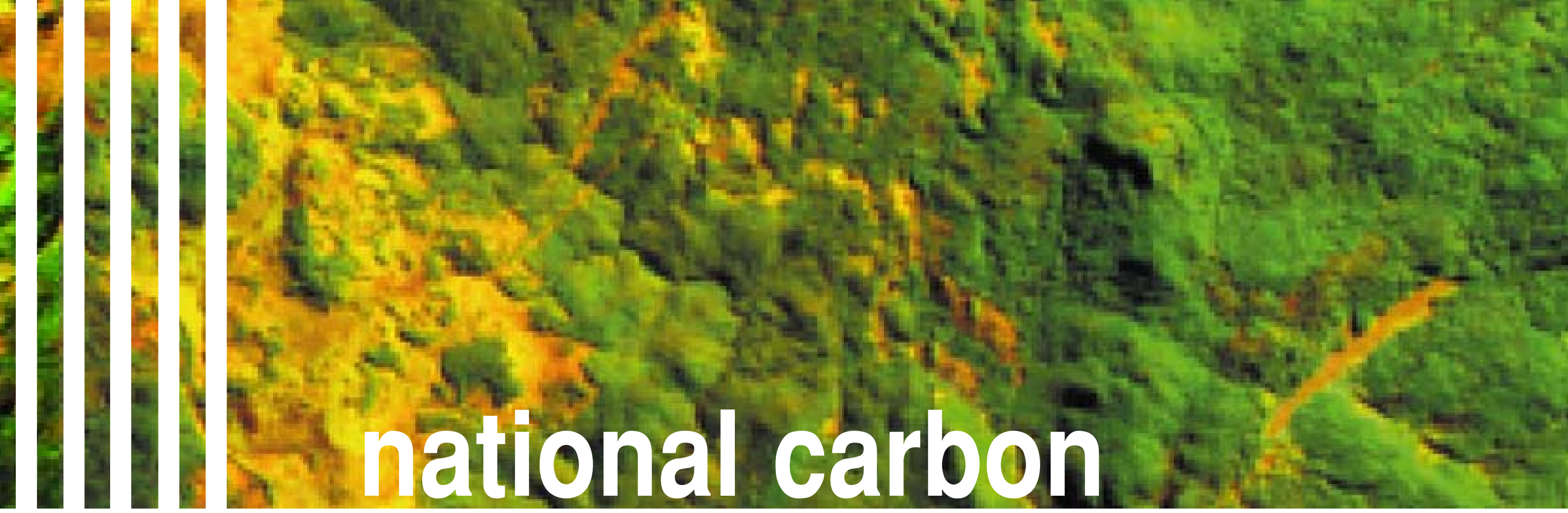

national carbon accounting system

technical report no. 32

Forest Management in Australia: Implications for Carbon Budgets

Edited by R.J. Raison and R.O. Squire

part 1 of 2

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FOREST MANAGEMENT IN AUSTRALIA: IMPLICATIONS FOR CARBON BUDGETS

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part 1 of 2

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TABLE OF CONTENTS

PREFACE

The way that forests are managed affects the timing and quantum of greenhouse gas emissions and removals from the atmosphere. The SE effects may persist for decades after the event, making it necessary to understand historical management practices and how these have changed over time in order to calculate current carbon exchange.

As a background to estimating emissions and removals by Australia's forests, this technical report has considered management practices on a state-by-state basis. Each state is broken into regions defined by either management units or forest types. This review considers public and private native forests, and plantations.

The various authors have thoroughly reviewed the changes in forest management practice in each state, beginning with the period after World War II. Adoption of a co-ordinated approach, combined with external review has resulted in this synthesis which will support modelling of greenhouse gas exchange within the National Carbon Accounting System.

SECTION 1

Overview and Integration

John Raison

Ross Squire

TABLE OF CONTENTS

Page No.

LIST OF TABLES

OVERVIEW AND INTEGRATION

1. INTRODUCTION

This national review is part of a suite of projects being undertaken by the National Carbon Accounting System (NCAS) of the Department of Climate Change to develop an improved capacity for tracking and forecasting C stocks and fluxes in Australian forests following changes in forest management practices. The work was initiated by the Australian Greenhouse Office (AGO), which is now part of the Department of Climate Change. The project contributes to the development and application of a spatial model that uses remote sensing linked to a partly process-based and partly rule-based forest information system.

Forest management has the potential to have a marked effect on C stocks at both the site and landscape level, and possibly at the continental level. Forest management practices can have both immediate and on-going (decadal) effects on C stocks in soil and biomass. Consequently, in order to understand current C flux, or to be able to reasonably forecast future C balance, it is necessary to understand forest management and its impact over approximately the past half century.

In Australia, forest management has changed dramatically, both in terms of its nature and geographical extent since World War II. Major changes include widespread adoption of intensive harvesting (including clearfelling) and regeneration burning in native forests during the 1960s and 1970s, access to major pulpwood markets for hardwood, greater fuelwood extraction, increased conversion of native forest to pine plantations, widespread implementation of low-intensity fuel reduction burning and better fire management that has generally reduced the severity and extent of wildfire, marked increase in transfer of native forest to conservation reserves; and recent significant increases in hardwood plantations, mostly established on previously cleared agricultural land.

The purpose of this review is to describe forest management practices that are likely to have a significant impact on C stocks in the forest estate and their change over time. The review covers both qualitative components (e.g. floristics and structure of the forest, harvesting and regeneration methods) and quantitative components (e.g. area contributing to wood production, degree of canopy disturbance, mass of timber products removed, percentage of logging slash consumed in regeneration burning, and post-harvest biomass accumulation). Expert opinion has been very important in deriving quantitative estimates that can be applied over space and time. Information from this review can be combined with an application of satellite data to produce a multi-temporal spatial forest management layer for important Australian forest regions. These management data, when linked to ancillary information (e.g. climate, soils, elevation, aspect, topographic position, vegetation), can be used to model change in forest carbon stocks during past decades and into the future.

2. PROJECT IMPLEMENTATION

The AGO through the NCAS contracted CSIRO Forestry and Forest Products (CFFP) to co-ordinate a review of forest management practices in Australia. The aim of this review was to describe temporal change in forest management practices, and to determine the potential implications for change in the forest C stock. The task was not to undertake a detailed quantitative assessment of C balance for any part of or the entire forest estate. Management of the project within the NCAS was by Dr Gary Richards (Director and Principal Scientist), with support from Drs Cris Brack and Brian Turner from the Forestry Department, Australian National University. Rob Waterworth of the AGO provided a significant contribution to the editing of the final report.

It was agreed that the project would be best carried out on a State-by-State and topic-by-topic basis, by people with a strong background and long experience of forest management. This approach allowed best use of 'local' knowledge and experience. Separate reports were produced for each State (native forests) and for the important topics of plantations and fire.

2.1 PROJECT TEAM

A team of highly qualified and experienced people was assembled for each reporting task. Each team collected and synthesised detailed information based on examination of published literature, records/reports held by State agencies, discussions with retired foresters and senior staff within agencies, and their own resources and experience. Brief information on the background and expertise of the people involved in each aspect of the project is given in Appendix 1.

2.2 KEY ACTIVITIES

Briefing Workshop

The purpose of the workshop was to bring the contributors together for a briefing by AGO and CSIRO on the purpose and scope of the project. In summary this covered:

1. Carbon Stocks

The three major impacts, excluding changes in forest area, of forest management practices on future C balance for forests are:

- Biomass removal (i.e. harvested products)
- Slash production and management (e.g. regeneration burning)
- Post-harvest growth (i.e. C sequestration by the modified or newly regenerated forest).

2. Approach

Reports to cover both a qualitative description of temporal changes in forest practices and a collation of quantitative data in a set of Tables. This involved mainly the following considerations:

- Initially, the forest estate would be divided into primary strata (e.g. forest type) on the basis that such strata were to be well-aligned with management practices and data on biomass removals, and could be spatially defined by the AGO. If necessary, broad forest community groupings or even a specified part of the State such as a management area, would suffice.
- The second level of stratification would be on the basis of time, with the nominal interval of 5 years over the period 1945-2000. Longer time intervals would be used where there was no significant change in management.
- The third level of stratification would be on the basis of major differences in management practices (e.g. selection versus clearfelling harvesting and regeneration methods).
- The number of strata was to be kept to a minimum, with differences between States in the number and type expected.
- In addition to written information (e.g. floristics and management history for each forest type), information would be provided in tabular format (e.g. forest type, time period, felling method and type, canopy disturbance, removals of timber products, slash production). Although all data tables have a similar general form (Appendix 2), some flexibility was needed to deal with the considerable variation in native forests and, therefore, management practices around the nation.

- All assumptions made with respect to stratification, and derivation of data in the tables would be clearly documented. A consistent approach (Campbell, 1997) to documenting data quality standards was suggested (Appendix 3), for tabular data and for key statements made in the text.

3. Issues

- A great deal of expert judgement would be required in deriving the information presented in the data tables, especially for diverse native forests where, for example, knowledge on biomass accumulation and partitioning is very limited.
- Quantification of areas harvested would be the primary responsibility of the AGO, but because satellite imagery data are not available before 1970, estimates of the areas logged would be very useful for the 1945-1970 period.
- There would be a fundamental difference in the approaches used for the native forest and plantations. For plantations, the focus would be on activities/practices as land enters the estate, that is, on establishment and then ongoing management, whereas for native forests the major interest is from the time of the first harvest during the period 1945-2000.
- Changes in the area of native forest being used for commercial wood production would need to be considered. Such changes would include conversions to plantations, transfers to formal conservation reserves (e.g. National Parks), and conservation provisions within State Forest such as Special Protection Zones from which timber production is excluded, and stream and fauna reserves within production forests.

Teleconferences

Three teleconferences were held involving the AGO, CSIRO and the consultants to review progress, raise issues for discussion and clarification, and review timelines. The main outcomes of these conferences are summarised below.

- It was apparent that the success of the project would very much depend on an on-going, cooperative approach for clarifying and refining the methodology and allowing consultants some flexibility in tailoring the methodology on a State-by-State or topic-by-topic basis.
- Data presented in the tables, in most cases, would be derived by integration over space and time within strata defined by forest types x time periods x felling types and would, therefore, be based largely on expert judgment. For example, the spatial distribution of wood removal is often unknown and sometimes highly variable. The data presented in the tables would be generalised for specific forest strata, and not necessarily be accurate for a specific location.
- Because wildfire has a major impact on C flux (e.g. fires in SE Australia in early 2003), an effort would be made to collect information on areas affected by, and the impacts of, wildfires. The main emphasis would be in the 'Fire' report, although the 'State' reports would make reference to the consequences of wildfire.
- An appendix to the data tables should clearly outline sources of data, their reliability, and any assumptions made in estimating values.
- The AGO will infer understorey biomass change from the floristics information given in the text of the reports, and a knowledge of the impacts of disturbance.
- Soil C is not a high priority for the present project. The AGO is examining soil issues as part of other projects.

Review Workshop

The main purpose of the workshop was to expose the contents of the draft reports to critical review by the project team and by State agency representatives, and to review progress. The main outcomes are summarised as follows:

- For most forest types and stand structures, there are only limited quantitative data available to support the estimates of canopy removal, slash production, and post-harvest growth (especially gross bole volume production, a surrogate for total biomass production by the forest). This reality check resulted in some useful sharing of data. For example, the above-ground biomass model assembled for River Red Gum in Victoria (Flinn *et. al.*, 2007) was of value for estimating slash production in the same forest type in New South Wales (Florence, 2007a).
- Generally, there are very good data on the amount of wood removed (volumes x products) from a forest during a particular time period and the area (hectares) from which it was harvested. The precise location of wood harvest is generally poorly known, although satellite imagery will help determine this for the period post-1970.
- The large areas of native forest with some history of logging transferred to conservation reserves during the last 20-30 years are likely to contain substantial areas (logging and fire regrowth) of forest capable of additional C sequestration.
- State agencies are likely to provide very conservative estimates of post-harvest growth, and to focus on merchantable yield. It will be necessary to reconcile such estimates with biomass accumulation based on published data.

Draft and Final Reports

The magnitude and complexity of the project exceeded initial expectations and, given time and resource constraints, an impressive amount has been achieved. It was soon evident that it would be beyond the scope of this project to assemble systematic reliable information on management practices used in native forests on private land. The review gave priority to forests on public land. There was insufficient time to assemble all available data on transfers to parks and reserves, and on conversions to plantations. Further work would improve estimates of important determinants of C balance, such as post-harvest biomass accumulation, slash production and fuel consumption in regeneration and fuel reduction burning. However, some interim national default values, based on synthesis of available information, for these parameters are given later in this chapter.

The consultants needed to use expert judgement to a considerable degree, especially in deriving the data presented in the tables. For example, in Victoria, 'in order to apportion the total annual harvest to the four forest types, a number of assumptions were used together with expert judgement supported by corporate knowledge and Annual Reports which often contained useful comments on forest activities across the State' (Flinn *et. al.*, 2007). A consistent approach (Campbell, 1997) to documenting data quality standards was, therefore, suggested (Appendix 3). State forest management agencies and an independent reviewer provided comments on a penultimate draft.

The project has been successful in unearthing much new and useful material, including priority areas for further data collection and analysis by the AGO.

3. RESULTS AND DISCUSSION

3.1 BRIEF ECOLOGY OF AUSTRALIA'S WOOD PRODUCTION FORESTS

Native Forests

The native eucalypt forests of Australia have evolved over many millions of years (Pryor, 1959). They are complex and dynamic ecosystems, and the interactions between their physical, chemical and biotic components are highly variable and incompletely understood (Squire *et. al.*, 1987). Since European settlement, much of the tree-covered coastal lands and foothills have been cleared for agriculture: and only about 50 per cent of the original forest remains.

Australia's commercially important native forests are found in the mountains, foothills and plains, and "... provide a rich fabric of environmental, species and community patterns" (Florence, 2007a). Commonly, the harvestable components of forests are composed of a mixture of eucalypt species, e.g. Victoria's Mixed species forests account for 70-80 per cent of the statewide public native forest estate (Flinn *et. al.*, 2007). However, they also include relatively pure forests, such as the *Eucalyptus camaldulensis* (River Red Gum) forest along the middle reaches of the River Murray in NSW and Victoria (Florence, 2007a; Flinn *et. al.*, 2007), extensive forests dominated by *Eucalyptus marginata* (Jarrah) in the south-west of Western Australia (Bradshaw, 2007), and the magnificent forests of Ash-type eucalypts of SE Australia.

Adaptations of the eucalypts to fire, low soil fertility and high moisture stress during periods of drought have contributed to their evolutionary success (Florence, 1981; Jackson, 1968). In particular, the eucalypts are highly adapted to the ubiquitous presence of fire in the Australian environment. The survival and proliferation of eucalypts following fire is primarily ensured by the storage of large quantities of seeds in the canopy that are protected from fire by resistant capsules (Ashton, 1981) and then subsequently released onto the fire-prepared seedbed where they germinate and grow rapidly. Survival is also greatly assisted by other adaptations such as epicormic shoots and development of lignotubers. In the absence of fire, trees may attain an age of about 400 years, as reported for *E. regnans* by Gilbert (1958) and for *E. marginata* by Whitford (1998).

Notwithstanding the massive change in the environment associated with settlement, the present forests contain a wide variety of species and an extraordinarily wide range of plant associations. In NSW alone, some 235 species associations or types have been recognised for forest management purposes (Forestry Commission of NSW, 1989). For the purpose of this review, the forests in each State have been subdivided into a manageable number of major forest types for which it is possible to get useful information on the main factors affecting temporal changes in C stocks. For example, for Victoria, Flinn *et. al.*, (2007) stratified the native forest estate into four forest types: Ash, Mixed species, River Red Gum, and Box-Ironbark.

Forest structure is very largely determined by the constituent species and the ways in which the eucalypts that dominate the ecosystem respond to disturbance. The two main causes of disturbance are wildfire and forest management practices such as harvesting and regeneration burning. The way in which a eucalypt species responds to disturbance is very much influenced by its 'relative tolerance' (Florence, 2007a). A relatively tolerant species has growth attributes or adaptations that enable it to survive in a small canopy gap where the surrounding trees and understorey restrict the penetration of light to the forest floor, and by laterally extending root systems to provide access to soil resources.

Florence (2007a) suggested that there are two broad structural categories within eucalypt forests: simple, or more complex structures.

Victoria's Mountain Ash forest is an example of a simple structure. The forest typically consists of pure (i.e. monospecific), even-aged stands of *E. regnans*, a relatively intolerant species, with a luxuriant, multi-layered understorey of tolerant trees and shrubs. The Dry Hardwood forest type of NSW is an example of a complex structure. This forest may have two more or less distinct eucalypt canopy strata: the large-boled, wide-crowned trees of the upper stratum/canopy (often intolerant but also including tolerant species), and a lower stratum of smaller trees of tolerant species merging with the upper canopy (Florence, 2007a). There is an added degree of structural complexity where there is also a stratum of small trees or shrubs (e.g. up to 10 m tall) beneath the upper and secondary tree strata.

Biomass production rates and biomass stocks for Australia's native forests vary enormously with forest type, reflecting, probably in large part, the ecological aggregating/sorting of species according to climatic conditions and soil fertility, especially water and nutrient availability. For example, in Victoria Flinn *et. al.*, (2007), estimate that above-ground biomass ranges from about 570 t ha^{-1} for a 50 year-old stand of *E. regnans* to 85 t ha^{-1} for a fully stocked uneven aged Box-Ironbark forest. *E. regnans* forest occurs at altitudes of 120-1000 m on deep, friable, fertile soils where the average annual rainfall exceeds 1000 mm. Box-Ironbark forest occurs mainly on the poor soils of the inland plains where average annual rainfall is 380-510 mm and hot, dry summers are common. Biomass production rates also vary markedly within a forest type, reflecting site differences in both soil fertility and climate, and prior disturbance. High site occupancy by eucalypts is critical to achieving the biomass production potential of the site.

Plantations

For useful background, also see Raupach (1967). The total area of plantations in Australia in 2005 is some 1.8 million ha consisting of some 0.99 million ha of softwoods (*Pinus* species) and about 0.71 million ha of hardwoods (*Eucalyptus* species) (Parsons *et. al.*, 2006).

Australia's plantation estate is mainly located in the southern States, though tropical pines are planted in northern NSW and Queensland. *Pinus radiata* (Radiata Pine) is the predominant softwood species, and *Eucalyptus globulus* (Blue Gum) is the predominant hardwood species. *P. radiata* is well accepted as a high quality sawlog and pulpwood species, and *E. globulus* is a premium pulping species. Almost all the plantations are managed using even-aged systems based on clearfelling and regeneration by-planting.

