduate studies have been, or are being, based at the Site. A list of projects at Warra is available on the Warra website (www.warra.com), and is updated regularly. Ecological monitoring at Warra and other long-term sites by Forestry Tasmania is reviewed in Taylor (1999). Some of the main Warra projects (apart from operational aspects of the silvicultural systems trial, see Chapter 2) involving Forestry Tasmania staff are summarised below. A recently established study on a wildfire chronosequence is discussed in Chapter 3.

Fungal and invertebrate diversity in decaying log habitat

Logs on the forest floor provide a very important habitat for fungi and invertebrates but the planned rotation lengths of 80–90 years

A long-term study, the first of its kind in Australia, was instigated at the Warra LTER Site by Rob Taylor (right) to compare the invertebrates and fungi inhabiting large and small decaying logs. Discussing the project with him is lichenologist Gintaras Kantvilas.

in production forests in Tasmania will result in smaller sized decaying logs in the forest compared with the situation in unlogged native forests. A study, the first of its type in Australia, was established by Rob Taylor at Warra in 1999 in co-operation with the CRC for Sustainable Production Forestry and the University of Tasmania. It aimed to:

- Determine if small logs and large logs decayed to the same extent supported a similar assemblage of fungi and insects; and
- Compare fungal and invertebrate succession in similar-sized logs in 20-year-old regrowth and in oldgrowth *E. obliqua*.

The biodiversity of two age classes of decaying logs are being monitored using twelve logs (six large oldgrowth logs and six smaller regrowth logs) specially felled for the study. Invertebrates are sampled by enclosing three-metre sections of the logs in muslin-type netting and collecting emerging adults in bottles at ground level

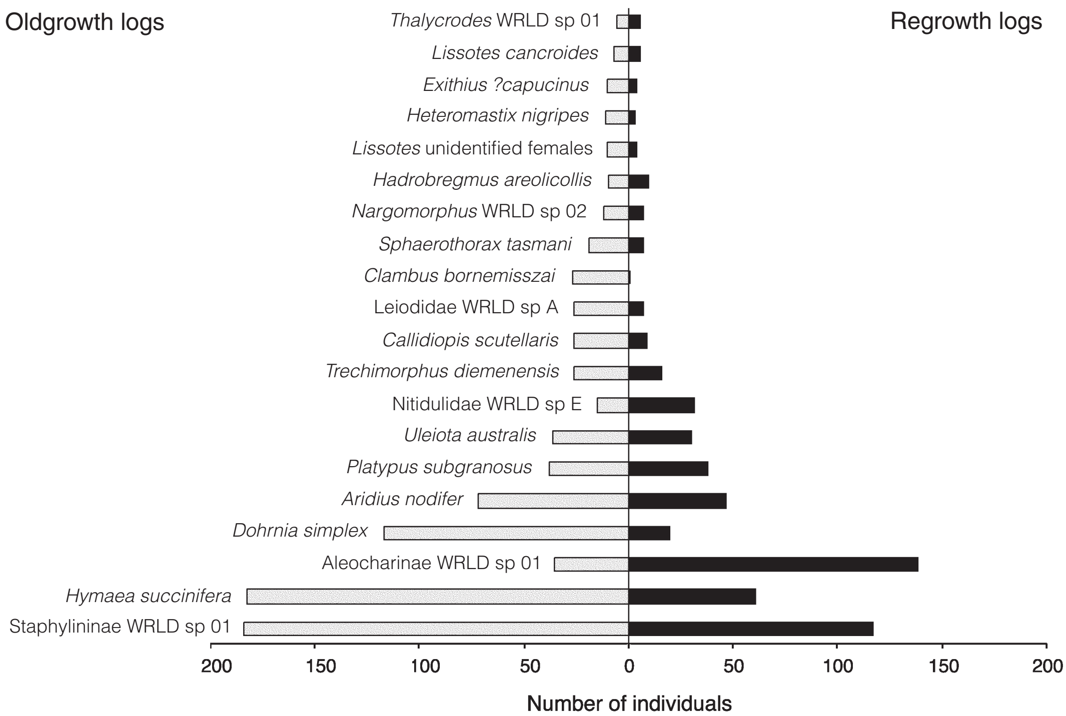
Construction of an emergence trap in the log-decay project, showing the aluminium frame and shade-cloth tent.

Emergence traps in position on eucalypt logs (regrowth log in foreground; oldgrowth log in background) at the Warra LTER Site.

A large log with an enclosed section (left) to trap emerging invertebrates and an adjacent section that has been opened to allow recolonisation. (Simon Grove pictured.)

and at the top of the tents. The sections were covered at three different times of the year and remain covered for three years. They are then opened for two years to allow recolonisation to occur, then covered again for another three-year cycle of sampling. The study will continue for several years and will enable seasonal patterns and successional processes to be recorded and compared in the two log-size classes.

In the first three years of sampling, 12 000 individuals, comprising 308 species of saproxylic beetles, were collected. Abundance and species richness show a clearer relationship with sampled surface area than with log volume. There was no difference in abundance or species richness between the two log age classes, but there were slight differences in the composition of the beetle fauna emerging from the two age classes of logs (Grove *et al.* 2005). The ecology and habitat requirements of the saproxylic beetles have also been studied (Yee 2005).