Pinus radiata

The first major expansion of the plantation estate occurred in the 1920s, motivated by the common view that softwoods could be grown successfully on poor soils (Snowdon and James, 2007). Much of this expansion was based on conversion of native forest, much of which was poor quality mixed-species eucalypt forest. In the 1970s, research suggested that, for many of the existing plantation sites, growth was being seriously limited by low availability of both water and nutrients (Waring, 1972). This knowledge sparked the rapid development of intensive management regimes involving cultivation, weed control and fertiliser applications to optimise water and nutrient availability (e.g. Woods, 1976). It also shifted attention to conversion of more productive native forests until, in the late 1980s, many States banned the clearing of native forests for plantation establishment because of environmental pressures. Today, almost all new plantations are established on previously cleared land, usually farmland.

P. radiata is a robust species that is easy to grow under a wide range of soil and climatic conditions. With good practice management inputs, reasonable depth of useable soil and an average annual rainfall of 800-1000 mm yr^{-1}, the mean annual volume increment (MAI) would generally be expected to be in the order of 20-30 m^{3} ha^{-1} yr^{-1} over a 30-35 year growth period (i.e. rotation).

Maintaining the long-term productivity of Australia's plantation land-base is of fundamental importance to ensuring on-going C sequestration. There is now a considerable weight of evidence from research (e.g. Squire *et. al.*, 1991) that there shouldn't be a productivity problem provided the management regime maintains soil organic levels, limits soil compaction, conserves/replaces nutrients, and prevents soil degradation due to erosion.

Eucalyptus globulus

There has been an exponential expansion in the *E. globulus* plantation estate in southern Australia in the past 5-10 years. This activity has been almost entirely driven by the private sector and confined to previously cleared agricultural land. Knowledge about the requirements (i.e. soils and climate) for profitable and sustainable growth of the species is still at a very early stage of development relative to that for *P. radiata*. Hence, in the main, there has been a direct transfer of scientific, technical and management knowledge and experience from the *P. radiata* plantation sector to the *E. globulus* plantation sector. With good management practices, reasonable depth of useable soil and an average annual rainfall of 800-1000 mm yr^{-1}, the mean annual volume increment (MAI) would generally be expected to be in the order of 15-25 $m^3\ ha^{-1}\ yr^{-1}$ over a 10-12 year rotation.

3.2 SUMMARY OF FOREST MANAGEMENT HISTORY SINCE EUROPEAN SETTLEMENT

Native Forests

The management of Australia's native forests has followed the classical path of exploitation, control and active management (Squire *et. al.*, 1987).

Exploitation (1788-1920)

From the time of European settlement until the early 1900s, the native forest resource represented a seemingly limitless supply of timber. Hence, there was little effective control over clearing for agriculture (Flinn *et. al.*, 2007), and harvesting of the residual forest was highly selective, that is, the sawmillers selected the best trees for their purpose and left the remainder standing (Sawmillers' Selection System) with no deliberate attempt to ensure adequate establishment and development of regeneration (Florence, 2007a). Dargavel (1995) gives an excellent account of the social and political forces that fuelled the early exploitation of the native forests. However, selective logging was not the only factor that degraded the original forest: "following settlement, forest fires increased in frequency and intensity, causing enormous damage to the forests" (Florence, 2007a).

Control (1920-1960)

By the early 1900s, the States had recognised the need for effective control of forest exploitation, and moved to put in place "...special forest legislation, permanent and inalienable forest reserves, and permanent management authorities with statutory powers" (Dargavel, 1995). For example, Victoria established the Forests Commission in 1918 (Flinn *et. al.*, 2007).

The need for well-trained professional foresters to manage the forests was axiomatic. Victoria acted first, by establishing the Victorian School of Forestry at Creswick in 1907, and in the 1920s, the Commonwealth set up the Australian Forestry School in Canberra. These are still the main centres for forestry training in Australia.

During this period, the emphasis was on controlling the flow of timber to the market by imposing diameter-limit cutting: "...trees of commercial quality above a specified diameter were harvested, irrespective of continuing growth potential, and all trees below that limit were retained, again, irrespective of growth potential" (Florence, 2007a). Fire protection was also a priority, but was minimal by today's standards, being limited to the ad hoc use of low intensity fire to burn, often only partially, the crowns of felled trees.

Throughout Australia, effective management continued to be hindered by lack of resources and inadequate knowledge of natural processes controlling the regeneration and healthy growth of the eucalypts that dominated the forests. Clearing of forests for agriculture continued. The period following World War II imposed great pressures on the forest resources.

Active Management (1960-present)

By the 1960s, all the States had permanent management authorities in place, well resourced by today's standards, and well staffed by professional foresters, most of whom had been trained to degree level. However, emphasis was still on wood production and protection of that resource from fire. In Victoria, "Intensive silvicultural research in mountain forests in the late 1950s (Cunningham, 1960; Grose, 1960) led to the development (Grose*et. al.*, 1964) of a regeneration method involving clearfelling and slashburning." (Flinn *et. al.*, 2007). Importantly, this method consistently produced a new forest following harvesting (Craig, 1984). Regeneration burning achieved two purposes: it prepared a seedbed and reduced the fire hazard posed by the crowns of felled trees. At about this time, fuel reduction burning on a broad-area basis became an integral part of fire management strategies (Gould and Cheney, 2007).

By the early 1970s, there was increasing community acknowledgement of the finite nature of Australia's native forests and the diverse benefits they can provide (Squire *et. al.*, 1987). The management authorities responded by expanding the research emphasis from wood production to include other benefits such as flora, fauna and water. They were also active in setting aside "small areas of state forests for flora and fauna reserves, historic sites, recreation, scientific and many other purposes" (Dargavel, 1995).

However, by then, several States (especially NSW, Tasmania and Victoria) were using (but not exclusively) very intensive harvesting and regeneration methods (heavy felling with seedtrees; or clearfelling followed by regeneration burning and direct seeding or planting) in mountain forests and, increasingly in the more open mixed-species forests. These methods were often combined with integrated harvesting of sawlogs and pulpwood, with the latter being increasingly used to supply the woodchip export market. It is estimated that, by the 1990s, these methods had been applied to about 0.5 million ha (Dargavel, 1995). Community concern over the environmental impacts of intensive forest management, especially clearfelling, sparked... "decades of conflict about the role and management of the public forests" (Florence, 2007a). As discussed later, 'environmentalism' has had a profound influence throughout Australia on the current approach to native forest management.

Main Historical Activities and Events

The main historical activities and events that have shaped the extent and condition of Australia's native forest estate are, in approximate chronological order:

- Clearing for agriculture
- Use of wood as a major energy source
- Discovery of gold
- Major wildfires
- Post-World War II housing boom
- Development of clearfelling as a widespread harvesting and regeneration method
- Environmentalism – some would argue that this was triggered by clearfelling
- Woodchip exports

The impact of these events and activities varies, somewhat, between States. For example:

- The discovery of gold probably had the greatest impact in Victoria where the miners "stripped the vegetation from the land above and around the alluvial gold deposits, and clearfelled nearby forests for timber and fuel." (Flinn *et. al.*, 2007).

- The last two items (i.e. woodchips and environmentalism) are linked, and would seem to have had the greatest impact in the Eden region of NSW where, as will be discussed later, current practice is far removed from that used in the early 1970s when extensive pulpwood harvesting commenced.

Plantations

Softwood

The management of Australia's plantation resource has been driven largely by developments in the *P. radiata* sector. Early plantations were established with minimal cultural inputs, such as weed control and fertiliser applications, and the Commonwealth's self-sufficiency objective of 1964 was pursued almost entirely by increasing the area of the plantation estate. Then, two developments forced managers to consider using cultural inputs to improve plantation productivity:

- First, the South Australians, faced with a 2R (second rotation) decline and a highly capitalised timber industry based on a finite plantation area, were inspired by the work of Waring (1972) and others to increase cultural inputs (cultivation, weed control and fertiliser applications) in an attempt to offset the 2R-decline (Woods, 1976). The results were quite spectacular, with early improvements of up to two site quality classes being achieved (i.e. 10-15 m^3 ha^{-1} yr^{-1} over 35 years). At the same time, at Renwick, just over the State border, Victorian research (Squire *et. al.*, 1979, Squire *et. al.*, 1991) suggested that the 2R-decline could be avoided using a conservation approach based on retaining the residue of the first crop (i.e. mulching). The residue from the first crop usually ranges from 50 to 100 t ha^{-1} on a dry weight basis (Snowdon and James, 2007). The Victorian approach stimulated more widespread practice of slash retention often with some, albeit minimal, inputs of weed control and fertiliser applications. These responses to the 2R-decline problem have had a major influence on plantation management practice (Snowdon and James, 2007).
- Secondly, in the late 1980s, for environmental reasons most States heavily restricted the clearing of native forests for plantation establishment, and alternative, cleared land, was being very largely allocated by market forces to the hardwood plantation sector and government share farming schemes – e.g. Victoria.

Hardwood

As indicated earlier, the hardwood plantation resource (mainly *E. globulus*) has been expanding exponentially during the last decade. It is still developing, though the following factors are expected to have a strong influence on its final form:

- Knowledge of the growth of hardwoods under different soils and climatic conditions is still very limited, and there is a risk, that assumptions about widespread high productivity are optimistic.
- Risk of infrequent, but severe drought leading to mortality, or of unsuspected disease or insect attack.
- Interest in hardwood plantations is primarily driven by the global supply and demand for woodchips, and Australian growers may find competition difficult.
- Government taxation concessions for plantation establishment, have changed markedly in recent years, with resultant downturn in investment.

Main Historical Activities and Events

The main historical activities and events that have shaped the extent and condition of Australia's plantation estate are listed below in approximate chronological order.

- Formation of the South Australian Woods and Forests Department in 1883, and consequent establishment of the first commercial plantations of *P. radiata*, in the Adelaide Hills and south-east region near Mount Gambier.
- Use of relief workers for plantation establishment, during the Depression in the late 1920s and early 1930s.
- A major expansion of private plantations commencing in the 1950s (Dargavel, 1995).
- Commonwealth policy of 1964 for achieving self-sufficiency in most forest products by 2000. This policy provided Commonwealth funding assistance for the States until about 1976, and led to a rapid expansion of softwood plantations.
- Evidence from South Australia (Keeves, 1966) of a drop in productivity between rotations of *P. radiata* on sandy soils, i.e. the so-called 2R-decline.
- Evidence (e.g. Waring, 1972) suggesting that, for many of the existing plantation sites, early growth had been seriously restricted by weed competition, mainly for water, and by low availability of soil nutrients, especially nitrogen and phosphorus. The lack of a market for thinnings in many regions leading to a significant area of overstocked stands, some of which were prone to attack by Sirex wasp.
- Environmentalism.
- Expansion of short-rotation hardwood plantations on ex-agricultural land for pulpwood production in the 1990s.

3.3 TOWARDS ECOLOGICALLY SUSTAINABLE FOREST MANAGEMENT

Ecologically sustainable forest management (ESFM) is a relatively new concept with, perhaps, its most logical progenitor being the long-standing forestry concept of multiple-use management. The concept has equal relevance to native forests and plantations, but for obvious reasons is applied in a much more narrow sense to plantations than native forests.

The Ecologically Sustainable Working Group (1991) identified three key principles for ESFM:

- Maintaining the ecological basis of forested land.
- Maintaining the biological diversity of forests within ecological constraints.
- Optimising benefits to the community from all uses of the forest.

Subsequently, a framework of Criteria and Indicators for Sustainable Forest Management was developed by the Montreal Process Working Group (Santiago Declaration, 1995).

For Australia, the journey towards ESFM really commenced in the 1960s when concerns were emerging about an excessive priority being given to wood production over other forest values. The focus was, and still is, on native forests. By the 1970s, there was mounting community concern over whether wood production should continue in native forests, with the environmental impacts of management practices such as clearfelling and slash burning, and the adequacy of conservation reserves being of most concern. There is no doubt that the incentive for change increased in the 1980s, when community concern over clearfelling was heightened by claims that the practice was being driven by the export woodchip industry.

Real progress in resolving this prolonged conflict can be traced to two key developments:

- In the late 1980s and early 1990s, most State governments developed and ratified Codes of Forest Practices for timber production. In some cases a single code is used for public and private forests. However, in general, private forests are much less well regulated by Codes.
- The National Forest Policy Statement (NFPS) agreed by the Commonwealth, States and Territories in 1992. The obligations of each State included a requirement to establish a comprehensive, adequate and representative (CAR) reserve system as a prerequisite to the

signing of a Regional Forest Agreement (RFA). The RFAs relate mostly to native forest. The CAR reserve system is a major step towards the "ideal of reserving areas which together could provide a system representative of all of Australia's ecosystems" (Dargavel, 1995).

Much progress has been achieved but the ESFM journey is on-going. Stakeholders must decide the goals of ESFM: these will vary markedly from place to place, and over time. ESFM must include the capacity for monitoring the outcomes of forest management, comparison of these with management goals, and for adapting plans and practices where required (Raison *et. al.*, 2001).

Native Forests

The RFA process is complete in all States except Queensland. However, in recent years several State governments have introduced changes to reserved areas and wood flows that threaten some RFAs. For most States, therefore, ESFM is pursued within the framework of RFAs and Codes of Forest Practices. Forest Management Plans (FMP) are an RFA requirement, and are the principal instruments for integrating the goals of wood production, conservation of biodiversity, water quality and yield, and recreation. Preparation of a FMP involves extensive stakeholder input to the detailed consideration of the cultural, social, environmental and economic aspects of forest management. This process has excluded very large areas of native forest from timber harvesting. For example, in Tasmania more than 1 million ha have been transferred to conservation reserves since 1980 (Walker and Felton, 2007). As mentioned above, enhanced monitoring and reporting based on the use of Criteria and Indicators is currently being operationalised.

Although all States except Queensland operate within a fundamentally similar ESFM framework, there is variation between States in current management practices. This variation partly reflects the wide variation in the ecological attributes of tree species (Florence, 2007a, b), differing growing environments, and variation in the structure and condition of the forest resulting, in large part, from past disturbance. Some of the variation also seems to be due to policy responses to continuing local conflict about the role and management of public forests. For example, the Mixed species forests of East Gippsland in Victoria and SE (Eden area) NSW are very similar, but are now being managed quite differently. In NSW the forests are managed using 'flexible selection practice', and depending on the forest structure and environmental needs, stands may be thinned or harvested with single tree or group selection methods that produce/maintain uneven-aged stands. However, in East Gippsland, similar stands are managed with seedtree methods that produce even-aged stands. In the late 1980s, Victoria established a major forest experiment in East Gippsland to evaluate alternative silvicultural systems in terms of economic and environmental considerations (Squire, 1990). The results are having a considerable influence on management practices.

Plantations

Most States rely upon a Code of Forest Practices to ensure that plantations, both public and private, are managed in accord with ESFM principles.
For example, the Victorian Code (Department of Natural Resources and Environment, 1996) applies to both public and private land, and lays down statewide principles and guidelines applying to timber harvesting, roading for timber extraction, and plantation establishment. The Code recognises that plantations are established primarily for timber production. Thus planning controls concerned with the development of plantations must explicitly permit their subsequent management and harvesting.

From a business perspective, there are important additional incentives for managing forests in accord with ESFM principles. First, there is the commercial and ethical imperative of maintaining the long term productivity of the land base underpinning the business. Secondly, there is a need for corporate demonstration that the business is genuinely committed to the concept of the plantation as a renewable resource. There is a possibility that local and global markets will pay a premium for timber products that have an ESFM certification.

Plantation species, especially *P. radiata*, have been selected and tailored by tree breeding to provide plantation managers with great flexibility in the choice of management regimes. Choice is largely determined by expected future demand by local and overseas markets for different timber products, such as knotty or clearwood sawlogs, posts and pulpwood. Hence, there is some variation, even within a State, in management regimes, though there is no clear distinction between public and private sectors.

Plantation establishment treatments such as cultivation, weed control, and fertiliser applications are now firmly entrenched throughout the country as key components of good practice management, and residue retention between rotations is becoming more common. In commercial plantations, the initial stocking rate is usually about 1000 stems ha^{-1} (Snowdon and James, 2007). This represents a compromise between the use of high stocking densities to keep branches small and thus limit the size of knots in the sawn product, and the use of low stocking to sacrifice total volume production for fast growth of valuable final crop trees and shorter rotations.

There are two main post-establishment management regimes (Snowdon and James, 2007):

- Pulpwood: high initial stocking, no thinning, clearfelling at 10-20 years, depending on species and product specifications.
- Sawlog: standard initial (i.e. about 1000 stems ha^{-1}) stocking, repeated thinning to optimise the distribution of log size classes and achieve desirable wood properties, and clearfelling at about 30 years.

In both Tasmania and Western Australia (WA), some management regimes are very different from the two described above (Snowdon and James, 2007). For example: thinning up to half the stems to waste at age 6-7 years, pruning in several stages to 6 m, at most one commercial thinning, and clearfelling at 25-30 years.

3.4 AREA OF COMMERCIAL WOOD PRODUCTION FOREST

Native Forest

There have been four major factors influencing the area of commercial wood production forest: clearing for agriculture, transfers to conservation reserves, management zoning, and conversions to plantations. The first three influences are described in this section, and the fourth in the following section on plantations.

Clearing for Agriculture

Following European settlement of Australia in 1788, forests were cleared for agriculture wherever climate, soils, topography and access were considered to be suitable. By the 1980s, some 26 million ha had been cleared, leaving some 43 million ha as the productive native forest estate (Dargavel, 1995). As a result, today's native forests generally occupy the less productive and less accessible parts of the landscape. Clearing for agriculture and not timber production has therefore been the primary cause of forest change (Flinn *et. al.*, 2007).

In Victoria, native forest cover declined from over 90 per cent in 1824 to about 36 per cent by the mid-1980s (Campbell *et. al.*, 1984). Bradshaw (2007) estimates that about 33 per cent of native forests in WA have been cleared for agriculture, and Walker and Felton (2007) state that "all of the arable land and land under the towns of Tasmania was once forested".

In Queensland during the period after World War II, much of the wood production on private land was a by-product of clearing native forests for agricultural development. Land clearing has been very extensive. For example, in southern Queensland, most clearing has been for pastures, especially during the 1970 to 1990 period. Successive clearing cycles at intervals of 25-30 years are required to control the forest regrowth (Scattini and Carrigan, 2000) to maintain agricultural productivity.