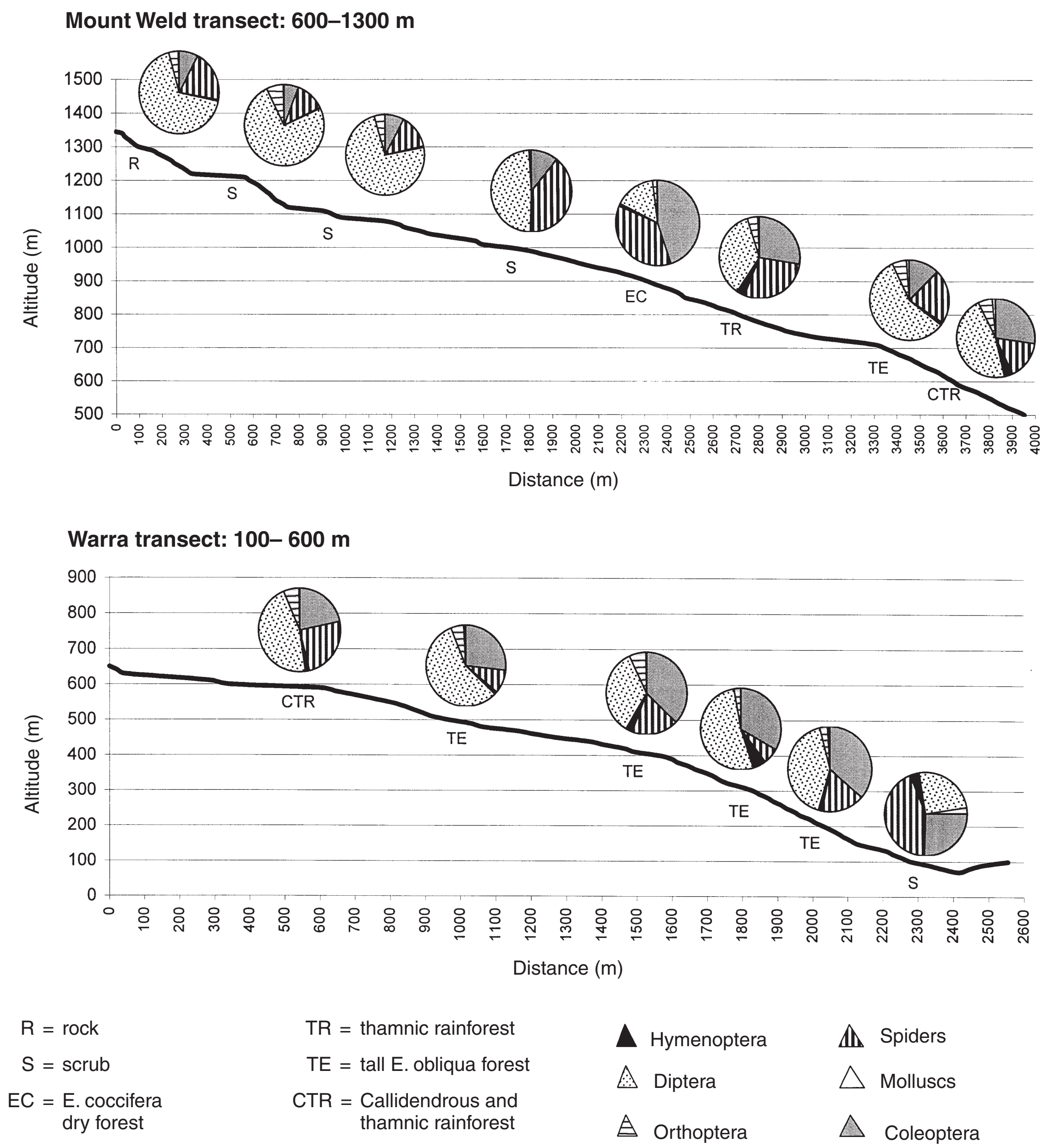


Total abundance in oldgrowth and regrowth logs of the 20 most frequent beetle species in samples from the first year of sampling in the Warra log-decay project. (WRLD in the insect names is an abbreviation for 'Warra log decay'.) (From Grove and Bashford 2003.)

Baseline monitoring of biodiversity trends

An essential component of research at all the LTER sites around the world is baseline monitoring of biodiversity to identify any trends which may then be able to be related to causal factors such as global warming.

Such a system has been established at Warra, involving sampling of plots at 100 m intervals along an altitudinal gradient from 60 m at the Huon River to 1300 m on Mount Weld. Plots have also been set up to allow sampling across the ecotone between different vegetation communities along the altitudinal gradient.



The changes in composition of six major invertebrate groups at each 100 m interval along the Mount Weld and Warra transects. (From Bashford *et al.* 2001.)

A Malaise trap used to collect samples of invertebrates at the Warra LTER Site.