Transfers to Conservation Reserves

As indicated previously, it has not been possible to compile complete information at either the State or National level. Hence, an indicative approach has been necessary for the purpose of this report.

Transfers of native forest to conservation reserves, including National Parks, fall into two reasonably distinct periods: 1945-1970 when transfers were limited in area and often confined to areas unsuitable for wood production or other commercial uses; and 1970-2000, when transfers were very substantial and increasingly based on ecological considerations driven by environmentalism and culminating with the RFA outcomes agreed by the Commonwealth and most State Governments. In Victoria, for example, public land in conservation reserves increased from about 3 per cent in 1970 to 45 per cent in 1997. The distribution of land use categories by forest types in Victoria is shown in Table 1 and demonstrate that conservation reserves account for a substantial part of each of the four broad forest types. During the same period, all rainforest logging ceased in New South Wales (Florence, 2007a), most of the forested public land on the west coast of Tasmania was registered as World Heritage (Walker and Felton, 2007), and very large increases in reserves resulted from the RFA in 1999 and post-RFA management planning in Western Australia (Bradshaw, 2007). According to Dargavel (1995), during the 1970s and 1980s, the area of forests in parks and reserves in Australia increased four-fold, from 1.8 to 6.2 million ha.

Zoning for Conservation Within Wood Production Forests

The introduction of Forest Management Zoning (FMZ) was a key response by the States to meeting ESFM requirements.

Fundamentally, all States have adopted a similar approach to FMZ. In Victoria, for example, the Forest Management Plan (i.e. the primary planning instrument) divides State Forest into three FMZs:

- Special Protection Zone: managed for conservation.

Table 1. Allocation of different land use categories to important native eucalypt forest types in Victoria in 2000 (P. Dennison, Department of Natural Resources and Environment, Victoria, 2001, *pers. comm.*).

Land use Category	Area (ha)	Forest Types				
		Ash	Mixed Species	Box/Ironbark	River Red Gum	Other
Conservation Reserves	3667600	203800	2105300	382200	52700	923600
State Forest (Total)	3517900	367700	2475100	343500	76600	255000
Special Protection Zones	747400	47700	549000	98000	16000	36700
Code of Forest Practice Exclusions	394900	55000	324900	6300	300	8400
State Forest (Remainder)	2375600	265000	1601200	239200	60300	209900

- Special Management Zone: managed to conserve specific features, while catering for sustainable timber production under certain conditions.
- General Management Zone: managed for a range of uses and values, with sustainable timber production as a major use.

The productive area of forest (i.e. the area available for sustained sawlog production after taking account of Forest Management Plan Zoning, harvesting exclusions due to the Code of Forest Practices for Timber Production and areas considered to be unproductive for sawlog production) varies from plan to plan. In Victoria it is typically about 65-79 per cent of the total area of State forest.

Under FMZ, harvesting exclusions are explicit and substantial. For example, in NSW a large area (300 ha) must be permanently retained within a 2 km radius of recording either a Powerful or Masked Owl (Florence, 2007a).

Plantations

Conversions of Native Forests to Plantations

As indicated previously, it has not been possible to compile full information (i.e. area of conversions of different forest types x time) at either the State or National level. Hence, an indicative approach has been necessary for the purpose of this report.

In 2005, Australia had approximately 1.8 million ha of plantations, consisting of softwoods (57 per cent) and hardwoods (43 per cent), with the northern part of the country (i.e. essentially, Queensland) accounting for 20 per cent of the softwoods and just 3 per cent of the hardwoods (Snowdon and James, 2007). The main softwood species is *P. radiata*, though some tropical pines are planted in Queensland (e.g. *Pinus caribaea var. hondurensis* (Hondurus Caribbean Pine)) and northern New South Wales.

Conversions of native forest to plantations fall into two reasonably distinct periods: 1945-1960, 1960-85.

1945-60

The first major expansion of plantation estate occurred in the 1920s and continued slowly over the following 35 years. This expansion was based mainly on conversion of native forest, much of which was poor quality Mixed species eucalypt forest (Snowdon and James, 2007). *P. radiata* was the favoured species, and SA led the way with plantings in the Adelaide Hills and around Mount Gambier in the south-east region. Victoria, Tasmania and WA followed, but on a smaller scale. By 1960, Australia had about 200,000ha of plantations (nearly 100 per cent softwood), South Australia's *P. radiata* estate was the largest, followed by Victoria, which had widely dispersed units all under about 5000 ha (Flinn *et. al*., 2007).

1960-1985

This was a period of rapid expansion, driven by Commonwealth financial assistance to the States. A national goal was to increase the annual planting rate from about 16,000 ha to 28,000 ha and to attain an estate of 1.2 million ha by the year 2000. The target rate was exceeded during the 1970s when the average annual planting rate was about 33,000 ha (Dargavel, 1995). Private planting also made a substantial contribution. For example, in Victoria, APM planted 40,000 ha, mainly with *P. radiata* (Dargavel, 1995). The beginnings of Farm Forestry were evident, with farmers being encouraged to use part of their land for small plantations or woodlots. Towards the end of the period, there was strong community opposition on environmental grounds to further conversion of native forests to plantations. In New South Wales, financial priority was given to the rapid development of a softwood resource at the expense of native forest management (Florence, 2007a).

By 1985 Australia had about 850,000 ha of plantations (95 per cent softwood and 5 per cent hardwood). Much of the plantation expansion during this period was based on conversion or exploitation (Florence, 2007a) of native forests in

Queensland, NSW, Victoria, and WA. In WA the main focus was on the Donnybrook Sunklands, which carried Jarrah (*E. marginata*) forest that had become infected by the root pathogen *Phytophthora cinnamomi* (Bradshaw, 2007). A significant part of the national plantation estate was also established on previously cleared land. For example, in Victoria up until 1992 this accounted for about 15 per cent of the State-owned softwood plantations (Flinn *et. al.*, 2007). In WA, the majority of *P. radiata* plantations established during the late 1950s and 1960s was on re-purchased farmland (Bradshaw, 2007).

Conversion of Agricultural Land: 1985-2000

This was a period of rapid expansion in hardwood plantations, mainly *E. globulus* in the southern part of the country. For various reasons, in the mid-1980s the timber industry and the conservation movement had supported the establishment of more eucalypt plantations. Expansion of eucalypt plantations was to be on previously cleared land (as advocated by the National Forest Policy Statement). Between 1990 and 2000, the total plantation estate increased from about 1 million ha to 1.5 million ha through mainly private investment, and based almost entirely on previously cleared agricultural land (Snowdon and James, 2007).

The expansion was underpinned by Commonwealth policy support including:

- Promotion of farm forestry and plantations in the National Forest Policy Statement (1992).
- National Farm Forestry Program (1993).
- Wood and Paper Industry Strategy (1995).
- Plantations for Australia; The 2020 Vision (1997).

In 1999, some $600 million nationally was invested in *E. globulus* plantations, mainly through prospectus companies. In 2000, the national target of some 85,000 ha of new plantations was achieved. Future planting rates will depend on taxation policy, as well as the commercial success of the first wave of plantings, with wood yields and the demand (i.e. price) for woodchips by the export market being the key indicators.

Approximate default values for conversion of native forest to plantations for the period 1950 to 2000 are given in Table 2 (largely based on Snowdon and James 2007).

3.5 TEMPORAL TRENDS IN KEY FACTORS AFFECTING CARBON STOCKS – NATIVE FORESTS

3.5.1 Harvest Removals

Until about 1990, most of Australia's wood harvest came from native forests. By the mid to late 1990s approximately equal yields were obtained from both the native and plantation estate.

Table 2. Temporal pattern of plantation establishment and nature of the land base.

Time Period	Softwood Plantations		Hardwood Plantations	
	Area (ha yr^{-1})	% previously native forest	Area (ha yr^{-1})	% previously native forest
1950	10000	95	Small	95
1960	12500	95	Small	95
1970	32000	70	Small	95
1980	30000	50	2000	95
1985	20000	10	3000	50
1990	13000	5	23000	Small
2000	20000	5	108000	Small

For many years the Forestry and Timber Bureau (Commonwealth Government) recorded wood removal from Australia's native forests and plantations. Recently, Australian Bureau of Agriculture and Resource Economics (ABARE) has undertaken this role. The national picture, certainly in terms of sawlogs and pulpwood, has already been reported in other studies using the Bureau's data. It is known, for example, from Dargavel (1995) that:

- The post World War II housing boom and continued economic recovery resulted in a sharp increase in annual sawlog production from about 5 million m^3 in 1945 to about 9 million m^3 in 1960.
- Total sawlog production remained fairly constant from 1960 at least until the early 1990s. During this period a fairly large reduction in hardwood sawlog production was balanced by an increase in softwood sawlog production. In the early 1990s, annual sawlog production was close to 4 million m^3 for both hardwoods and softwoods.
- Pulpwood production has always been greater for hardwoods than softwoods. There was a sharp increase in total annual production from about 2 million m^3 in the early 1970s to about 8.5 million m^3 in the early 1990s, with hardwoods accounting for most of this increase. Export woodchips constituted a major part of the increase.

The exponential expansion of hardwood plantations from the mid-1990s will result in a large increase in hardwood pulpwood production (mainly *E. globulus* for the woodchip export market) by about 2010.

However, from a C modelling perspective, it is necessary to disaggregate the national picture to obtain an understanding for specific management areas and forest types of temporal changes in the methods of wood removal, the amounts removed and, at that level, to include information on other forest products such as firewood, poles and posts. This project has undertaken that task.

For the purpose of this review, harvesting is considered at the coupe level, not the landscape level and, as an operation, only treefelling is taken into account. There is no consideration of other components, namely, crosscutting and delimbing, transport of logs to the landing (snigging) and log preparation. The felling method is very important because it is the primary basis for stratifying management practices for the purpose of presenting information in the data tables. It is of fundamental importance to be able to use satellite imagery to distinguish between felling methods on the ground in the forest and thus to determine the areas logged and their locations. Canopy disturbance is the distinguishing variable.

Felling methods differ in terms of the spatial and temporal distribution of tree removal and, therefore, in the resultant patterns of canopy disturbance. Spatially, they lie on one of two continua related to the size of the opening or the density of the retained trees (Campbell, 1997). Temporally, they fall into two broad categories: methods that remove the trees in one or more operations over a relatively small part of the life of the stand (i.e. rotation) and those that do so at regular intervals throughout the rotation. The name of the felling method is commonly applied to the harvesting and regeneration method and, as such, would also be linked with methods of seedbed preparation (e.g. fire or mechanical disturbance) and methods of seeding or seedling supply (e.g. natural/applied seed or planting).

The main felling methods used between 1945 and 2000 are described below in three main categories.

1. Harvesting and Regeneration Methods (based on Squire *et. al.*, 1987, Squire, 1990, Campbell, 1997 and Flinn *et. al.*, 2007)

Clearfelling

Clearfelling is the removal of all commercial (and most other) trees from a predefined coupe, usually in one operation. Selected trees may be retained for fauna habitat. The method involves major disturbance of the site only once during a single rotation although some trees may have been removed earlier in thinning operations. The eucalypts on a single coupe are essentially even-aged. The resultant canopy disturbance is almost 100 per cent. Today, coupe size is generally less than 40 ha but, in some cases (e.g. DNRE, 1996), may be aggregated over a period of five years and extend up to a total of 120 ha. Coupes were much larger in the 1970s when, in an extreme case, clearfelling units of up to 800 ha were used in the Eden Management Area of NSW (Florence, 2007a).

Seedtree

The seedtree method removes all but a set of seed-trees on the coupe, carefully selected to provide an above-ground eucalypt seed source and fauna habitat. Otherwise, the method is the same as clearfelling. The resultant canopy disturbance is about 90-95 per cent. Seedtrees are silvicuturally, best removed soon after seedfall and ideally before germination. However, practice varies. For example, in the Lowland Forest of East Gippsland, Victoria, the seedtrees are retained indefinitely (Flinn *et. al.,* 2007) and, in the Karri forest of WA, they are usually removed within two years (Bradshaw, 2007).

Shelterwood

The shelterwood method involves removing trees on a coupe in two or more fellings when mature trees are retained for shelter, seed or other purposes (e.g. aesthetic). The period between the two fellings (regeneration and final) is usually within 5-20 years. The eucalypts on a single coupe are essentially even-aged. The method involves major disturbance of the site twice during a single rotation, with the area of forest being disturbed in any given year being up to double that for a clearfelling method producing similar wood volumes. The resultant upper canopy disturbance would be expected to be within the 30-50 per cent range for the first felling and almost 100 per cent after the final felling.

Selection

The selection method is fundamentally different from the above methods because, within an individual coupe, trees are removed at a regular time interval (felling cycle) throughout the rotation. Trees may be removed individually or as small groups, the size and shape of which may be varied to meet biological (e.g. seedfall attributes) or management objectives (e.g. aesthetics). The maximum distance of effective seedfall (usually up to 1.5 x tree height) sets the upper theoretical limits to the size and shape of the opening (i.e. about 2 x tree height if all trees in a patch (i.e. the group) are felled). However, in some cases, these limits are exceeded. For example, in WA (Bradshaw, 2007), the current group selection prescription for the Jarrah forest type, which often contains a high density of lignotubers, states that the preferred minimum gap size is four times tree height, especially in mature forest. In Victoria, an upper limit of about 3 ha is prescribed for the River Red Gum forest type (Flinn *et. al*., 2007). In practice, depending on forest type and structure, canopy disturbance would usually range from about one crown width (e.g. about 10-20 m for the removal of a mature tree about 60 cm in diameter (Jacobs, 1955)) to about 3 ha. Such disturbance usually would be more or less evenly distributed throughout the stand.

Selection methods will disturb a coupe several times during a rotation, and greatly extend the area of forest disturbed in any year to produce a similar volume of wood to the clearfelling method. For example, a selection method with a 20-year felling cycle and a 100-year rotation would require entry into the coupe five times during a single rotation. However, in practice, selection methods seem often to have been implemented in a somewhat ad hoc manner with a variable felling cycle determined more by commercial than biological imperatives, and with little attention being given to the establishment of regeneration.

For the purpose of this report, if essentially all trees in a patch are felled and the size of the opening exceeds about 2 x tree height, the felling method is taken to be clearfelling.

2. Partial Cut Method

The partial cut method removes all or most merchantable trees on a coupe. It is not a harvesting and regeneration method, because there is no intention to obtain regeneration. The method typically removes about 45 per cent of the standing basal area, but application of the method has been highly variable. The Sawmillers' Selection System is a variant.

3. Timber Stand Improvement

Timber Stand Improvement (TSI) is usually used to cull trees by ringbarking or with herbicides, to stimulate the growth of the remaining trees, which depending on stand history, could represent many stages of stand development but, most, often, the young regeneration and sapling stages. In effect, TSI is a form of non-commercial thinning. Regeneration would be an unintended outcome.

A summary of the application of these harvesting methods is given in Table 3.

Amounts of Wood Removed

The annual removal of wood from Australia's commercially important native forests over various time intervals during the period from 1945-2000 are given in the State reports together with the assumptions used in deriving the data. Some significant and interesting findings are summarised here.

- In NSW, annual 'quota' (high quality) sawlog production declined from 1.8 million m^3 in 1952 to 970,000 m^3 during 1975/80 and then to 547,000 m^3 during 1995/2000. The reduction is "...a consequence of the cessation of rainforest logging, withdrawal of old-growth logging, and the decision to move towards sustained yield on the regrowth forests" (Florence, 2007a).
- Annual sawlog volumes obtained from Queensland hardwood forests declined from about 600,000 m^3 during the 1950s to about 300,000 m^3 in the 1990s. Private forests have been an important source of sawlogs. Recently, the State government decided that native forests were "to play a more significant role in resource conservation than in wood production" (Florence, 2007b). Harvesting of public native forests will be phased out over the next 20 years.

Table 3. Indicative information on trends in harvesting methods for Australian forests during the period 1945 to 2000.

Felling Method	Main Time Period
Clearfelling Seedtree	1960 – present. Mainly Victoria, Tasmania and New South Wales (Eden until the early 1990s), Karri forest in Western Australia.
Shelterwood	1975 – present. Wombat Forest in Central Victoria, Highland forests in Tasmania. Jarrah forest in Western Australia.
Selection	1945 – present. Widely in all States until about 1960, then mainly in New South Wales and Queensland. Now being used increasingly in all States (including Eden in NSW) except Victoria.
Partial Cut	1945 – present. All States.
Timber Stand Improvement	1935 – present. Mainly in NSW where 69,000 ha were treated in 1935/36 and 51,000 ha in 1938/39. Also during 1950s and 1960s. In East Gippsland, about 6,500 ha of Mixed species forest were treated during 1965–75. Some 64,000 ha of Jarrah forest in Western Australia have been treated following commercial harvesting. Little current use.

- In Tasmania, private land has always been a significant source of sawlogs with, for example, a contribution of about 200,000 m^3 (about 30 per cent of the total) in 1995/96 (Walker and Felton, 2007). The same authors report that annual pulpwood production from native forests has increased from about 1 million m^3 in the mid-1970s to about 2.3 million m^3 in 1999/2000.
- Most of Victoria's forest products have come from the extensive mixed-species forest and the Ash forests (Flinn *et. al.*, 2007). The authors indicate that there have been major shifts in the production of specific products during the 1945-2000 period: pulpwood production has increased consistently from less than 100,000 $m^3\,yr^{-1}$ to over 1.1 million $m^3\,yr^{-1}$; firewood production has fallen from more than 1.3 million $m^3\,yr^{-1}$ to about 150,000 $m^3\,yr^{-1}$; and annual sawlog production has been fairly stable at about 1 million m^3. It is interesting to note the compensating changes in firewood and pulpwood production.
- In WA wood removal from the forest (public and private land) has been steady at just under 2 million t yr^{-1} since the 1950s. However there has been a shift towards an increasing proportion of pulpwood and a virtual cessation of production from private land (Bradshaw, 2007).

3.5.2 Slash Production and Management

The production and management of slash in forests has a major impact on forest C stocks over time. This issue has previously been over looked, and is thus treated in some detail here.