Left: An array of collecting funnels being hoisted into the canopy of a *Eucalyptus obliqua* tree at Warra. This method was used to collect canopy invertebrates sampled by insecticidal fogging as part of the International Biodiversity Observer Year project aimed at elucidating biodiversity patterns and processes through intensive studies at selected sites around the world.

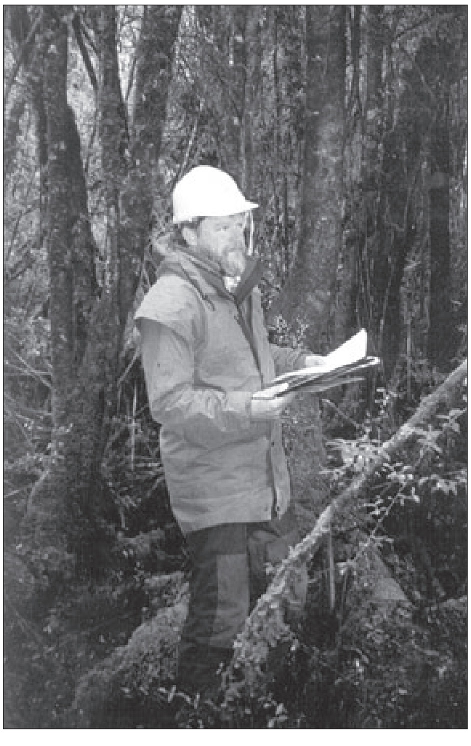
The collecting funnels in position, viewed from below.

The plots have been sampled for vascular plants, birds and invertebrates in conjunction with staff from the Department of Primary Industries, Water and Environment and the University of Tasmania. Species richness and abundance of birds decreased with increasing altitude, particularly above the tree line. Invertebrates sampled included carabid and lucanid beetles, grasshoppers, scorpion-flies, molluscs, spiders and amphipods. There were clear relationships between species richness and particular altitudinal ranges for many species.

Impacts of silvicultural practices on flora and fauna

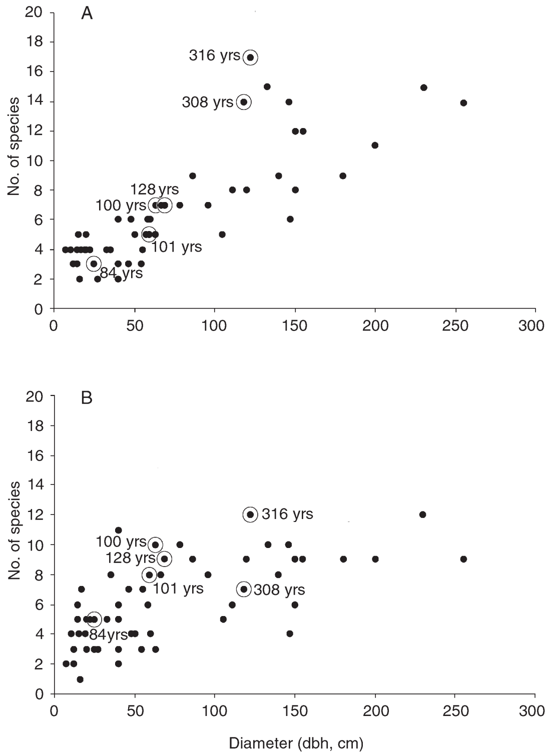
The Warra silvicultural systems trial (SST) (described in Chapter 2) is being used to evaluate various treatments for the conservation of biodiversity. Alternatives range from the current standard treatment in wet forests of clearfelling and burning, through increasing levels and patterns of tree retention to the very low disturbance single tree/group selection treatment. The results of investigations into the value of each treatment for flora and fauna conservation will be an important part of the overall assessment of the performance of the SST treatments. These treatments have been sampled for a range of plant and animal groups and lists of the species found are available on the Warra website (www.warra.com). By 2006, pre-logging sampling had been completed for most of the major groups and the early post-logging work was well underway.

Intensive field surveys of the vascular plants have been undertaken by David Ziegeler, and the results are being interpreted and analysed by Mark Neyland. The studies indicate that before harvesting there were three major vegetation types in the forest. All were dominated by *Eucalyptus obliqua* but differed in their understoreys which comprised callidendrous rainforest, thamnic rainforest, or wet sclerophyll dominated by *Melaleuca* or *Leptospermum* species. The vascular flora consisted of 59 species of flowering plants, one conifer and 25 ferns or fern allies (Neyland 2001).



Over 300 plots have been examined in the SST area in a study of vascular plants. The sampling has been mostly undertaken by David Ziegeler (left), with field assistance from many others, and the data are being analysed by Mark Neyland (pictured above).

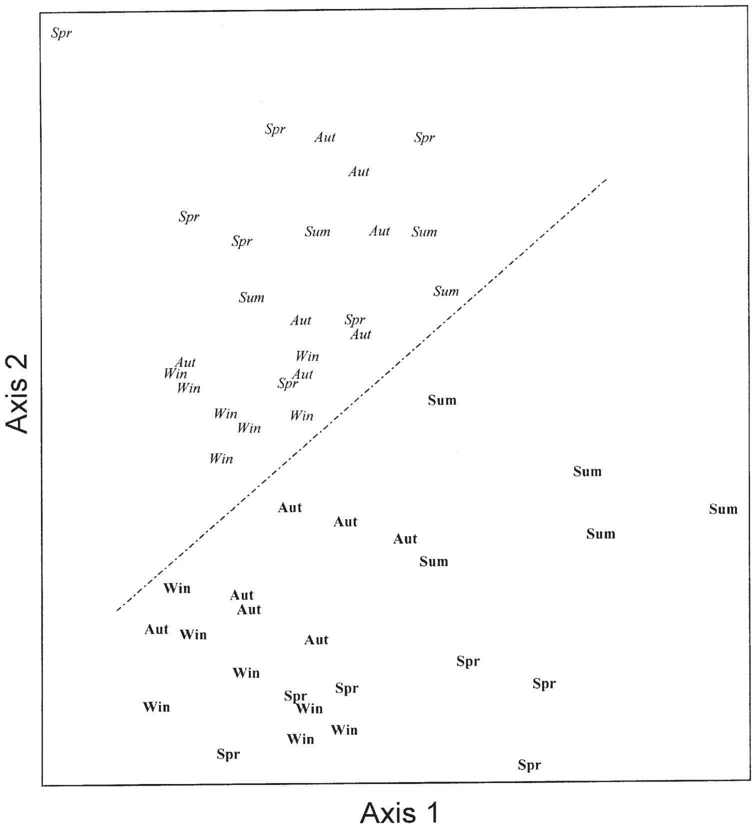
Sampling epiphytic lichens and bryophytes on large stringybark trunks in the SST area, 1997. (Gintaras Kantvilas and Jean Jarman.)



The relationship between tree size (diameter) and richness of lichens (A) and bryophytes (B) on eucalypts in the SST area. Encircled dots represent trees for which ages are known. (From Kantvilas and Jarman 2004; ages are from a study by Alcorn *et al.* 2001.)

Non-vascular plant studies are being conducted through a co-operative project between the Tasmanian Herbarium and Forestry Tasmania, with Gintaras Kantvilas responsible for the lichens and Jean Jarman for the bryophytes. Most of the survey work has been undertaken in wet sclerophyll forest, which represents a single vascular plant community. Species numbers reported for the unharvested forest include 144 for bryophytes and 134 for lichens, based on sampling up to 1999 (Jarman and Kantvilas 2001a). Several new lichen species (McCarthy and Kantvilas 2000; Kantvilas 2004), and many rare or previously unrecorded species for Tasmania have been found (McCarthy *et al.* 2001; Jarman and Kantvilas 2001a; Kantvilas 2005). At 12 months, the post-harvest cryptogamic flora was dominated by short-lived fire species, akin to the fireweeds seen in the vascular flora (Tasmanian Herbarium 2005). An assessment of lichens at year three (Kantvilas and Jarman 2006) found that less than one-quarter of the species recorded in the pre-harvest plots had re-established in the post-harvest plots. This low number is not unexpected because the distribution of species in the forest is closely linked to particular habitats (Jarman and Kantvilas 2001b) so the pre-logging flora is unlikely to re-establish until the diversity of pre-harvest habitats is restored.

A study of the epiphytic cryptogams of eucalypts showed differences between small and large diameter trees, with several specialist species, particularly among the lichens, found only on the large trees. The floristic differences are attributed mainly to the greater habitat diversity on large old trees, which have greater variability in buttress topography and surface features than smaller trees (Kantvilas and Jarman 2004).



An ordination using presence/absence data for fungi to compare young, regenerating vegetation (2–3 years old) and unharvested forest (about 70 years old) in the Warra SST area. Plots in harvested and unharvested vegetation lie on opposite sides of the diagonal line, indicating that species composition of the fungi is different in the two types of vegetation. Time of sampling (season) has been superimposed over the plots to examine seasonal trends. (From Gates *et al.* 2005.)

Surveys of macrofungi, indicated by fruiting bodies, are being undertaken by David Ratkowsky and Genevieve Gates, based at the University of Tasmania. In one study, species richness in an unharvested control area was compared to that in a harvested coupe. A total of 307 species of fungi were recorded, with 248 being found in the unharvested forest and 131 in the three-year-old regeneration (Gates *et al.* 2005). Fewer than half of the species recorded were known to be formally described. The majority of species were associated with wood or soil.

The two coupes supported a different set of species, with more than three-quarters of the total recorded being exclusive to one coupe or the other. The differences in species composition have been attributed to the differences in habitats before and after harvesting. Of the species found only in the regeneration, many are known from studies elsewhere to be associated with

David Ratkowsky and Genevieve Gates collecting fungi in harvested vegetation in the SST area.

burnt or otherwise disturbed environments. There were very low numbers of certain litter-degrading fungi in the regeneration, and the lack of a humus layer and small diameter twigs, branchlets and bark were considered likely to account for the absence of certain mature-forest species. Although plenty of wood was present in both coupes, that found in the regeneration did not appear to be in a suitable condition for many of the species occurring in the unharvested forest. Most fungi known to be mycorrhizal were found only in the mature forest, suggesting such species may take many years to recover from a major disturbance (Gates *et al.* 2005).