Slash is a collective term that includes logging slash, fallen accumulated deadwood, and the existing litter layer. Logging slash is the parts of the trees not removed from the site when the forest is harvested plus understorey 'felled' during the harvesting operation. Fallen deadwood (also known as 'old wood' or coarse woody debris), consists of partly decomposed wood contributed via slash from previous harvesting operations, trees that fell to the ground after dying of natural causes (e.g. wildfire and disease) or due to treatments such as ringbarking or poisoning, and trees felled in tending operations such as thinning. The litter layer usually consists of partly decomposed parts of trees that are shed naturally. This discussion will be confined to the two major components of the mass of slash, that is, logging slash and other coarse woody debris (CWD). The understorey is usually a minor component of logging slash and, for the purposes of this report, is ignored. However, this is clearly not the case in the wet mixed eucalypt-rainforests of southern Tasmania. Standing dead trees are also ignored. For descriptive purposes, slash is considered to have two components: fines (material less than 100 mm diameter) and coarse material (greater than 100 mm diameter).

The rate of C release from logging slash by natural decay and fire will have a major impact on C stocks in the managed forest estate and their change over time.

Four main factors affect the production of logging slash:

- Biomass production, which is determined by the interacting effects of inherent growth potential of the site (a function of climate and soil fertility) and forest condition. Australian forests vary greatly in biomass production and accumulation as discussed earlier.
- Harvest Index (HI), which is the ratio of harvested stem mass to the total above-ground biomass. Native forests exhibit a wide variation in HI. Rarely is all stemwood harvested, especially in native forests, because wood removals very much depend on the interplay of stem defect, utilisation standards, and markets for products, especially pulpwood.
- Stand history, which can have an important effect on HI. For example, for the same species, HI could be expected to be lower for trees growing in more open conditions (wide crowns and

heavy branching) as would result if there were poor establishment of regeneration following harvesting. HI would be expected to be lower for trees with poor quality stems due to defects caused by wildfire damage and wood rotting pathogens. Moreover, the use of exploitative felling methods, such as the Sawmillers' Selection System, or 'High Grading' (Flinn *et. al*., 2007, Florence, 2007a) would be expected to increase over time the proportion of wide-crowned trees with defective stems in the stand.

- Utilisation Standards. The higher the utilisation standard, the higher the proportion of stem biomass removed when a tree is harvested, and the lower the production of logging slash. Generally, since 1945, there has been an increase in utilisation standards, commencing around 1960 when there was increasing acceptance by industry that Australia's native forests were a diminishing resource. Hence, there "...was an increasing willingness by industry to accept sawlogs of lower quality or of less preferred species" (Florence, 2007a).

Perhaps a more important change occurred in the early 1970s, with a greatly expanded application of integrated harvesting, that is, the concurrent harvesting of sawlogs and pulpwood material. The pulpwood came from both non-sawlog trees and from that part of sawlog trees that would otherwise remain on the ground in the forest.

Integrated harvesting had been conducted for some 20 years in selected Victorian forests before it became a major system in Mixed species forests at Eden in NSW, where it was combined with clearfelling to produce sawlogs for the local industry and woodchips for export (Florence, 2007a). However, utilisation standards were still low compared with today's and, when combined with high biomass production and harvesting by clearfelling, even integrated harvesting could produce huge amounts of logging slash per unit area harvested. For example, Walker and Felton (2007) report a case in wet eucalypt forests of southern Tasmania where, in the 1980s, clearfelling with integrated harvesting produced about 1000 t ha^{-1} of logging slash. In such forests, the contribution of slash from understorey trees is substantial.

Improvements in utilisation standards continued through the 1980s and 1990s, as transfers to conservation reserves continued to reduce the area of native forests available for wood production. In the late 1980s, Victoria proposed an expansion of integrated logging in East Gippsland, under the proposed Value Adding Utilisation System (VAUS) (Department of Conservation, Forests and Lands, 1988). Introduction of VAUS resulted in a large increase in the utilisation of lower quality logs (residual roundwood), mainly for woodchips but also for processing as sawlogs. An appreciable

Table 4. The percentage of harvested above-ground tree biomass remaining as slash residues in Australian eucalypt forests subjected to differing harvesting and utilisation regimes. Adapted from Snowdon *et. al.*, (2000).

	Sawlog only removal	Sawlog plus pulpwood removal
(i) Moist high quality forest		
Clearfell	65	40
selection harvest	45	20
(ii) Dry low quality forest		
Clearfell	50	30
selection harvest	55	25

Table 5. Approximate quantities (t ha^{-1}) of slash produced in contrasting (wet, moist and dry types) Australian native (sclerophyll) forests, under differing harvest (selection, clearfelling) and utilisation scenarios. Estimates based on individual State reports, Snowdon *et. al.*, (1999), Jackson (2000), Snowdon et. al., (2000).

	Wet		Moist		Dry	
	Selection †	CF	Selection	CF	Selection	CF
Sawlog only	75	500	60	350	45	250
Sawlog + pulpwood	30	300	25	150	20	100

† selection based on removal of 20% of stand basal area.

Table 6. Approximate quantities (t ha^{-1}) of slash (including litter layer) produced in coniferous and eucalypt plantations during thinning or final harvest. Based on Snowdon and James (2007) and O'Connell (CSIRO, *pers. comm.*).

	Conifer	Eucalypt
Thinning		
non commercial	60	NA*
commercial	20	
Final harvest		
low SQ	50	30
high SQ	100	60

* only applies to sawlog crops which are not widespread in Australia.

part of the increase came from the extension of harvesting operations to lower quality stands where sawlog-only harvesting was not economically viable.

Following harvest of native forest, somewhere between 20 and 80 per cent of harvested biomass can remain in the forest as slash residues (Table 4). In forests with a significant mass of non-merchantable understorey, the quantity of slash will be further increased.

The approximate quantities of slash generated under a range of harvesting regimes are shown in Table 5. They vary greatly, from as little as 20 t ha^{-1} in selectively logged dry forests, to as high as 500 t ha^{-1} in clearfelled wet forests where there is no market for pulpwood. The key point is that the amounts of slash are often very high, and sometimes exceed the quantity of wood (and C) removed from the forest.

In plantations, the mass of slash produced during thinning or final harvest can range from about 30 to 100 t ha^{-1} depending on site quality and the degree of utilisation of woody materials (Table 6).

Dynamics of Coarse Woody Debris

Significant quantities of CWD (fallen tree trunks and large branches) can also occur on the forest floor in Australia's woodlands and native forests (Snowdon *et. al.*, 1999, Woldendorp *et. al.*, 2001). These result from prior disturbance (e.g. windthrow, wildfire) as well as natural tree senescence and turnover. The quantities of CWD are highly spatially variable, but are important in adding to the slash pool created by harvesting operations. A variable proportion of this slash pool may be combusted by management burns or by wildfire (Table 7) with the remainder subjected to variable rates of biological decomposition. Woldendorp *et. al., (*2001) estimated mean CWD loads on the forest floor of 51 t ha^{-1} (n = 14, sd = 64) in dry sclerophyll forests and 109 t ha^{-1} (n = 28, sd = 242) in wet sclerophyll forests. In WA, fallen tree trunks plus stumps (in harvested areas) could account for 25-180t ha^{-1} in Karri forest and 35-80 t ha^{-1} in Jarrah forest (Bradshaw, 2007). These can be compared with harvest slash production (Tables 5 and 6). For drier eucalypt forests Snowden *et. al., (*1999) considered that the mass of CWD may be 50-100 per cent of the mass of slash produced during a harvesting operation. They considered 50 per cent to be a conservative figure. The key point is that the existing CWD contains a significant amount of C that could be rapidly released by fire, particularly after forest harvesting.

CWD has not been included in the estimates of post-harvest slash presented in the data tables accompanying the State reports, so use of those estimates are likely to lead to an underestimate of C release in fires after harvesting.

Two main factors affect the production of fallen deadwood:

1. Wildfires and Environmental Damage

The Ash-type eucalypts are fire sensitive and are usually killed or severely damaged by fires that scorch more than 50-75 per cent of leaves in the crown (Flinn *et. al*., 2007). Extensive areas of Ash forest occur in fire prone areas of southern NSW, Victoria and Tasmania. Trees killed by wildfire (i.e. stags), if unsalvaged, will eventually fall to the ground over the following 50-100 years to become part of the pool of fallen deadwood. In Tasmania, a regrowth *E. regnans* forest contained more than 400 t/ha of fallen deadwood (downed material) from a fire-killed overstorey (Gould and Cheney, 2007).

In mountain forests, wind and snow damage can periodically result in crown loss or wind throw with significant addition of woody debris to the forest floor. Self-thinning of dense eucalypt regrowth forest, sometimes accentuated by drought, can also add significant woody input to the forest floor.

2. Management

TSI and non-commercial thinning (reject tree felling) are the two main ways management can increase the pool of fallen deadwood. TSI is similar to wildfire, the only difference being the way in which the trees are killed. Reject tree felling was used in NSW and Queensland in the late 1950s to improve both wood yields per ha and the condition of the growing stock. An allowance was paid for felling any tree of sawlog size in which defect might be unacceptable and, in NSW, up to 25,000 ha were treated annually (Florence, 2007a). From a slash perspective, these treatments had an immediate (reject tree felling) or subsequent (TSI) effect on slash loads.

Slash Management

Slash management has two main purposes:

1. Fire Protection

Logging slash increases the risk of wildfire during the first few years after harvesting. Fire protection has always been a high priority in Australian forest management and, during the period 1945-60 when selection type felling methods (i.e. in uneven-aged stands) were used widely in all States, a form of fuel reduction burning, termed 'slash burning' or 'top disposal' was often practised. To minimise the risk of fire escape or damage to retained trees, especially the smaller size classes, the burns were carried out under safe fuel and weather conditions and, as a result, were probably patchy and of low intensity. This has continued as the general approach in NSW (excepting Eden) and Queensland (Florence, 2007b). However, for silvicultural reasons explained below, the situation from 1960-2000 has been very different for some other States.

2. Silvicultural

In the 1950s, it was acknowledged that eucalypts often do not regenerate profusely after harvesting, especially in wet forests. Research into this problem resulted in the development of a regeneration method based on clearfelling and slash burning for Victoria's mountain forests (Grose *et al.*, 1964). Slash burning was a cost-effective method of preparing a receptive seedbed and also served a fire protection purpose. From both the regeneration and protection perspectives, high intensity burning gave the best results. The method was successful and is still used extensively in Victoria's Ash and Mixed species forests (Flinn *et al.*, 2007). It has also been used widely in Tasmania (Walker and Felton, 2007) in WA Karri Forest, and was used at Eden in NSW from the late 1960s for about 25 years (Florence, 2007a).

During the last decade, several States, largely for conservation reasons, have moved away from clearfelling and are increasingly using variants of shelterwood and selection harvesting and regeneration methods. High intensity slash burning is now largely confined to Victoria and Tasmania, and increasingly to areas where integrated harvesting is not yet practised. Integrated harvesting means less fuel and, therefore, lower intensity burning. In fact, in some cases with integrated harvesting, slash burning may not be needed for either fire protection or seedbed preparation purposes, because the slash levels are so low that the fire risk could be acceptable, and the harvesting operation, alone, may produce sufficient soil disturbance to provide a receptive seedbed. This is especially so for drier forests, e.g. coastal Mixed species in East Gippsland, Victoria.

There have been historical changes in slash production and management.

1945-1960

- Slash production per m^3 of wood harvested was high, due to low utilisation standards. However, due to the widespread use of selection harvesting, the volume of wood harvested per ha (i.e. yield) was low and a large area of forest had to be worked over in a single year to sustain a steady flow of wood products.
- Use of low intensity fuel reduction burning for fire protection caused combustion losses of C, but the losses were probably largely confined to the fine fuel (i.e. less than 10 cm diameter) for which combustion was probably of the order of 80 per cent over 50 per cent of the coupe area giving a burning efficiency of about 40 per cent.

1960-1990

- Slash production per m^3 wood harvested decreased steadily during the period due to increasing utilisation standards associated, especially, with integrated harvesting.

Table 7. Approximate burning efficiency (% consumption of the available fuel present over the total area) in relation to fuel category (<10 cm fine fuel, new logging slash >10 cm in diameter, already present CWD >10 cm in diameter) and fire type. Based on Gould and Cheney (2007), Flinn, *et. al.*, (2007) and further review of published work by the authors.

	Fuel reduction burn	Regeneration burn	Wildfire
Fine fuel	60 †	70	80–100
Coarse logging slash	–	40	50
CWD	Low	50	25
Total fuel	**-**	**50***	**50**

† refers to fuels <6 mm in diameter for low–intensity fuel–reduction burning.
* likely to be higher in plantations where less large woody slash is usually left after harvesting.

In Victoria and Tasmania, the extensive use of the clearfelling harvesting and regeneration method meant higher yields so that a smaller area of forest was needed each year to match the 1945-1960 wood flow.

- Use of high intensity regeneration burning in Victoria, Tasmania and WA meant that C losses from the slash now included more of the CWD. It is likely that the burning efficiency was in the order of 70 per cent for fuel of <10 cm diameter and 50 per cent for fuel >10 cm (Flinn *et. al.*, 2007).

1990-2000

- Further decreases in slash production per m^3 wood harvested due to better management and further improvements in utilisation standards and systems. Reduction in yield per ha due to a shift away from clearfelling, in all States except Victoria.
- Reduced use and intensity of regeneration burning, with burning efficiency probably returning to the 1945-1960 level.

Carbon Implications

Any model of carbon balance of harvested forests must adequately deal with the temporal change in C stocks of slash residues, and existing forest floor biomass including CWD. Fire, whether managed or wildfire, can rapidly release some of this biomass C to the atmosphere. The approximate burning efficiencies for a range of fuel categories and fire types are summarised in Table 7. The burning efficiency is the product of the proportion of forest area burnt, and the fraction of fuel combusted on burnt areas. It is highly variable, being affected by topography and weather conditions, factors that affect fuel moisture content and fire intensity. It is important to apply these burning efficiencies at the landscape level when estimating the broad-scale effects of fire.

The consumption of coarse fuels is often <50 per cent (Table 7) and is dependent on long-term drought to dry out large woody material.

Snowdon *et. al.*, (1999) conducted a preliminary analysis of the effects of slash decay and fire on the C balance of Australian forests. They concluded that:

- Annual emissions of C from slash (including decaying roots) that has accumulated over many decades is high and increasing over time.
- Fire has a significant impact on short-term emissions of C from managed forests. Annual release (Mt CO_2 equiv.) was estimated to be approximately 12 for fuel-reduction burning, 8 for regeneration burning, and 50-300 for wildfire.
- Carbon emissions resulting from fire in managed forests should be considered as anthropogenic because management affects fire risk (e.g. by creation of logging slash; use of fuel-reduction burning) and considerable conscious effort is made to mitigate fire risk and to suppress wildfire.

Given the magnitude of slash inputs described above, more detailed analysis of slash dynamics and slash fire-carbon interactions is required.

3.5.3 Post-harvest Growth

The rate of net C fixation following forest harvesting is critical to determining the C balance of the managed forest estate. Currently, growth rates after harvesting are poorly known for Australia’s diverse native forest. Information is better for even-aged native forests regenerating after clear-felling or stand-replacing wildfire, but poor for selectively-harvested forests where both the forest and harvesting regimes vary. Growth rates after selective harvesting must be integrated over the whole forest, which is a mosaic of treated and untreated areas. Fewer data are available for these extensive and more complex forest structures that cover a range of age classes. The best spatial data on growth rates are available for plantations.

In this section, the synthesis is concerned with the temporal effects of harvesting and regeneration methods and stand improvement treatments (e.g. thinning) on post-harvest growth per unit area of forest. The analysis attempts to integrate across all States and forests to provide a national perspective. No account is taken of other factors that could influence C stocks, such as reduction of the commercial forest area due to transfers to conservation reserves. These factors are evaluated qualitatively later.

From a C perspective, total biomass production (i.e. above and below ground) is relevant. However, for the present project, information has been sought only for above-ground biomass, and the focus has been on the eucalypts that dominate the forest ecosystems, and two attributes of eucalypt growth: gross bole volume (a surrogate for biomass) and merchantable bole volume, an indication of wood available for future removal.

Tree growth (biomass production) is primarily determined by climate and soil fertility interaction and genetic factors. Stand growth is determined by the stocking of the trees and stand age. Hence, the success of regeneration following harvesting is an important consideration. Low regeneration stocking results in only partial occupation of the site at least for some years, which will significantly reduce volume growth. Hence, regeneration stocking standards are now an important management tool in all States, albeit to optimise future production of sawlogs.

Regeneration

There is limited information for Australia's native forests on the influence of initial stocking on subsequent volume and product characteristics in mature stands (Hamilton, 1986). For the purpose of this report, it is assumed that, generally, for 1945 –1960, regeneration stocking was less than optimum for maximum stand growth. During this period, knowledge of the requirements for successful natural regeneration was limited (Squire *et. al.*, 1984). This was reflected in operational observations and experience (e.g. Florence, 2007a, Walker and Felton, 2007), and the priority given in Victoria to research in this area from the late-1950s and beyond (Squire, *et. al.*, 1984).

Table 8. Generalised growth rates for broad eucalypt productivity classes (NGGI, 1997).

	C increment (t ha^{-1} yr^{-1})	Approx. Volume increment (m^3 ha^{-1} yr^{-1})
Eucalypt Class I	2.04	8.0
Eucalypt Class II	0.59	2.4
Eucalypt Class III	0.25	1.0

Table 9. Approximate total stand bole volume increment (m^3 ha^{-1} yr^{-1}) following harvest of wet, moist and dry types of Australian native forest.

	Wet	Moist	Dry
Selection Harvest	3–4	2–3	1–2
Clear Felling	5–9	3–4	2–3

Stem Growth

Current knowledge of tree growth/biomass production for different harvesting and regeneration methods (e.g. selection versus clearfelling) and stand structures in native forests is still very empirical and limited. This is reflected in the State reports, which provide highly qualified estimates of growth and do not attempt to compare the effects of different harvesting and regeneration methods.

Earlier efforts (Table 8; NGGI 1997) to define generalised growth rates for 3 broad eucalypt productivity classes (roughly equivalent to the wet, moist and dry categories of Table 9) did not separate out the effects of harvest type or stand age.

Growth rates have been estimated as part of the State reports forming part of this review. In some cases, the State management agency provided estimates of merchantable and gross volume increment. These estimates have been generalised for total stand volume increment and are presented in Table 9. They represent the average over a 80-120 year forest rotation.

These growth rates appear too low to enable forests of equivalent pre-harvest biomass to regrow over proposed sawlog rotations of 80-120 years. For example, after clearfelling in wet forest only about 300-400 m^3 of stem volume (~150-200 t stem wood) would regrow over 50 years. Studies by Feller (1980) in *E. regnans* forest indicate much greater growth rates of ~11 $m^3\ ha^{-1}\ yr^{-1}$ during the initial 50 years.

Many of the Ash-type eucalypts comprising Australia's wood production forests are inherently productive when grown in well-stocked stands on good sites. Under such conditions, gross volume production can average 10-20 $m^3\ ha^{-1}\ yr^{-1}$ over a 60 year rotation (Borough *et. al.*, 1978; Attiwill 1979; West and Mattay 1993). The growth rates quoted in the State reports for Victoria (Flinn *et. al.*, 2007) and Tasmania (Walker and Felton, 2007) for even-aged regenerating wet (Ash-type) forest range from 5 to 8 $m^3\ ha^{-1}\ yr^{-1}$ merchantable volume. For Victoria, gross volumes were estimated to be slightly above the merchantable volumes; an unresolved question is whether such calculations are only for merchantable trees or refer to the whole stand. These estimates appear, given the inherent high productivity of young Ash regrowth (e.g. Attiwill 1992; Connell and Raison 1986).

The productivity (gross bole volume) of wet forests (e.g. *E. pilularis*) in coastal NSW is quoted to be about 7-9 $m^3\ ha^{-1}\ yr^{-1}$ in even-aged stands, but growth is only about half this in uneven-aged stands (Curtin *et. al.*, 1991; Florence, 2007a). Again these figures are much less than the data for Blackbutt (range 4-15 $m^3\ ha^{-1}\ yr^{-1}$ depending on site index) quoted by West and Mattay (1993).

Issues to be resolved include:

- Integration of observations across a variable forest estate; and
- Conversion of merchantable volumes to gross volumes, and then to total stand biomass.

Table 10. Above-ground biomass estimates for the forest types adopted in the Victorian State Review (Flinn *et. al.*, 2007).

Forest Type	Total above-ground biomass (t ha^{-1})	Comment
Ash	540	50–year old regrowth forest of *E. regnans.*
Mixed species	340	Typical Mixed species forest of medium to high productivity.
River Red Gum	135	Average River Red Gum forest grown under pre–river regulation flooding regimes.
Box–Ironbark	85	Average forest managed using a form of coppice with standards silvicultural system.

Further work is needed to strengthen our understanding of native forest growth rates nationally. Part of this would involve studies in commercially important forest types to quantify relationships between merchantable volume increment and total stand biomass increment. This will require application of allometric equations (or better the weighing of all components) to stands where all stems have been inventoried and where merchantable volume estimates have been made. Without this information, and reliance on existing forest growth estimates, the C sink in regrowth forest will probably be under-estimated.

There seems little doubt that exploitative management using selection methods during the 1945-1960 period degraded many forests and reduced merchantable, and perhaps total, growth. Florence (2007a) suggested that these practices reduced gross bole volume and probably above-ground biomass production, but there are no quantitative data to support this judgement. For our analysis we have assumed that the relatively ad hoc application of selection methods, with doubtful success in obtaining regeneration, would have resulted in lower subsequent biomass increments than after use of clearfelling and seedtree methods.

Above-ground Biomass

Field inventory and mensuration has concentrated on merchantable wood volumes, rather than total (i.e. gross) stem volume or stand biomass. The relationship between stem mass and total tree biomass is reasonably well defined (Snowdon *et. al.,* 2000) but the relationship between merchantable stem mass and stand biomass is highly variable (as reflected in Table 4).

Only one State, Victoria, provided estimates of above-ground biomass for its forest types This data (Flinn *et. al*., 2007) is summarised in Table 10.

Flinn *et. al*., (2007) emphasised that whilst the Ash and Mixed species models are based on “reasonably reliable biomass data” the other models have been deduced from a range of data sources and a great deal of expert judgement. On the basis of other biomass data (Keith *et. al*., 2000), Ash forest biomass is likely to be much higher than the Flinn *et. al.,* (2007) value in ‘mature’ stands. None of the biomass studies could possibly be considered as being representative of the spatial variation in the forest as a whole. Using the Flinn *et. al.,* (2007) estimates of biomass and a nominal rotation of 80 years, the regrowth forest would need to grow at a rate of about 13 m^3 ha^{-1} yr^{-1} in order to create equivalent biomass.

Maintenance of Soil Fertility

Forest harvesting and site preparation practices, especially regeneration burning, have the potential to reduce soil nutrient-supplying capacity, and may directly lower forest productivity. Raison *et. al., (*1993) have demonstrated that this is a risk for Mixed species forests in the coastal region of Victoria. Low availabilities of N and P limit the growth of these forests. Care must be taken to minimise losses of N and P during harvesting and regeneration procedures. Eventually, it may be necessary to use fertiliser applications to replace nutrients contained in wood removed in harvesting or lost in fire. P fertilising offers potential as a cost-effective means of increasing productivity and C uptake in selected areas of regrowth forest (Raison *et. al*., 1997).

3.5.4 Fire Management

History

The important influence of fire in the evolution of Australia’s native forest ecosystems has been discussed earlier. Lightning and the extensive use of fire by Aborigines made fire a common and widespread event before European settlement. European settlement has altered the frequency, intensity and extent of fire in many places.

The first use of fire by European settlers was to burn trees felled as part of land clearing activities and then to stimulate the development of native grasses for grazing purposes. This use declined after World War II. Since then planned use of fire has become an integral part of public land management in native forests and other natural vegetation. However, it must be acknowledged that people cause many wildfires, with lightning being the other major cause.

Fire protection (i.e. prevention and control) was the initial priority of fire management. This priority strengthened following the catastrophic 1939 wildfires. However, by the early 1960s, knowledge of fire behaviour had improved sufficiently to allow the use of fire as a tool in forest protection (e.g. fuel reduction burning) and management (e.g. regeneration burning).

Current Management Arrangements

State and Territory governments have jurisdiction over public lands and natural resources within their borders, and therefore have responsibility for fire management on public land (Gould and Cheney, 2007). This responsibility is usually expressed in regional fire management plans covering native forests, plantations on public land, and adjacent private property. These plans are closely linked with Forest Management Plans to ensure that burning will not unacceptably compromise conservation and wood production values. They also describe fire suppression strategies and arrangements, including detection, preparedness, training, equipment and liaison requirements. From a C perspective, key considerations relate to the use of fire as a management tool, and the success of the plan(s) in reducing the incidence, severity and spread of wildfires.

Fire management practices in native forests and plantations must comply with the Codes of Forest Practices ratified by State Governments and thereby ensure reasonable protection of conservation and wood production values. Responsibility for fire suppression rests increasingly with the State rural fire authorities, although it is often a joint obligation. For example, in Victoria, forestry industry fire brigades have been formed under the auspices of the Country Fire Authority, and private forest owners are expected to contribute resources to these brigades.

Fire Protection

From a C perspective two practices are of most interest, fuel reduction burning, and the fire suppression operation termed ‘back burning’.

Fuel Reduction Burning

Australia, especially the southern part, is one of most wildfire-prone areas in the world. Protection of human life, property, and natural and cultural values from wildfire is a high priority. In native forests, large quantities of highly flammable litter accumulate on the forest floor. Keeping the quantity of fine fuel (i.e. leaves, twigs and flammable ground vegetation less than 6mm diameter) on the forest floor below about 10 $t\,ha^{-1}$ is the primary aim of fuel reduction burning. Until about 1960, a form of fuel reduction burning was used to dispose of the fine fuel contained in the heads of trees felled during harvesting and regeneration operations. Whilst such burns assisted the establishment of eucalypt regeneration by improving seedbed receptivity, their primary purpose was fuel reduction, and they are recorded as such here. The use of fuel reduction burning as a broad-area operation increased greatly from about the mid-1960s. It is carried out under carefully selected weather and fuel conditions so that the fire is generally confined within pre-determined boundaries and burns with prescribed rates of spread and intensity, and results in “a mosaic of burnt and unburnt patches with unburnt areas comprising 20-90 per cent of the total area” (Gould and Cheney, 2007). It is well accepted that fuel reduction burning reduces the spread of wildfire, but there is less consensus as to the degree of benefit in relation to fuel age and forest structure, and on how fuel reduction burning should be implemented.

During the 1960s, use of broad-area fuel reduction burning increased in all States, and the national area burnt annually reached about 750,000 ha in the mid-1970s (Gould and Cheney, 2007). Fuel reduction burning declined during the 1990s due mainly to decreasing resources in the public sector, smoke pollution issues, and to increasing exclusion/restriction of burning on conservation grounds. For example, burning is likely to be incompatible with other objectives such as conservation in rainforest and protection of water values in some catchments.

Back Burning

Back burning, sometimes termed indirect attack, is a fire suppression practice. It is used to reduce the spread of a wildfire by depriving it of fuel. A fire is lit along a safe boundary (e.g. road or fire break) a considerable distance (perhaps several km) ahead of the wildfire front and burns back, consuming the intervening fuel, to meet the wildfire. The annual area of native forest burnt by this management practice could be a significant proportion of the areas attributed to wildfires.

Forest Regeneration Burning

When the primary purpose of the use of fire as a management tool is to burn the slash resulting from harvesting the forest, and the existing litter layer, to prepare a receptive seedbed for eucalypt regeneration, the fire is termed regeneration burning, even though the fire also serves a fire protection (i.e. fuel reduction) purpose. As such, regeneration burning became prominent in the early 1960s, especially in Victoria and Tasmania, where clearfelling and high intensity regeneration burning was used extensively in the Ash and Mixed species forests. During the last decade, this intensive practice has become less common, except in areas where integrated harvesting is not yet practised.

Since the early 1970s, the use of clearfelling and high intensity regeneration burning has been strongly criticised on environmental grounds. Often, this practice has been defended as being ecologically sound because it imitates the way the forest is regenerated in nature by wildfire. In a strict sense, this assertion is not true for several reasons. Under clearfelling, wood and constituent nutrients are removed, altered seed supply may alter genetic selection, fire and harvesting effects on soil properties may be different, and exposure of the seedbed is different. The burning frequency is also higher for managed than natural regeneration systems. Questions arise, therefore, about the impacts of this management practice on long-term wood production and carbon uptake. Hence, resilience of the forest to disturbance, including that caused by high intensity regeneration burning, is an important consideration. There is encouraging evidence (Attiwill, 1991; Weston and Attiwill, 1996) that Victoria's *E. regnans* forest, a fire-climax ecosystem that generally grows on fertile soils, is characterised by processes that limit nutrient loss after disturbance so that productivity could be maintained. However, there are few, if any field data to demonstrate that biomass production rates are being maintained between forest rotations, although observation suggests adequate regeneration and rapid early growth in many situations.

Wildfire

Knowledge of the natural patterns of wildfire, both pre- and post-European settlement is very limited.

Experience has shown that even with a high level of fire protection planning and suppression resources, the right combinations of ignition sources, weather conditions and fuel levels can still lead to catastrophic wildfires. For example, in 1983, the Ash Wednesday fires burnt over 486,000 ha (Gould and Cheney, 2007) and approximately 600,000 ha were burnt by the 2001-02 wildfires in NSW. During early 2003, several million hectares of native forest were burnt in SE Australia.

Major fire events will probably occur in the future at about the same frequency as in the past. For example, major fires have occurred in Victoria's native forests in 1851, 1898, 1919, 1926, 1932, 1939, 1983, 1985 and 2003, and have had a major influence in shaping the condition of Victoria's forests presently available for commercial forestry (Flinn *et. al*., 2007).

Gould and Cheney (2007) conclude that:

- In Australia, each year an average of about 213,000 ha of State forest (native forest and plantations) are burnt by wildfires. This figure could exceed 500,000 ha if conservation reserves and other public land were included.
- Victoria and NSW, together, account for about 70 per cent of the average annual area of State forest burnt.
- There is a large annual variation in the number of wildfires and, especially, in the area that they burn.
- In terms of area burnt, there is evidence of a decline since the early 1980s. This trend is attributed to the effectiveness of broad area fuel reduction burning and regeneration burning in depleting heavy fuel accumulations, and to improved fire management (i.e. prevention, detection and suppression). However, bad fire years in 2001-02 and 2002-03 in SE Australia show that wildfire extent is very unpredictable.

Carbon Implications

Carbon losses due to fire will depend on the amount of biomass consumed by fire which, in turn, will depend on the area burnt, fuel type and load, and burning conditions. Fuel load varies with forest type, management history/stage and fire history. Within a forest type, variation is much less for fine fuel than CWD (Gould and Cheney, 2007). Burn coverage is highly variable due to the influence of weather and aspect on burning conditions (Flinn *et. al*., 2007).

An indication of the proportion of available fuel consumed in varying types of fire is given in Table 7.

3.5.5 Summary of Key Factors Affecting Carbon Stocks of Native Forests

The following inferences/judgements are made regarding the likely national trends in post-harvest growth (unit forest area basis) and their implications for C stocks for three time periods: 1945-1960, 1960-1990 and 1990-2000. An attempt is made to integrate the effects of management practices on the three factors likely to have the greatest influence on post-harvest growth per unit forest area, namely: tree growth (essentially the eucalypts), tree stocking (stems per unit area) and stand structure. Carbon implications are assessed in terms of likely trends in post-harvest growth initiated by management practices used during a given period. It is beyond the scope of this analysis to translate such trends into probable decadal effects on C uptake.

1945-1960

1. Management Practices

There was a continued application of selection type harvesting and regeneration methods, with little attempt to ensure successful establishment and development of regeneration. Given the fairly extensive application of treatments to improve stand condition, such as reject felling in New South Wales (Florence, 2007a) and continued thinning of Box-Ironbark forests in Victoria (Flinn *et. al*., 2007), it is reasonable to assume that, generally, the condition of the growing stock in public native forests was not compromised by management practices during the period and, that the rate of above-ground biomass production was at least maintained at the previous level. There was heavy cutting of private native forests during this period, especially in NSW, Tasmania and Queensland. Some of this was a preliminary step prior to conversion to agriculture, and this obviously led to a net loss of carbon from the ecosystem.

2. Wildfire

Wildfire is an integral part of the forest environment and can have major impact on C budgets. For this reason, mention is made of the implications of the devastating wildfires of 1939 for C stocks in Victoria's Ash forests. The fires burned through 1.3 million ha of native forests, and killed extensive stands of mature Ash. Salvage operations were carried out over several years. In most cases, prolific natural regeneration resulted from the fires.

3. Carbon Stocks

Management practices are unlikely to have initiated a significant change in C stocks in public native forests, but significant declines would have occurred in the private native forest estate. The 1939 wildfires occurred in Victoria and NSW and converted mature forests to regrowth forests with lower C stock but higher uptake and, in the process, huge losses of C resulted from combustion and salvage logging. Only moderate areas of new plantations were established during this period mostly on ex-native forest sites.

1960-1990

1. Management Practices

NSW, Queensland and WA continued to use selection harvesting and regeneration methods, except for the Eden region of NSW, where clearfelling and low intensity regeneration/fuel reduction burning was applied over extensive areas for about 25 years. Victoria and Tasmania introduced clearfelling and applied it extensively. There was a large increase in the use of integrated harvesting, which by greatly raising utilisation standards, also facilitated the conversion of extensive areas of degraded stands, uneconomic for sawlog only harvesting, into vigorous, fully stocked regrowth stands (Department of Conservation, Forest and Lands, 1988). There was better knowledge of the regeneration needs of eucalypts and a greater commitment to meeting stocking standards. Generally, there was a greater allocation of resources to stand improvement treatments such as thinning regrowth Ash forests in Victoria (Squire, *et. al.*, 1984), and thinning and cull removal in the Jarrah forests in Western Australia (Bradshaw, 2007). However, there were some exceptions: NSW logged its Tableland forests with no investment in regeneration or stand improvement (Florence, 2007a). In Queensland it was reported that there was a "large burden of non-productive, non-sawlog grade material which is limiting both growth and regeneration" (DPI Forestry, 1998 – in Florence, 2007b). It is reasonable to assume that, generally, there was an increase in carbon uptake by the native forests during this period, especially associated with the use of clearfelling and integrated harvesting and improved regeneration establishment.

Native forests continued to be cleared for agriculture and new plantation development during this period, especially until the early 1980s.

2. Carbon Stocks

Management practices and an increase in the regrowth proportion of forest are likely to have initiated a significant increase in the rate of C uptake per unit forest area. Again however, wildfires had a significant impact, with the 1983 Ash Wednesday fires, burning some 44,000 ha of highly productive mountain forest in Victoria alone (Flinn *et. al.*, 2007). Plantation establishment rates were about 30,000 ha per year during the 1970s and 1980s (Snowdon and James, 2007).

1990-2000

1. Management Practices

There was an expanded use of selection harvesting and regeneration methods as a response to environmentalism; with clearfelling being increasingly confined to Ash and Mixed species forests in Victoria and Tasmania and Karri forests in WA. The trend is clearly one of decreasing priority to wood production objectives, with increasing use of complex harvesting and regeneration methods that could reduce forest growth due to less than optimum regeneration and stand structures, especially in Mixed species forests. There is a very poor understanding of growth responses to uneven-aged silvicultural methods. Stand level responses are complex, depending upon interactions between species, age classes and growing conditions.

2. Carbon Stocks

Management practices are likely to have initiated a significant decrease in C uptake per unit forest area. This trend is likely to strengthen in the next decade. The impacts of wildfires may be greater in the future (note the significant fires in SE Australia in 2001-2003 period) because of reduced emphasis given to fuel management and reduced infrastructure and professional capacity for fire suppression in native forests. Clearing of native forest for plantation establishment virtually ceased.

Transfers of regrowth forests to conservation tenures would have caused a major reduction in C uptake (forest level) in the native forest remaining for commercial wood production. At the forest level, C uptake is the product of forest area x uptake per unit area. Hence, area transfers (i.e. reductions), without offsetting increases in uptake per unit area in the remaining forest, will reduce C uptake at the forest level.

There are corresponding implications for wood production. For example, as a result of conservation imperatives, wood production from public forest in WA is expected to reduce to about 35 per cent of the levels of the previous decade (Bradshaw, 2007).

Further Analysis

A full analysis of the carbon implications of forestry would require information on the impact of temporal changes in management practices on C uptake per unit area, combined with other considerations such as the length of the nominal rotation and the impact of transfers to conservation reserves and wildfires on the growing stock used for commercial wood production. At the level of the forest stand, if the nominal rotation for the regrowth stand is less than the age of the previous stand when it was harvested then, the C stock may be 'reset' at a lower level. At the national level, there is little doubt that the C stocks of Australia's commercial native forest have declined during the period 1945-2000. This is a consequence of several factors, but especially clearing, conversion of 'mature' stands to regrowth, and transfer of large areas of forest to the conservation estate.