Searching for beetles and other invertebrates under a large log rolled by an excavator at Wielangta, 2006. Information from a variety of plant communities and locations provides a context for the log data from Warra. (Simon Grove, nearest camera, Chris Spencer, Belinda Yaxley, others unidentified.)

Invertebrate studies were set up by Rob Taylor at the start of the trial and have been continued by Simon Grove, with much of the field work being undertaken by Dick Bashford. Pre-logging sampling of invertebrates has been completed in all treatments using pitfall and malaise traps within each of two surveyed botanical plots with different floristics at each site. Collections have been sorted into morphospecies (Bashford *et al.* 2001); some post-logging sampling has been conducted.

All these studies are necessarily long term and it will take several years of post-logging data to become available before the value of each of the SST treatments for biodiversity conservation can be assessed meaningfully. Early results will be presented at a major conference to be held in Hobart. Whatever the findings in terms of the relative impacts of the treatments, the research conducted so far is providing a major boost to an understanding of the ecology of wet eucalypt forest in Tasmania.

Biodiversity in coarse woody debris in wet eucalypt forests

Proposals to harvest fuelwood from post-logging slash in the Southern Forests led to investigations of the implications of this practice for the biota dependent on the coarse woody debris (CWD) habitat. In 2002, Simon Grove conducted a literature review which concluded that, if fuel-wood harvesting proceeded, mitigation measures would be needed at coupe and landscape level to reduce the impacts on biodiversity over the longer term (Forestry Tasmania 2002d).

The overall aim of the studies of CWD was to develop prescriptions to allow harvesting of wet forests without severe impacts on CWD habitat and dependent biota. Volumes and locations of CWD were investigated before and after harvesting and CWD biodiversity researched. Interim harvesting prescriptions have been developed and refined for maintaining CWD-dependent biota.

Hydrological studies

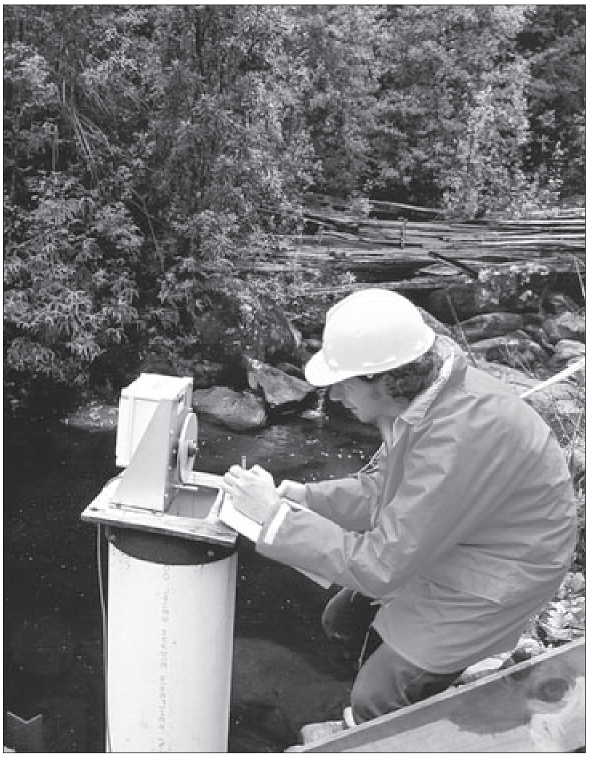
A major hydrological project was established at Warra in 1998 by Tom Lynch, and continued subsequently by Sven Meyer, Carolyn Ringrose and Sandra Roberts. There are three discrete studies within the project:

- Characterisation of a stream draining an unlogged catchment;
- Determination of the effects of commercial logging on stream hydrology;
- Broadscale water sampling of the Warra LTER Site to provide information on the physical water quality of the major rivers and streams.

Tom Lynch with a model weir on display at the launch of the Warra LTER Site, 1998.

The aim of the stream characterisation project is to provide baseline data over several years by monitoring the flow and physical characteristics of Warra Creek, which drains an unlogged, forested catchment. Instrumented weirs have been established on three streams: Warra, Swanson and King Creeks. Data on stream flow,

The weir on Swanson Creek in the Warra LTER Site.



Sven Meyer recording stream flow at the Warra Creek weir site, 2002.

temperature, conductivity and turbidity have been collected over several years at these weirs (Ringrose *et al.* 2001). Studies of stream biology have also been conducted (Davies *et al.* 2001).

The three streams carry water that is coloured with organic matter but a stream draining an adjacent catchment, Crystal Creek, has clear water and the reasons for the difference in water quality have been investigated as part of the stream characterisation project. It was found that, during low stream height periods, Crystal Creek has lower concentrations of nutrients, metals and lower minimum levels of turbidity and colour than those which occur in Warra Creek. The area around the headwaters of the Warra Creek catchment contains a high proportion of sedimentary rock with associated yellow-brown gley soils. It was burnt by wildfire in 1934, is flat and has vegetation composed of low *Eucalyptus nitida* with wet sclerophyll and mixed understoreys. These environmental characteristics have resulted in a highly organic soak which results in constant leaching of decomposing material and weathering products into the stream. Crystal Creek does not have these characteristics (Meyer *et al.* 2002).