3.6 TEMPORAL TRENDS IN KEY FACTORS AFFECTING CARBON STOCKS - PLANTATIONS

The history of development of Australia's plantation estate of softwoods and hardwoods and changes in management practices has been covered by Snowdon and James (2007). Almost without exception, Australia's plantations are managed using an even-aged clearfelling and regeneration (re-planting) regime. Here we evaluate the potential effects of plantation management on carbon stocks with respect to some important factors: site conversion, slash management between rotations, forest growth and use of fire as a management tool.

Site Conversion

Native forests and grasslands have been converted to plantations (Table 2), with native forests being by far the major source of land (Snowdon and James, 2007). However in recent decades most new plantations have been established on cleared agricultural land.

From a C perspective, the conversion of native forest to plantation is of considerable interest. Some 600,000 ha of native forest have been converted to plantations, mainly softwoods (Snowdon and James, 2007). The quantity of biomass cleared has been highly variable, depending on the quality of the native forest. The range would be expected to be 250-350 t ha^{-1}. Many of the earlier plantations were established on infertile soils supporting Mixed species eucalypt forests, where above-ground biomass would have been about

150 t ha^{-1}. The native forests replaced by very productive *P. radiata* plantations in the Green Triangle region of SA and Victoria are an excellent example of where low biomass native forest was converted (Lewis *et. al*., 1976).

The fate of the C contained in the above-ground eucalypt biomass has varied, depending on the proportion removed in wood products (up to 30 per cent, but often zero) and whether residue (logging slash) was burnt in situ (i.e. broadcast burning) or heaped and burnt (i.e. windrow burning). Broadcast burning was used mainly from 1945-1970 and windrow burning from about 1970 to the effective cessation of native forest conversion in about 1985. The consumption of residue or slash is variable depending on burning coverage and temperature duration, but may be high, and even broadcast burning can consume for 82 per cent of residue less than 70 mm diameter (Stewart and Flinn, 1985). Fuel consumption is higher in windrows, especially where these are re-heaped (stoked), and there can be release of 50-150 t C ha^{-1}. Burn coverage is variable, especially for broadcast burning, and therefore residue consumption is generally about 50 per cent of the available fuel (Table 7).

Slash Management Between Rotations

Harvesting operations leave a substantial amount of residue on the site (Table 6). From 1945 to about 1980, residue burning was a common practice to prepare the site for replanting. The main reason was to facilitate manual planting operations, but it also removed a fire risk and a bridge for infection by pathogens and insects (Snowdon and James, 2007). Residue burning can remove a high proportion of the available fuel, but it also removes nutrients and soil organic matter (Flinn *et. al*., 1979). By 1980, residue burning in plantations had decreased, with increasing acceptance of the view that residue retention could be important for maintenance of site productivity over successive rotations (Squire *et. al*., 1991).

The amount of residue produced when plantations are harvested depends on site productivity (i.e. climate and soil), management history (e.g. weed control, fertilising, pruning, thinning) and utilisation standards. Residue production for *P. radiata* usually ranges from 50-100 t ha^{-1} (Table 6), but values as high as 187 t ha^{-1} have been reported (Balneaves *et. al*., 1991).

Today, residue burning is limited to about 10 per cent of the harvested area. In these cases, generally only the coarse debris is heaped and burned (Snowdon and James, 2007).

Growth

Plantation growth rates vary with differences in species, site, stage of stand development and management regimes (Snowdon and James, 2007). Within the same rainfall region and topography, growth rates can vary greatly over short distances due to changes in soil fertility and access to ground water (e.g. in the 'Green Triangle' region).

Since 1945 and, especially since about 1975, there has been a substantial improvement in plantation growth due to changes in management practices. For the older plantations (i.e. 1945-1975), with more conservative management regimes, growth rates in terms of mean annual increment (MAI) in volume production generally ranged from 9 to 34 m^3 ha^{-1} yr^{-1} for *P. radiata*, and 9 to 16 m^3 ha^{-1} yr^{-1} for other softwoods (Snowdon and James, 2007). Since 1975, the use of weed control, carefully tailored fertiliser applications and improved genetics have produced excellent growth responses The new improved regimes can increase *P. radiata* MAI by an average of about 50 per cent over 30 years (Snowdon and James, 2007). With hardwoods (e.g. *E. globulus*) on previous agricultural land, depending on rainfall, MAIs over 10-12 years are generally within the range 15-25 m^3 ha^{-1} yr^{-1}. Hence, growth and yield functions for stands established before about 1975 may not be representative of contemporary management practices.

Snowdon and James (2007) suggest a way of adapting growth curves or functions for old regimes to estimate growth for the new regimes.

Pruning has not been extensively practiced, and should not affect stand total volume growth. Thinning regimes vary depending on the main product (e.g. knotty sawlog or clearwood). The amount of thinning residue can be predicted using a biometric approach. A first thinning of a *P. radiata* stand, at age 10 years, would be expected to produce about 40 kg of residue per tree felled (Carlyle, 1995). Many of the early *P. radiata* stands were not thinned, and today it is usual for thinning to be geared to market forces (i.e. demand for the products of thinning) rather than silvicultural imperatives.

Fire as a Management Tool

Fire has the potential to impair soil fertility, and thus subsequent productivity, by adversely affecting nutrient (especially N) balance and cycling, and by increasing soil erosion.

From a C perspective, two practices are of most interest: fuel reduction burning (slash residue burning is considered as regeneration burning) and burning just before the final harvest to kill unwanted natural regeneration.

Fuel reduction burning is not often used in plantations, except in Queensland where it is common practice with tropical and sub-tropical species with up to about 12,000 ha being treated annually between 1981/82 and 1999/00, removing about 14 t ha^{-1} of biomass, or about 55 percent of the fuel less than 25 mm in diameter (Gould and Cheney, 2007). The extremely high priority given to protection of plantations from wildfire damage generates C emissions by fuel reduction burning in native forests adjoining the plantations (Snowdon and James, 2007). These C losses should really be attributed to plantation management and not native forest management.

Burning to kill unwanted natural regeneration of fire-sensitive pine is a rarely used, though a potentially important, management option.

4. PRIORITY AREAS FOR FURTHER DATA COLLECTION AND ANALYSIS

The magnitude and complexity of this project exceeded initial expectations. This was due in part to the highly variable quality and accessibility of data. This had two important consequences: first, expert judgement had to be used to a very considerable degree, especially in completing the data tables; and, secondly, there was insufficient time to compile full and reliable information for management practices on private land, on transfers of State forest to parks and reserves, and on the type of native forest converted to plantations.

Whilst the project has compiled good historical descriptions and been a valuable data gathering exercise, and should substantially improve our capacity for tracking and forecasting C stocks and fluxes, considerable further work will be needed in order to develop a reasonable capacity to forecast future C balance for Australia's forests.

Further work can be divided into two broad categories: synthesis of existing information, and collection of new information. The high order issues in each category are addressed below.

Synthesis of Existing Information

This can be achieved relatively easily and quickly by sound corporate and historical knowledge to compile the information from existing data sources. The priorities should be:

- Summarise the chronology of transfers from native forests to parks and reserves, describing forest condition prior to transfer, fire management impact, and biomass accumulation rates.
- Improve knowledge of the private forest estate. Add to the present work by better describing practices (including wood removals) that are likely to have a significant impact on C stocks

and their change over time. In particular, more information is required on the impact of heavy harvesting during the 1960-1985 period in New South Wales and Tasmania.

- Develop a better interpretative basis for applying spatially the information summarised in the data tables. Use reference sites to help calibrate satellite imagery, with the help of field foresters experienced with historical forest operations.

Expert opinion will be very important in deriving both qualitative and quantitative components of the information. In some cases (e.g. private forest) there is likely to be even greater reliance on expert opinion.

Collection of New Information

The following are important areas:

- *Post-harvest biomass accumulation.* The ultimate objective should be a capacity to model total biomass accumulation and Harvest Index for a range of harvest regimes and utilisation standards. These studies are required for all major forest types but especially for Mixed species forests and selection felling methods. Selection methods have long been favoured for Australia's very extensive Mixed species forests and, during the last decade, have increasingly displaced even-aged methods (e.g. clearfelling) introduced in some States in the 1960s. It is emphasised that there is a very poor understanding of the quantitative effects of selection harvesting on tree and stand growth.
- *Slash production and decay*. Each year, the amount of C contained in new logging slash is very high. Acceptable estimates are required of temporal change in C stocks of slash and existing forest floor biomass, including CWD, resulting from forest management practices and wildfire.
- *Fuel consumption (burning/combustion efficiency).* More robust figures are needed especially for regeneration burning and wildfire.
- *Effects of forest management on C release in wildfire.* Good estimates are required of the extent to which C emissions from wildfires are influenced by management practices such as creation of logging slash, use of fuel reduction burning, and fire suppression.

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6. APPENDICES

6.1 APPENDIX 1

PROJECT TEAM

Jack Bradshaw

Dip.For.(AFS), B.Sc.For.(UWA), F.I.F.A.

Jack Bradshaw began work with the Forests Department of Western Australia in 1963 where he was engaged in forest inventory, yield regulation and resource planning. He was appointed Manager of the Silviculture Branch in the WA Department of Conservation and Land Management in 1987 and, in 1993, Manager of the Forest Management Branch. Since 1999, he has worked as a consultant on various projects including catchment management, native forest silviculture, yield regulation, woodland inventory and the management of private native forests.

Phil Cheney PSM

Dip.For.(AFS), B.Sc.For.(Melb), F.I.F.A.

Has undertaken research into bushfires since 1964 and was the project leader of CSIRO Bushfire Research Group from 1975 to 2003. He is now an Honorary Research Fellow with CSIRO. He has carried out fire behaviour research in fuel types ranging from tropical grasslands to cool temperate tall eucalypt forests, evaluated the effectiveness of different suppression systems including large air tankers, and measured the physiology of fire fighters undertaking fire line construction with hand tools. He has investigated most major bushfire disasters in Australia since 1965.

Ken Felton

B.Sc.(Hons.)(Bangor), M.F.(Syracuse), F.I.F.A.

Ken has forty-four years of experience in forestry in Tasmania, with the Forestry Commission and then Forestry Tasmania, working in forest planning, silvicultural and pathology research, and then public policy development and implementation. He was a member of the Boards of Forestry Tasmania and Forest Practices 1994–2002, until retirement.

Dr David Flinn

Dip.For.(Cres.), B.Sc.For.(Hons.)(Melb.), Ph.D.(Melb.)

After a career as a forest scientist, Dr Flinn was the inaugural Director of both the Centre for Forest Tree Technology (CFTT - a Victorian Government Institute) and the Forest Science Centre (an alliance between CFTT and the Department of Forestry, University of Melbourne). In 1997, he was appointed an Associate Professor of the University of Melbourne, and was awarded the Commonwealth Forestry Association Medal (Asia-Pacific Region) in 2000 for “excellence in forest management”. He is currently a part-time consultant with David Flinn Consulting Services.

Dr Ross Florence

Dip.For.(AFS), M.Sc.For.(Qld), Ph.D.(Syd.), F.I.F.A.

Dr Florence graduated in forestry in 1952 and worked initially with the Queensland Department of Forestry in tree breeding and eucalypt forest silviculture. In 1961, he was awarded a Ph.D. at the University of Sydney for studies on the ecology of *Eucalyptus pilularis*. He lectured at the ANU Department of Forestry from 1965, developing teaching, research and professional interests in forest ecology, silviculture, land use and forest policy. He has more than 100 publications related to these fields, and his book, “The Ecology and Silviculture of Eucalypt Forests”, was published in 1996. Dr Florence was awarded the Institute of Foresters’ Jolly Memorial Medal in 1993.

Jim Gould
B.Sc.For.(University of Alberta)

Jim Gould is a Research Leader with the Ensis (the joint forces of CSIRO and SCION) Bushfire Research Group and Program Leader with the Bushfire Cooperative Research Centre's (CRC) Safe Prevention, Preparation and Suppression Program. Jim has been with CSIRO for over 20 years and, for most of this time, his research has concentrated on fire behaviour and fuel management of various vegetation types throughout Australia. His research led to a revision of grassland fire behaviour models and prescribed burning guidelines for regrowth forest in SE NSW. He has published scientific papers on fire behaviour in national and international journals. Jim is currently coordinating a research project for both Ensis and the Bushfire CRC in the area of fire behaviour, fire weather and bushfire risk management.

Dr Ryde James
B.Sc.(Wellington), B.Sc.(For.)(ANU), D.Phil.(Oxon)

Dr James worked as a planning officer with the New Zealand Forest Service and as a scientist and then Program Manager at the NZ Forest Research Institute where he lead a group developing silvicultural and management systems for plantation forestry. He has been at the ANU since 1992, where he has taught Plantation Forest Management and supervised a range of silvicultural studies, including the use of stem analysis to determine growth trends for *Pinus radiata*. He has been involved in estimating wood yields by product type at estate level for Australian plantations and at global level for the FAO.

Dr R. John Raison
B.Rur.Sc.(UNE), PhD(UNE)

John Raison is a Chief Research Scientist at Ensis (Forestry joint venture between CSIRO and Scion, NZ) and is based in Canberra. He has conducted research on the ecology of Australia's forests for nearly 30 years, with an emphasis on the effects of fire and harvesting on nutrient cycling and productivity. In recent years he has contributed to a range of policy and practices aimed at facilitating sustainable forest management. These have included revision of Codes of Forest Practice, the development of sustainability indicators, and conduct of sustainability assessments as part of the development of Regional Forest Agreements in all Australian States. His recent research has focused on greenhouse and climate science, particularly carbon accounting in forest ecosystems. He has represented Australia on the Intergovernmental Panel on Climate Change on major task to refine the Guidelines for greenhouse gas accounting and reporting for the land sectors.

Peter Snowdon
B.Sc.Agr.(Syd.), M.Sc.(ANU), B.A.(ANU)

Peter Snowdon: philosopher of life, storyteller and poet, also has a broad knowledge of forest soils and nutrition, silviculture, statistics, and growth modelling. During 40 years with CSIRO he carried out research on the improvement of plantation management. He has been particularly involved with rotation length (30+ years) experiments that have become central to research on the sustainability of plantation productivity. He has used data from these experiments to develop hybrid models linking empirical and process models of forest growth over complete rotations. These have advanced our theoretical knowledge of stand growth over long periods.

Dr Ross Squire
Dip.For.(Cres.), B.Sc.For.(Melb.), M.Sc.For.(Melb.), Ph.D.(Melb.)

Dr Squire is a part-time consultant based in Ballarat. He was previously a Super Scientist and Manager, Forests Research Program with the Victorian Department of Conservation and Environment (now Department of Sustainability and Environment). He led the design and implementation of two major multi-disciplinary silvicultural research projects in Victoria: during the 1970s and 1980s, Maintenance of Long-term Productivity of Radiata

Pine Plantations, and from the mid 1980s to the early 1990s, the Silvicultural Systems Project. He is a Churchill Fellow and was the forestry representative on CSIRO's former Agricultural Sector Advisory Committee in the early 1990s.

Bernard Walker
B.Sc.For.(ANU)

Bernard Walker is a private forestry consultant based in Hobart, Tasmania. After graduating as a professional forester in 1982, he gained extensive experience in both the government and private sectors holding positions in Forestry Tasmania, the Forest and Forests Industry Council and North Forest Products. In his current role as a private consultant, he specialises in forest information management and forest estate modelling with a client base throughout southern Australia and New Zealand.

Kevin Wareing
Dip.For.(Cres.), B.Sc.For.(Melb.), M.F.(Yale)

Kevin held various positions in the Forests Commission, Victoria and its successors, associated with land use, plantation expansion, forest management, timber production and implementation of industry development policies. For seven years, from 1988 to 1995, he was manager of commercial forestry activities in Victoria's public native forests and plantations. In 1995, he left the public sector and after two years with the Victorian Association of Forest Industries, became a self-employed forestry consultant. He has completed a range of projects primarily concerned with commercial and economic aspects of native forests and plantations for both public and private sector clients.

6.2 APPENDIX 2

DATA TABLES PROFORMA/GUIDE

To ensure consistency in the reporting of quantitative data on forest management by the different authors, a set of reporting tables were developed. Authors were required to fill in these tables for each different forest type, region and management regime. A single table was developed for native forests (Table 11). Three tables, based on previous land use (i.e. native forest, pasture, plantation (2R)) were developed for plantations (Table 12).

Due to the large number of tables produced they are not printed in this report but are available from the AGO upon request. These tables form Part 2 of this report.

6.3 APPENDIX 3

DATA QUALITY STANDARDS

The data quality standards referred to in this report

Table 11. Template used to document native forest management in this report.

Native Forests

IBRA Regions	(vers. 4.0)		Treatment	Frequency
Time Period	5 Year Time Steps (or Range of Years if No Significant Change)			
Forest Type	Floristic Descriptor			
Tenure	Private, Public or All			
Status	Mature or Regrowth			

		Harvest			Fire				Products Removals (t/ha)					Slash (t/ha)		Post-Harvest Growth			
Felling Type		Felling Purpose (Regen, Release)	% Total Basal Area Removed	% Canopy Removed	Fire Type	% Harvested Area Burnt	% Burnt Efficiency Fines (Combustion)	% Burnt Efficiency CWD (Combustion)	Sawlog	Poles/ Posts	Firewood	Pulpwood	Bark (Onsite or Offsite)	<50mm	>50mm	MAI Merchantable	MAI Total	Notional Years to Next Cut	Adeq. Regenerated
Uniform	Single Tree																		
	Shelterwood																		
	Seed Tree																		
	Conversion																		
Small Gap																			
Large Gap/ Clearfell	Clearfell																		
Timber Stand Improvement																			

The IBRA Region to Status attributes defines the unique set of conditions that are represented in the remainder of the table. Status refers to whether forest is mature (approaching equilibrium site biomass) or a form of regrowth (pole, spar etc). Harvest harvested, NOT to net harvestable area.

Felling Types – uniform (4 or more types), small gaps (< 2 X dominant stand height), large gaps (clear felling), TSI.

TSI – treatment of forest to enhance growth/regeneration but without product removal.

Felling Purpose – combinations of product removal, stand release, regeneration.

Fire Type – low intensity prescribed, slash reduction, high intensity regeneration. Note for low–intensity prescribed fires, areas greatly exceeding the harvested area are burnt.

Post–harvest growth (MAI) refers to growth over the period to the notional next cut (rotation length).

% Adequately Regenerated related to that required to maximise volume production for the period of the notional next cut.

The % felling Type is the relative representation of each in the Time Period. The % basal area removed refers to all trees harvested. The % canopy disturbance should consider the Impact of the cut on the upper canopies (not the lower shrubs or grasses) an any additional loss of trees after the harvest event.

Table 12. Template used to document plantation forest management in this report.

Plantations

Plantations from Native Forest

Forest Region		from NPI
Type		from Turner and James
Species		*(if not genus)*

Year of Change	**Preparation**		**Cultivation**			**Post-planting Weed Control**			**Initial Stocking**	**Thin and Prune**					
	Broadcast Burn	Windrow and Burn **	No Cultivation or Spot Cultivation	Strip Cultivation (Rip, Mound etc.)	Broadcast Cultivation (Plough, Rotary Hoe etc.)	Manual (Includes Use of Hand Tools and Manual Spraying)	Strip (Mowing, Hoeing or Spraying by Machine)	Blanket (Usually Aerial Application)		Thin 1	% First Thin to Waste	Thin 2	Thin 3	Thin 4	Prune
Year	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**spha**	**spha**	**%**	**spha**	**spha**	**spha**	**Yes/No**
	Need Not Sum to 100%		Sum to 100%			Need Not Sum to 100%									

Plantations from Pasture

Forest Region		from NPI
Type		from Turner and James
Species		*(if not genus)*

Year of Change	**Pre-planting Preparation**				**Cultivation**			**Post-planting Weed Control**			**Initial Stocking**	**Thin and Prune**					
	Intensive Grazing	Spot Weed Control Using Herbicides	Strip Weed Control Using Herbicides	Blanket Weed Control Using Herbicides	No Cultivation or Spot Cultivation	Strip Cultivation (Rip, Mound etc.)	Broadcast Cultivation (Plough, Rotary Hoe etc.)	Manual (Includes Use of Hand Tools and Manual Spraying)	Strip (Mowing, Hoeing or Spraying by Machine)	Blanket (Usually Aerial Application)		Thin 1	% First Thin to Waste	Thin 2	Thin 3	Thin 4	Prune
Year	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**spha**	**spha**	**%**	**spha**	**spha**	**spha**	**Yes/No**
	Need Not Sum to 100%				Sum to 100%			Need Not Sum to 100%									

Plantations from Plantation

Forest Region		from NPI
Type		from Turner and James
Species		*(if not genus)*

Year of Change	**Preparation**				**Cultivation**			**Post-planting Weed Control**			**Initial Stocking**	**Thin and Prune**					
	Broadcast Burn	Windrow and Burn **	Chopper Roll	Interplant Slash	No Cultivation or Spot Cultivation	Strip Cultivation (Rip, Mound etc.)	Broadcast Cultivation (Plough, Rotary Hoe etc.)	Manual (Includes Use of Hand Tools and Manual Spraying)	Strip (Mowing, Hoeing or Spraying by Machine)	Blanket (Usually Aerial Application)		Thin 1	% First Thin to Waste	Thin 2	Thin 3	Thin 4	Prune
Year	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**% of Area**	**spha**	**spha**	**%**	**spha**	**spha**	**spha**	**Yes/No**
	Need Not Sum to 100%				Sum to 100%			Need Not Sum to 100%									

are those used by Dr Rob Campbell (Department Sustainability and Environment, Victoria) in the development of a knowledge base for evaluating alternative silvicultural systems for ecologically sustainable wood production (see Campbell, 1997). They are as follows:

1. Opinion without experience or science, including political, legislative or organisational mandates without scientific backing.
2. Opinion of expert(s) (views, rationale or beliefs) based on logic without real world observations and experience, including predictions by heuristic models (for key information, cite expert and summarise logic).
3. Opinion of expert(s) based on logic backed up by real world observations and/or experience, but without quantitative data to support the logic. Includes predictions by untested models (for key information cite expert and summarise logic).
4. Information based on empirical, real world data from high quality surveys, case studies and experiments without randomisation or replication and possibly subject to confounding by uncontrolled factors. Includes predictions by models subject to limited testing in real world situations (quote source).
5. Information based on empirical, real world data from high quality surveys, experiments and case studies with replication, but not necessarily representative of the data population as a whole (quote source).
6. Information based on high quality, statistically valid data that is representative of the spatial variation of the population as a whole. That is, it provides a valid description of a system at a single point in time (quote source).
7. Information based on high quality, statistically valid data that is representative of the full spatial and temporal variation of the population under study. This data quality provides a valid description of system status and dynamics through both time and space (quote source).

The following examples show how the standards have been used in the Victorian Report (Flinn *et. al.*, 2007):

- "in many instances, maintaining the forest in an 'undisturbed' state, on a catchment or sub-catchment basis, may be the most appropriate course of action for adequate flora conservation(2)." The data quality standard of the statement is indicated by Level 2, that is, "Opinion of expert(s) — etc." In this case, the rating is given without a source (*pers. comm.*, or reference), and the author(s) accepts responsibility for the statement.
- "in even-aged *E. regnans* regrowth forests from before 1940, widespread insect pest problems have been associated with outbreaks of the Spur-legged Stick Insect --- (Neumann 1976, Neumann *et. al.,* 1977)(5)." In this case. The data quality standard is Level 5, that is, "Information based on empirical --- etc."

SECTION 2

New South Wales

Ross Florence

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NEW SOUTH WALES

SUMMARY

This report contributes to a national and comprehensive effort to model change in C stocks in Australian forests. It does so by:

- Describing changes in forest management practices in New South Wales (NSW), 1945 to 2000, which are likely to have had significant impacts on C stocks in the forest estate;
- Analysing these changes in relation to a stratification of the forests involving (important) forest types, management practices and time periods;
- Providing data tables which summarise, by forest types and time periods, information on management practices and their impacts on forests and C stocks; and
- Discussing trends in forest practice since World War II that have affected wood removals, C pools in biomass and harvest residues, and post-harvest forest growth.

NSW forests, both public and private, have been an important source of timber since settlement, making a critical contribution to State and national development.

Early harvesting operations removed only the most desirable species and highest quality boles, and recurrent wildfires did great damage to growing stock. The Forestry Act of 1916 created a modern Forest Service able to address the regulation and protection of the forests. While good progress was made by World War II, rapid economic expansion after the war placed great stress on the wood resource.

During the 1950s and 60s harvesting of previously managed forest was based on the selection system, ringbarking and reject tree felling treatments, and a range of programs to regenerate wet sclerophyll forest. However, wood supply could be maintained only by extending logging to the difficult terrain of escarpment and mountain forests, where all commercial product was extracted. Successive Governments committed themselves in this way to maintaining wood supply from the native forests, while building up a significant softwood plantation resource.

A policy review in the early 1970s determined that the existing regrowth stocking, together with the old-growth resource, were sufficient to maintain wood supply to industry until the softwood program reached maturity towards the end of the century. Thus, within the regrowth forests, more conservative selection practice was directed to conserving and stimulating trees with good increment potential, and regeneration and other improvement treatments were curtailed. This strategy continued to underpin native forest management until the 1990s.

Environmental concerns about forest management developed a higher profile through the 1980s, culminating in the Comprehensive Regional Assessment and Regional Forest Agreement programs of the mid - late 1990s. This resulted in a substantial re-allocation of wood production forest to conservation reserves, and greater integration of wood production and wildlife management within the residual State forests.

The impacts of forest policies, strategies and practices are discussed in terms of forest condition, carbon stocks and carbon increment. While there are uneven-aged and even-aged forests with good growing stock and wood production levels, the forests, overall, are in a suboptimal condition for wood production. The most critical problem relates to forest with a wet sclerophyll component.

Restoration of degraded forest can play an important role in both future wood production and enhancement of carbon storage. Under the Regional Forest Agreement, NSW is committed to forest restoration through its commitment to ecologically sustainable forest management.

1. INTRODUCTION

There are about 8 million ha of forest in NSW, 5.4 million ha in public ownership and 2.8 million ha in private ownership. Both public and private forests have played an important role in wood supply since settlement.

Early harvesting was purely exploitive, that is, extracting only those trees with near-perfect boles and specific wood attributes. Towards the end of the 19th century there were concerns about the extent of clearing and destructive utilisation of the forests, and some rudimentary regulatory processes and management regimes were put in place. However, it was not until 1916 that a formal regulated forest service was formed, and the State began to expand the area of forest committed to wood production, to protect forests from wildfire, and to institute consistent management practices within the more accessible forests.

Steady progress had been made by World War II. However, rapid economic expansion during the post-war decades highlighted critical deficiencies in wood production, and an increasing level of wood imports. This report reviews the response of the State to these circumstances, focusing on the strategies designed to maintain the flow of wood products to the markets, and the impacts of management practices on the forests.

This report is in two parts. The main report presents a history of forest management from 1945 to 2000, and an Appendix presents the background to, and assumptions made in compiling the data tables accompanying the report.

The main report outlines forests, forest zones and forest types. These are described in more detail in the Appendix. An account of management practices before 1945 is given in Section 3. Post-war programs designed to maintain sawlog supply and improve forest productivity are covered in Section 4. A review of forest policies and strategies in the early 1970s introduced more conservative management regimes for much of the forest, while continuing to draw heavily on the residual old-growth forest in mountainous regions These are covered in Section 5.

The continuing transition of coastal region forests to productive uneven-aged regrowth forest during the 1970s and 80s is described in Section 6, and the dramatic impact of 'environmentalism' on the wood production resource and management practice is described in Section 7.

Section 8 acknowledges that little is known about the private sector forests in NSW, and suggests that the data tables based on the public forests might also be taken to represent the private forests.

The Appendix addresses the zoning of the forests, the forest types within the zones, and for each zone and type outlines the management practices and the way they have changed with time. The Appendix also shows how estimates of wood production, fire impacts, logging residues, and post-harvest growth were derived, and the assumptions made in so doing.

2. THE FORESTS OF NEW SOUTH WALES

The Resource Assessment Commission (1992) estimated that there were 8.3 million ha of forest in NSW. Of this:

- 2.6 million ha were State forest
- 1.3 million ha were other Crown lands
- 1.6 million ha were conservation reserves; and
- 2.8 million ha were in private ownership

While there was a greater area in private ownership than in State forests, State forests are more productive. Within State forests, 63 per cent of the total area was classified as 'Tall Open Forest' and 31 per cent as 'Open Forest'. These percentages are reversed for the private property forests: 32 per cent classified as Tall Open, and 67 per cent as Open Forest. Rainforest within State forest makes up nearly 6 per cent of the total forest area. There is little rainforest on private property.

For purposes of this project, forests are placed in a number of zones with distinctive vegetation characteristics and/or utilisation and management histories. The reasons for doing so are given in the Appendix. The zones are:

- Coastal Regrowth Zone
- Mountain-Tablelands Zone
- Eden Management Area Zone
- The Alpine Ash Zone
- The Cypress Pine Zone
- The River Red Gum and Western Hardwoods Zone

The zones may be characterised, in turn, by their more or less distinctive forest types, that is, with different species combinations and inherent productivity. The forest types are fully described in the Appendix. And are as follows.

Coastal Regrowth Zone

- Rainforest
- Blackbutt
- Dry Hardwoods
- Moist Hardwoods
- Spotted Gum (Southern)
- Spotted Gum (Northern)

Mountain-Tablelands Zone

This zone contains the range of forest types within the Coastal Regrowth Zone plus:

- Messmate-Brown Barrel Type
- New England Blackbutt Type

The Eden Management Area Zone

- Silvertop Ash-Stringybark Type
- Messmate-Brown Barrel Type

The Alpine Ash Zone

- Alpine Ash Type

The Cypress Pine Zone

- Cypress Pine Type
- Cypress Pine-Hardwoods Type

The River Red Gum and Western Hardwoods Zone

- River Red Gum Type
- Black Box-Coolabah Type

3. IMPACTS OF FOREST PRACTICE PRIOR TO 1945

In order to fully appreciate the development of forest practice from 1945 to 2000, it is necessary to describe the impacts of exploitive logging and wildfire before some form of management was imposed, and the measures taken to regulate harvesting and silviculturally treat the forests.

3.1 HIGHGRADING AND WILDFIRE

Harvesting of native forests spread along the coast of NSW during the latter half of the 19th century, and was often preceded by the removal of red cedar and other valuable rainforest species. Logging of native forest was highly selective, that is, removing only large, straight and relatively defect-free boles ('highgrading' of the forest). This is understandable - there appeared to be vast forests and, apart from an 1890 government requirement that cutting be licensed, there was little or no regulation of forest operations.

Highly selective cutting was just one of the factors which degraded the original forests. Following settlement, forest fires increased in frequency and intensity, causing enormous damage to the forests, which greatly reduced the commercial potential of the growing stock. Greaves *et. al.*, (1965, 1967) show that the loss of revenue attributable to log defects, largely of fire origin and consequent termite infestation, could have exceeded actual log sales revenue by a factor of two.

When first brought under management early this century, the typical exploited forest had a number of components. The overstorey would have consisted of mature, overmature or senescent trees, many of which had fire damage at the butt, a central termite pipe, and outgrowths of callus tissue often associated with termites. In Mixed species forests a secondary stratum of tolerant species would have been largely in a stagnant condition. Patches of vigorous saplings or young pole trees might be present where regrowth had responded to logging and wildfire, with other, more restricted small stems developing slowly and often eventually being suppressed.

3.2 REGULATING THE HARVEST AND IMPROVING FOREST CONDITION

A Royal Commission into forestry in 1907 resulted in the first *Forestry Act in 1909*, and a second in 1916 created the Forestry Commission of NSW. In the early decades of forest management, regulation of harvesting sought to maintain wood supply to local industries from the then accessible and diminishing sawlog resource. This objective was often pursued simply by imposing a diameter limit in logging, that is, trees of commercial quality above a specified diameter were harvested, irrespective of continuing growth potential, and all trees below that limit were retained, again, irrespective of growth potential.

Because the early harvesting and sawmilling industries could accept only high quality boles, a silvicultural treatment designed to remove the 'overburden' of non-commercial trees, usually by ringbarking, and to conserve and release useful advance growth, was a vital component of early forest management. In its 1927 Annual Report the Commission stated that "the area worked through for regeneration during the last ten years has now embraced the greater part of the valuable and accessible forests which had been subjected to excessive exploitation during the preceding generation". Improvement treatment reached a climax during the Great Depression, with 69,000 ha treated in 1935/36, and 51,000 ha in 1938/39.

Despite their positive contributions to renewal of forest productivity, the combination of harvesting and ringbarking could not fully address the problem of 'substandard' growing stock. There remained a component of non-commercial old-growth trees, trees with marginal sawlog potential which were not ringbarked, and in some forests, a 'growth restricted' secondary stratum of shade tolerant species.

There were some exceptions to this situation, for example, where logging and ringbarking approached clearfelling in intensity, and a deliberate fire or wildfire helped regenerate near fully stocked, even-aged regrowth stands. There are many even-aged stands in NSW which developed in this way. Some were a response to logging and silvicultural treatment in the vicinity of logging tramways which had been constructed to harvest some of the better quality forest.

Even-aged stands could originate in other ways. For example, in Corunna State Forest (Narooma Management Area), dense stands of *Corymbia maculata* (Spotted Gum) regeneration had established following its abandonment as agricultural land in 1917. The regrowth was thinned in 1936/37 by unemployment relief labour. This work was extended to parts of Bodalla State Forest.

In summary, it can be said that by the time World War II intervened, good progress had been made in bringing substantially degraded forests under management. The war placed great pressures on the forest resources: many forests were heavily overcut, and management prescriptions virtually ignored. Thus many of the forests were not in a sufficiently productive condition to service the expanding timber demand associated with post-war development.

4. FOREST PRACTICE FOLLOWING WORLD WAR II - THE DYNAMIC DECADES BETWEEN 1950 AND 1970

The post-war years saw the consolidation of silvicultural and management practices which started before the war. Professionally trained foresters were appointed in larger numbers, fire-protection systems were imposed, forest inventories implemented, road construction and harvesting programs accelerated, growth and yield studies undertaken, and formal management plans prepared.

4.1 DEVELOPMENT OF SELECTION HARVESTING SYSTEMS

During the late 1950s and 1960s three States (Tasmania, Victoria and Western Australia) developed clearfelling systems (clearfelling with seed trees; and clearfelling, slash burning and direct seeding or planting). The clearfelling system was initially applied to the tall wet sclerophyll forests and, increasingly, to the more open dry sclerophyll forests. Alternatively, with the exception of early operations in the Eden region, neither NSW nor Queensland adopted clearfelling as a widescale practice. Rather, silvicultural practice within the more accessible forests brought under management before the war continued to be based primarily on selection logging systems.

There were two main reasons for this. The first relates to the complexity and diversity of species and community patterns in the subtropical forests, involving mixtures of tree species with different ecological attributes. Under these circumstances, clearfelling on any appreciable scale might not have been ecologically appropriate. The second reason relates to the sawlog supply strategy. Selection cutting was not designed to maximise wood production, rather it was applied in order to maintain supply to industry from a declining resource by conserving, at any one harvest, all stems likely to make sawlogs at future harvests. This was the imperative underpinning management of the greater part of the eucalypt forest in both NSW and Queensland.

Assessments of forests in the early 1950s demonstrated the deficiency of younger age classes which had resulted from inadequate natural regeneration over the previous 30 years. As the attributes of the more vigorous and often preferred species became better appreciated, it was recognised that canopy openings were needed to create vigorous regrowth. Thus in NSW, diameter-limit cutting began to be modified to the extent that specific regeneration openings were created within the stands (group selection). This happened in some forests as early as 1918. Group selection was subsequently applied with varying success (Florence, 1996). It was most effective where there was a single upper canopy of vigorous trees, no complicating stratum of more shade tolerant species, and good regeneration potential. This applied, for example, to purer stands of *E. pilularis* (Blackbutt) and *E. delegatensis* (Alpine Ash).

Group selection silviculture has been more problematic where applied to forests with more complex species mixtures, particularly where there was an upper canopy stratum of both shade intolerant and tolerant species, and a secondary stratum of tolerant species. In this case 'old' non-commercial stems of tolerant species might be retained in a canopy gap (e.g. trees 30 to 50 cm DBHOB), and throughout the stand. Group selection could also be ineffective where applied to wet sclerophyll forest without the more intense forms of site treatment needed to prepare an effective seedbed for regeneration.

In practice 'selection management' in NSW has been highly variable in terms of harvesting and treatment intensity, and application of regeneration treatments. This is discussed in the following Sections. Management diversity has contributed to the high level of growing stock and structural diversity in present day forests.