The significance of the Warra LTER Site

Warra has become the focal point for forest conservation research in Tasmania and is adding much valuable information on which to base continuous improvement in management of natural values and alternative silviculture. New silvicultural prescriptions have been developed and are being tested at operational scales in several Forest Districts. When the data from several years of post-logging sampling are available, the application of the research results to silvicultural practices will be considered in forest management prescriptions to improve the balance between commercial forestry and conservation.

Under the 'Tasmania Together' initiative introduced by the Tasmanian Government in 2002, a benchmark was set of phasing out clearfelling of oldgrowth forests by 2010 on public land while still maintaining sawlog and veneer supplies to industry. To begin the process of moving towards this goal, the Tasmanian Government asked Forestry Tasmania in September 2003 to provide advice on how this phase-out might be achieved. In April 2005, Forestry Tasmania published a document entitled *Towards a New Silviculture in Tasmania's Public Oldgrowth Forests: Final Advice to the Tasmanian Government* (www.forestrytas.com.au). It outlined four scenarios, each of which was compared with the current clearfell, burn and sow treatment for wet oldgrowth forests:

- Mixed silviculture;
- Variable retention silviculture;
- Single tree/small group selection silviculture;
- No logging in oldgrowth.

The advantages and disadvantages of each scenario were presented, including impacts on biodiversity conservation. This advice relied heavily on the research work and operational experience gained at the Warra LTER Site. The scenarios closely matched the treatments being evaluated in the SST trial, and even though the research on impacts of the treatments on biodiversity conservation was still in progress, there was enough information to guide the evaluation of the scenarios. Variable retention systems developed at Warra are currently being tested across several Districts.

Tasmanian Community Forest Agreement

In May 2005, the Commonwealth and Tasmanian Governments signed the Tasmanian Community Forest Agreement (TCFA 2005). This Agreement built on the initiatives in the Regional Forest Agreement of 1997 by introducing some significant conservation measures, including a substantial reduction in the clearfelling of oldgrowth, and incentives for the forest industry to introduce new practices and technology. Conservation initiatives included an additional 148 000 ha of reserves, phasing down clearfelling of oldgrowth to no more than 20% of the oldgrowth harvested each year by 2010, and phasing out the clearing and conversion of native forest. Again, without the information gained from the research work of Forestry Tasmania and collaborators, and in particular from the Warra trials, there would have been far less reliable information on which to base this agreement.

Three Decades of Forest Biology and Conservation Research

Research into non-wood values by Forestry Tasmania has been in progress for only a short time compared to wood-related studies, but it has had a profound effect on the way the State's forests are managed. Without the results from this research, there would be little basis for the design and implementation of landscape and coupe-level reserves, guidelines for soil and water care, and prescriptions for the management of landforms, archaeological sites and individual species of plants and animals.

A major outcome of this research is the environmental protection measures embodied in the Forest Practices Code, Australia's first comprehensive set of standards to protect environmental values during forest operations on public and private land. A huge benefit from the introduction of the Forest Practices system has been the increased expertise of field staff in environmental management. The maintenance of these skills within the large group of Forest Practices Officers is vital to the successful implementation and monitoring of forest practices standards.

Conservation studies conducted at Forestry Tasmania, often in collaboration with other agencies, have provided much of the factual information presented at numerous inquiries into Tasmanian forestry over the last 30 years. The findings of these inquiries, based in large part on this research, have reflected well on the standing of Forestry Tasmania as a forest manager. Many of these findings centred on what is the appropriate level and arrangement of vegetation reservation in the landscape. The research in this field has enabled the State to produce a world-class forest reserve system, which has been used as a model at the national and international level, whilst allowing the maintenance of a viable forest industry.

In summary, conservation-related research has assisted Forestry Tasmania to progress towards those sustainable forest management practices required to optimise 'the benefits to the public and the State of the non-wood values of forests' as prescribed in Section 7 (b) of the *Forestry Act 1920*.

Tall mixed forest in a streamside reserve (part of a larger Protection Zone) beside the Florentine River, near the site of the Pagoda (destroyed by fire some years ago). The Pagoda was an impressive shelter/barbecue site built by Australian Newsprint Mills and often used to entertain visitors, including Royalty.

Chapter 8

Concluding Comments

There have been many changes in research and development needs over the 85 years from the beginning of the Forestry Department in 1921 to the situation at Forestry Tasmania in 2006. The priorities of the organisation have progressed from the original focus on ensuring that forests were dedicated for the sustainable production of timber, through to managing a whole range of values of which timber is only one. Expressed another way, conservation of forests for timber supplies was the original task and this has now broadened to conservation of all forest values. The breadth of the research and development work described in this account reflect this broadening of management responsibilities.

The management practices now used are mostly from the organisation's own research studies and operational experience described in this account. However, there have been substantial contributions from many other organizations, some of which have been mentioned in individual chapters.

Examples of the innovation which has changed forest management in Tasmania include:

- Air-photo interpretation for forest inventory;
- Forest inventory projection system for multi-aged forests (FIPS);
- Development of the highly successful clearfall, burn and sow method for regenerating wet eucalypt forests, plus a range of alternative harvesting and regeneration methods for use in high-altitude and drier eucalypt forests, and in blackwood forests;
- Development of variable retention harvesting and regeneration techniques for use in oldgrowth wet eucalypt forests;
- Fire behaviour predictive tools, particularly the Soil Dryness Index;
- Capability classification of forest soils for site selection for plantations;
- Development of regimes for growing eucalypt plantations for solid wood products,
- Reduced use of chemicals and development of alternative weed control measures in plantation management;
- Forest health surveillance systems for plantations;
- Integrated pest management systems for controlling browsing animals and leaf beetles;
- Specialist support for the Forest Practices system;
- Scientifically based reservation of forest types;
- Development of the Warra LTER Site;
- A greatly increased understanding of the ecology of the different forest types and the impacts of forest management practices on flora, fauna and other natural values.

These examples clearly illustrate that the ultimate test of the value of research to a forest manager – *Have the results been incorporated into management practice to improve the way forests are being managed?* – has been passed in all the major subject areas.

Forestry Tasmania's research is scientifically driven through training and collaboration with other organisations, but is very operationally focussed, usually being undertaken co-operatively between scientists and forest managers. A key reason why operationally relevant outcomes from research have been consistently achieved is that forest policy and management functions have been retained within the one organisation, a rare occurrence in Australian public forest management. In addition, there has been a strong concentration on demonstrating the impacts and economics of forest management practices. Much of the research has been long term, thus providing a perspective which matches all, or a substantial proportion, of the length of crop rotations. This ability to maintain long-term research projects is now quite rare in Australian forestry and it has produced many benefits for Tasmania's forests.

Forestry Tasmania's achievements in research and development have also influenced the practices of other forest managers interstate and overseas. Examples include the development of regimes for growing solid wood in eucalypt plantations, the Forest Health Surveillance System, methods for reservation of forest types, and the use of the Soil Dryness Index for predicting fire behaviour. A recent practical example was the use of Forestry Tasmania's fire control expertise in major fires in the United States of America, New South Wales and Victoria.

Forestry Tasmania has maintained the value and relevance of its science by inputs from managers and operational staff into annual reviews of the research programs. In addition, representatives of the research branches meet regularly and all scientific research staff meet annually to keep abreast of current projects across all disciplines and to debate future directions. In so doing, the development of an integrated and coherent approach to research has been possible, with greatly improved scientific outcomes. Over the years, this science has been used (and thoroughly scrutinised) in Government inquiries into numerous public forestry-related issues, where it has been well received and has made important contributions to the ultimate findings of the inquiries.

The organisation has maintained a strong publishing record in scientific, peer-reviewed journals and in semi-technical and extension literature. The journal *Tasforests*, developed and published by Forestry Tasmania for some 16 years, has been an important tool in getting research results recorded which would otherwise be difficult to access.

Future research and development will need to address the continually increasing complexity of forest management practices. Regimes for managing native forests and plantations will require adaptation to cater for changing markets and economics, environmental considerations and community opinion. The ever-expanding database on flora, fauna, water and other forest values will necessitate changes to management practices. Scientific expertise from Forestry Tasmania and elsewhere will be required to interpret these data and formulate new prescriptions. The history of innovation covered in this account provides an excellent basis for meeting these future challenges. Even in the short time since 2006 (the final year of this account), there has been significant growth in reseach and development in several subject areas, including, for example, variable retention silviculture, hydrology research, and biological investigations at the Warra LTER Site. There is little doubt that ongoing research and development will provide ample subject matter for future accounts of innovation at Forestry Tasmania.

Appendix 1.
Some key inquiries and reports with implications for forest research in Tasmania.

1959	Parliament of Tasmania, Legislative Council. Select Committee on Regeneration of Eucalypt Forests.
1972	House of Representatives. Select Committee on Wildlife Conservation.
1972	Parliament of Tasmania, Legislative Council. Select Committee on Forest Regeneration.
1975	Working Group on the Economic and Environmental Aspects of the Export Hardwood Woodchip Industry.
1976	Senate Standing Committee on Science and the Environment. Interim Report on the Impact on the Australian Environment of the Current Woodchip Industry Programme.
1977	Senate Standing Committee on Science and the Environment. Woodchips and the Environment.
1977	Report of the Board of Inquiry into Private Forestry Development in Tasmania by M.G. Everett and S.W. Gentle.
1978	House of Representatives. Standing Committee on Science and the Environment. Woodchips and the Environment: Supplementary Report.
1985	Commonwealth Department of Arts, Heritage and Environment. Rainforest Conservation in Australia.
1985	Parliament of Tasmania, Legislative Council. Select Committee on Woodchip Exports.
1985	Commonwealth Department of Arts, Heritage and Environment. Environmental Assessment Report into Tasmanian Woodchip Exports beyond 1988.
1986	The Nixon Inquiry into the future of Jackeys Marsh and the Lemonthyme Forests.
1987	Commission of Inquiry into the Lemonthyme and Southern Forests. Interim Report.
1988	Commission of Inquiry into the Lemonthyme and Southern Forests. Final Report. 'Helsham Inquiry'.
1990	Interdepartmental Working Group for Forest Conservation. Recommended Areas for Protection of Rainforest, Wet Eucalypt and Dry Sclerophyll Forest in Tasmania. 'RAPs Report'.
1990	Tasmanian Forests and Forest Industry Council. 'Secure Futures for Forests and People: The Forests and Forest Industry Strategy'.
1991	National Plantations Advisory Committee. Final Report.
1991	Ecologically Sustainable Development. Working Group on Forest Use. Final Report.
1992	Resource Assessment Commission. Forest and Timber Inquiry. Final Report.
1992	Council of Australian Governments. National Strategy for Ecologically Sustainable Development.
1992	Commonwealth of Australia. National Forest Policy Statement: A New Focus for Australia's Forests.
1992	Council of Australian Governments. Intergovernmental Agreement on the Environment.
1994	Montreal Process Criteria and Indicators.

Appendix 1. *Continued.*

1995	Federal/State Scoping Agreement for Regional Forest Agreement. Interim Forest Agreement applied embargo to coupes during assessment.
1995	Department of Prime Minister and Cabinet. Wood and Paper Industry Strategy.
1996	Commonwealth Department of Primary Industries and Energy, Land Resources Division. Review of Tasmanian Plantation Codes of Practice.
1996	Senate Rural and Regional Affairs and Transport References Committee. Landcare Policies and Programs for Australia.
1996	ANZECC. Nature Conservation on Private Land: Commonwealth, State and Territory Programs.
1997	Joint Australian and New Zealand Environment and Conservation Council/Ministerial Council on Forestry, Fisheries and Aquaculture. Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia.
1997	Australian National Audit Office. Commonwealth Natural Resources Management and Environment Programs: Australia's Land, Water and Vegetation Resources. Audit Report 36.
1997	Regional Forest Agreement between the Commonwealth of Australia and the State of Tasmania.
1998	Industry Commission. Inquiry into Ecologically Sustainable Land Management. A Full Repairing Lease. Report 60.
1999	ARMCANZ. Managing Natural Resources in Rural Australia for a Sustainable Future.
1999	Resource Planning and Development Commission Inquiry into Areas to be Reserved under the Tasmania–Commonwealth Regional Forest Agreement. Final Recommendations Report: Comprehensive, Adequate and Representative Reserves.
2001	Department of Environment and Heritage National Forest Inventory.
2001	Natural Resources Management Ministerial Council. National Framework for the Management and Monitoring of Australia's Native Vegetation.
2002	Resource Planning and Development Commission Inquiry on the Progress with the Implementation of the Tasmanian Regional Forest Agreement. Final Recommendations Report.
2002	Senate Rural and Regional Affairs and Transport Committee Inquiry into the Plantation Forests Industry.
2003	Tasmania Together Progress Board; Development of an indicator for the sustainable management of oldgrowth forests; Development of an action plan to set a timetable and interim targets for benchmark 24.2.1(b) – phase out of clearfelling in oldgrowth forests by 2010.
2004	Productivity Commission. Impacts of Native Vegetation and Biodiversity Regulations. Dealt with restrictions to establishment of plantations.
2005	House of Representatives Select Committee on Agriculture. Inquiry into Pests. Dealt with the use of chemicals and browsing damage management.
2005	Tasmanian Community Forest Agreement. A joint commitment of the Australian and Tasmanian Governments to enhance protection of Tasmania's forest environment and provide growth in the forest industry and forestry jobs.

Photo Credits

DFRD = Division of Forest Research and Development, Forestry Tasmania
DSRD = Division of Silvicultural Research and Development, Forestry Commission, Tasmania
FT = Forestry Tasmania
FMB = Fire Management Branch, Forestry Tasmania
b, c, t, l, r = bottom, centre, top, left, right, respectively

The source of the photos is written in roman; photographers, where known, are given in *italics*.

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Index

Since 1921, the Forestry Department and its successors, Forestry Commission Tasmania and Forestry Tasmania, have been conducting research to improve forest management. This research initially concentrated on observing natural processes in the forests and their reaction to disturbances, particularly wildfire. Later, investigations broadened to gain a detailed understanding of the ecology of different forest types, and specialist research staff were appointed to cover an expanding range of forest values being managed.

This account covers the period 1921 to 2006. It documents the history of the main research and development work associated with determining wood resources and sustainable yield, silviculture of native forests and plantations, fire management, forest health, and the conservation of natural values. It has been compiled to provide a reference text for past, current and future forestry staff and other parties with an interest in the management of Tasmanian State forest.

Forestry Tasmania

ISBN 978-0-646-49207-0

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