4.2 THE POST WAR WOOD SUPPLY CRISIS

Continuing harvest of accessible forests brought under management before the World War II could not service the rapidly growing demand for sawlogs as the economy expanded and the demand for timber increased after the war. In 1937/38, the total sawlog volume harvested in NSW amounted to 815,000 m^3. By 1946/47 this had risen to 1,350,000 m^3, and by 1952, to 1,800,000 m^3 net volume. There was increasing concern that the forests could not continue to satisfy this demand. The Forestry Commission publicly warned the Government in 1959 of an impending resource shortage, and again several times in the early 1960s, for example, in the 1964/65 Annual Report.

Concerns about the inadequacy of the public forest resource were mirrored by concerns about the decline in supply from private native forest. An estimate in the 1954/55 Annual Report suggests that, at the then rate of harvest, the private forest might be eliminated in approximately twenty years!

4.3 HARDWOOD FORESTS: HARVESTING STATISTICS 1950 TO 2000

Prior to the 1950s, sawmills obtained their supplies from allocated areas but the actual rate of cut was largely left to the discretion of the mill. This system was changed in 1954, with each being given an annual quota, usually based on the volume of timber cut over the previous three years (Baur, 1982).

The Forestry Commission subsequently adopted the 'quota sawlog system' as a basis for log sales. This was designed to generate sales of sawlogs below the quality standards then acceptable to industry. 'Quota logs' were the higher quality sawlogs attracting full stumpage. Ex-quota logs were either smaller or had higher levels of defect than quota logs; they attracted a lower price, and were an optional purchase.

A timber yield summary for native forests, 1950 to 2000 (Table 1), presents both the sawlog volume (combining quota and ex-quota log volumes), and the total volume harvested (combining volumes of sawlogs, poles, piles, girders, sleepers and mining timber). Yields of fencing, firewood and other minor products are not included but are summarised below.

Despite the Forestry Commission's concerns about wood supply in the 1960s, the wood volume harvested from the public native forests of NSW did not decline appreciably during the next 30 years (Table 1). Reasons for this are discussed later. Sawlog production rose from around 650,000 m^3 yr^{-1} during 1950/55 to a peak of 970,000 m^3 yr^{-1} during 1975/80. It remained at a high level (890,000 m^3 yr^{-1}) until 1990, but then declined to 547,000 m^3 yr^{-1} during 1995/2000, a consequence of the cessation of rainforest logging, withdrawal of old-growth logging, and the move towards sustained yield within the regrowth forests.

The total production follows a similar pattern, though there was a decline with time in the relative production of non-sawlog materials. For example, non-sawlog production constituted 22 per cent of total production from 1950 to 1965, and 9 per cent from 1985 to 2000.

Until the early 1980s, industry accepted mainly quota logs - with only a relatively small volume of ex-quota logs. This began to change as the supply of full size quota logs declined, and industry had to accept both smaller and more defective logs.

There are a number of products not included in Table 1. The annual harvest of 'fencings, transoms and junk' was generally in the range 18,000 to 33,000 m^3 yr^{-1}, and firewood 40,000 to 70,000 t yr^{1}.

Table 1. Average yield of sawlogs and 'all products' from eucalypt forests (m^3 net volume) for 5-year periods. All products include sawlogs, poles, piles, girders, mining timber, hewn timber and sleepers.

	Public Lands		Private Lands	
5-year period	**All products**	**Sawlogs**	**All products**	**Sawlogs**
1950/51 to 1954/55	781,600	653,600	770,000	664,600
1955/56 to 1959/60	976,200	725,800	883,400	591,400
1960/61 to 1964/65	1,043,700	828,800	828,000	560,800
1965/66 to 1969/70	1,074,000	881,800	810,000	592,200
1970/71 to 1974/75	1,139,300	947,900	690,400	543,300
1974/75 to 1979/80	1,155,600	971,500	604,200	460,300
1980/81 to 1984/85	1,079,000	890,000	519,900	391,200
1985/86 to 1989/90	1,030,200	890,300	464,800	357,300
1990/91 to 1994/95	852,700	788,500	307,900	274,100
1995/96 to 1999/2000	555,200	547,800	190,200	188,900

The latter statistic seems surprisingly low, and suggests that the firewood harvest has not been fully reported.

The pattern in private property wood supply is also given in Table 1. Between 1950 and 1955 wood production on private property was similar to that on public lands. Private property production declined thereafter and, from the 1980-85 period, was less than half that on private lands. However, it is recognised that there may have been considerable under-reporting of private log sales, and, partly because of this, private property information was not included in the Forestry Commission Annual Reports from 1998/99.

4.4 SUSTAINING WOOD SUPPLY AND BUILDING THE RESOURCE BASE

There are quite a few reasons why the wood harvest from public lands remained more or less stable from 1960 through to 1990. These are addressed below.

One immediate reason for continuing sawlog harvest from reputedly 'cutout' forest was an increasing willingness by industry to accept sawlogs of lower quality or of less preferred species. Technological developments in both harvesting (chainsaws, more powerful tractors and diesel trucks) and sawmilling (amalgamation of small mills into more efficient units) meant that smaller and more defective sawlogs could be economically harvested. Industry also appreciated there was a declining resource base and the need to adjust to it.

There was also by the 1950s an increasing sawlog component derived from regrowth which had resulted from logging and fire in the late 1800s and early 1900s, and whose growth had been stimulated by ringbarking treatment. Thus it was possible in previously 'cutout' forests to progressively harvest both remnants of the original forest and regrowth trees developing in association with them.

Access to additional wood resources came through the incorporation of previously unharvested (and often marginal) Crown lands into State forests, an increase in logging of leasehold lands (especially the western Cypress Pine lands), the full utilisation of wood from State forest scheduled for plantation establishment (until this practice ceased in the late 1970s), and most critically, the logging of the mountain forests from the late 1950s.

The post-war access to new harvesting technologies permitted the extension of logging to the steep and rough terrain of the escarpment and mountain forests (referred to in some areas as 'foothill forests') along the eastern seaboard. Some logging had taken place at the edges of these forests but they were, for the most part, virgin old-growth forests – though variably disturbed and damaged by wildfire. In its 1956/57 Annual Report the Forestry Commission projected:

> *the development or extension of roading into those State Forests, at present inaccessible, where the quantity and quality of timber available will assist in maintaining, and where possible, increasing supplies, therefore affording relief to the more accessible and heavily cut forests.*

The roading required to tap the mountain forests was a very considerable undertaking for a forest service with limited financial resources. New road construction of all classes was around 700 km yr^{-1} for many years, consuming in 1963/64, for example, 27 per cent of all Forestry Commission expenditure (Forests Commission NSW Annual Report, 1963/64). Most coastal forestry districts were involved in these programs.

The mountain forests were not necessarily seen as part of the permanent managed estate, rather they were harvested to maintain supply to the market until both the planted softwood and the 'coastal regrowth' forests were able to meet most of the State's timber needs. Logging the old-growth mountain forests was to underpin wood production in NSW for nearly three decades. This strategy was given formal expression in the Indigenous Forest Policy of 1976 (see Section 5).

4.5 THE RESPONSE TO LOW PRODUCTIVITY WITHIN THE COASTAL FORESTS

By the 1960s, forest inventories and growth and yield studies in the coastal forests were demonstrating that after several decades of logging and silvicultural treatment, the growth rates of many forests remained low. These ranged from around 2.5 $m^3\ ha^{-1} yr^{-1}$ for the most productive of the uneven-aged *E. pilularis* forests (Table 2), to 0.4 $m^3\ ha^{-1}\ yr^{-1}$ for forests composed largely of the more tolerant species (Dry Hardwoods Type). These might be contrasted with average yields of 10 to 15 $m^3\ ha^{-1} yr^{-1}$, or more, from fully stocked, even-aged *E. pilularis* and *E. grandis* (Flooded Gum) stands.

The limited market at the time for all but the conventional products of the forests, that is, large diameter quota sawlogs, poles, piles and girders, contributed substantially to the problem. Other reasons for the low yields include the ecological

Table 2. Yields of merchantable sawlog from uneven-aged eucalypt forests ($m^3\ ha^{-1}\ yr^{-1}$) in the coastal region of New South Wales (Data from Curtin, 1970).

State Forest	Major forest type	Average net yield from 1920	Calculated sustained gross yield, 1969
Coopernook	Blackbutt	2.4	2.7
Kendall	Blackbutt	0.8	1.6
Lansdowne	Blackbutt	0.9	1.0
Wyong	various	0.5	0.9
Kiwarrak	Mixed hardwood[A]	0.4	0.6
Yarrat	Mixed hardwood[A]	0.2	0.4

[A] *E. acmenoides, E. propinqua, E. siderophloia, E. microcorys* and others diversity of the forests, variable and often low levels of effective growing stock, inadequate regeneration, the continuing stocking of trees of marginal sawlog quality (which were neither harvested nor ringbarked), and a continuing stocking of defective or smaller growth-restricted trees. During the 1960s the percentage volume of growing stock with no potential market ranged from 13 to 45 per cent of total volume on six representative forests (Curtin, 1970). It was clear that a more intensive approach to stand improvement was needed.

Silvicultural Treatment During the 1950s and 60s

During the early 1950s, the greater part of the treatment program had involved 'Timber Stand Improvement' (TSI), that is, the conventional ringbarking treatment aimed at rehabilitating cut-over old-growth forests in order to bring them to a condition allowing the application of a standard silvicultural system. Ringbarking treatment was not specifically designed to produce regeneration, though, of course, some did develop where other circumstances were appropriate, and particularly where a post-harvest burn was carried out.

By the mid-1950s, the Forestry Commission was pursuing two main objectives in its silvicultural treatment programs - to further resolve the problem of substandard growing stock, and to ensure more effective regeneration through wider use of regeneration burns, direct seeding and planting.

The Problem of Substandard Growing Stock in the Coastal Forests

The improvement in utilisation standards was important but had by no means resolved the problem of substandard growing stock. There still remained trees of sawlog size which were judged to have marginal sawlog potential, and the accumulation of smaller diameter trees in a stagnant condition - mostly of the light-tolerant species.

In the late 1950s, NSW introduced a 'reject tree felling allowance', that is, an allowance paid for felling any tree of sawlog size in which defect might be at an unacceptable level. Once felled, a decision could be made to utilise the bole or leave it on the forest floor. This practice was applied over large areas, for example, 25,000 ha in 1961/62 (Forest Commission NSW Annual Report for 1961/62). It brought an increase in the yield of marketable timber, and greatly facilitated silvicultural treatment of cutover stands.

The combination of conventional harvesting and felling trees of marginal bole quality could sometimes open up the canopy to a greater extent than envisaged under the group selection system. Thus, in some *E. pilularis* forests there might now be a general matrix of, say, 1960s regeneration within which there would be a scattered distribution of groups of older regrowth trees resulting from a number of previous selection harvests.

There still remained in some situations the problem of the smaller growth-restricted trees. For example, an analysis of growing stock on Pine Creek State Forest in 1985 showed that only 40 per cent of trees greater than 20 cm DBHOB had good boles and crowns (Florence 1996, p.247). Most of the remaining 60 per cent were suppressed regrowth trees of tolerant species, and trees with boles and crowns restricted by strong competition. At one end of the growth spectrum the mean diameter increment of the best *E. pilularis* category was 1.1 cm yr^{-1}. The other, the weakest tolerant species category was averaging only around 0.2 cm yr^{-1}. Similar increment patterns have been shown for *C. maculata* within uneven-aged stands on Bodalla State Forest (Keady, 1978, Florence, 1996, p. 249).

It was not possible to deal with the accumulation of small-diameter slow-growing trees until there was a market for them, and this did not generally happen until the 1980s.

Regeneration Treatments Within the Coastal Forests

Throughout the 1950s it was becoming increasingly apparent that regeneration of commercially desirable species was inadequate on wet sclerophyll sites throughout most of the coastal forests, despite application of the group selection silvicultural system and follow-up ringbarking treatment. Some form of site treatment was needed to remove competing species and to create a receptive seedbed. Hence, regeneration establishment became a recognised component of silvicultural treatment.

In 1957/58, the Forestry Commission began to differentiate 'TSI' and 'Regeneration establishment' in reporting on the silvicultural treatment of native forests. 'Regeneration establishment' was used to describe work aimed at the establishment of a new crop where natural regeneration was unlikely to occur. It was specified in management plans and had several components:

1. Establishing a certain area of regeneration where forest had been logged on a selection basis (usually by post-harvest burning);
2. Regenerating understocked but high growth potential wet sclerophyll forest sites by clearfelling, burning of debris and broadcast or spot seeding with species having fast growth rates; and
3. Planting out tube stock at wide spacings in gaps in natural forest or along extended snig tracks (this practice was known as 'enrichment planting' 'partial planting', and 'snig track extension').

Direct seeding began in the mid-1950s, and was applied following clearfelling of wet sclerophyll gully vegetation, burning of the slash and direct seeding (mainly with *E. grandis*). While some excellent results were achieved, it was difficult to regulate regrowth stocking effectively. By 1963/64 there were concerns about the future timber quality of direct seeded *E. grandis*, and the program was suspended. Excessive stocking on poorer sites may have played a role in this.

Enrichment planting was being undertaken in the mid-1950s on a small scale in order to introduce desirable species into forests where these species did not occur naturally, or did not regenerate naturally after heavy and selective logging. Although planting stock tube was expensive, it was often favoured over burning. While burning in small patches can create an effective seedbed, the prolific development of fire-successional species under summer rainfall conditions can suppress the development of eucalypt regrowth.

The development by 1965 of the relatively inexpensive 'jiffy pot' technique for planting eucalypt seedlings saw an expansion of both enrichment planting and clearfelling and planting programs. Planting was recognised as a much more reliable way of restocking wet sclerophyll forest than was seeding. Thus quite a few Districts developed small jiffy pot nurseries, and planting became a regular part of the silvicultural treatment program.

Another regeneration technique used was based on pre-harvest site preparation. This involved tractor clearing of old-growth forest understorey and exposure of mineral soil. Regrowth developed, often prolifically, following the overwood harvest. The process was discontinued because the large accumulation of debris would affect the efficiency of later thinning.

4.6 A STATE SUMMARY OF SILVICULTURAL TREATMENT IN THE COASTAL FORESTS: 1950 TO 1995

A State summary of silvicultural treatment work between 1950 and 1995 is presented in Table 3, based on the area planted per year, the area of enrichment planting, the area within which regeneration treatments were carried out, and the area subject to Timber Stand Improvement (TSI). This data is drawn from Annual Reports of the Forestry Commission.

TSI was the primary treatment during the 1950s (an average of about 12,000 ha yr^{-1}). There was no extensive planting recorded at this time, and only a minor amount of enrichment planting. Regeneration establishment operations (including site preparation and direct seeding) commenced in the mid-1950s (3,300 ha yr^{-1}). The area covered by TSI treatment

Table 3. Silvicultural treatment of eucalypt forests, 1950 to 1995. Mean area (ha) treated for each 5-year period.

5-year period	Hardwood planting	Enrichment planting	Regeneration establishment	TSI
1950 to 1955	–	–	–	9,800[C]
1955 to 1960	–	50[A]	3,350[A]	13,560[C]
1960 to 1965	–	50	3,330	11,320
1965 to 1970	250	400	1,670	10,070
1970 to 1975	1,600	850	1,050	7,710
1975 to 1980	780	1,480	170	6,080
1980 to 1985	390	910	60	3,960
1985 to 1990	155	490	110	610
1990 to 1995	100[B]	70	2,260	–

[A]Data from 1956/57 [B]Records available only until 1991/92 [C]Includes Cypress Pine treatment until 1960/61.

was more or less similar throughout the 1960s (11,000 ha yr^{-1}) but regeneration establishment fell away during the second half of the decade (from around 3,300 to 1,670 ha yr^{-1}). This may have been related to the priority given to jiffy pot planting. The area accorded TSI treatment declined appreciably from the 1970s, as did regeneration establishment.

Planting was first recorded as a formal silvicultural treatment in 1967/68, though on a relatively small scale (250 ha yr^{-1} during the next three years). There was also an increase in the area subject to enrichment planting in the second half of the 1960s (400 ha yr^{-1}). Planting and enrichment planting increased substantially during the 1970s (average of 2,350 ha yr^{-1}). However, all silvicultural treatments, including planting and enrichment planting, declined through the 1980s and 90s. The reasons for this are explained in Sections 5 - 7.

Regeneration establishment, enrichment planting and planting reaches a peak of about 3,400 ha yr^{-1} between 1955 and 1965. When compared with the 25,000 ha subject to the reject felling allowance at this time, it becomes clear that the bulk of the forest received no regeneration treatment at all. Reliance was placed on natural regeneration, which was only partly effective and created a continuing need for forest restoration through much of the coastal zone.

4.7 A TREND TOWARDS HEAVIER HARVESTING AND CLEARFELLING WITHIN THE COASTAL FORESTS

Given increasing awareness of stand regeneration problems, foresters were understandably attracted to harvesting practices which facilitated the establishment and management of regeneration. Thus during the late 1950s and the 1960s there was a trend towards heavier logging within the coastal forests.

This trend may not have been formally sanctioned, rather it reflected growing frustration with low productivity levels under selection management, and difficulties in enhancing that productivity. Sometimes it involved clearfelling with seed trees (e.g. within previously unharvested or highgraded parts of coastal forests), and clearfelling and planting on a compartment-wide scale, even where the forest had been subject in the past to conventional silvicultural treatment.

The near clearfelling of *C. maculata* forest on Kioloa State Forest is a good example of this trend (Florence, 1996 p. 253). As a consequence of highly selective logging in the late 1800s, the forest contained, by the late 1960s, residual old-growth trees, some mature regrowth of good quality, and a large number of persistent but growth-restricted *C. maculata* merging with the upper canopy. The local forester elected to apply a selection system – one based on the retention of only those trees meeting defined bole and crown quality standards. The effect was to essentially clearfell the forest.

4.8 HARDWOOD PULPWOOD PRODUCTION

Small quantities of pulpwood were being produced in NSW in the early 1950s. The quantities increased considerably with the establishment of a masonite industry at Raymond Terrace near Newcastle. It was not until the introduction of the sawlog-export woodchip program in the Eden region in 1969/70 that hardwood pulpwood became a major product of the State's forests. The export of hardwood chips was extended to other southern and north coast forests in the early 1980s.

Reasons for Initiating the Eden Area Sawlog-woodchip Export Program

In 1967, the NSW Government signed an agreement with an Australian/Japanese company to supply wood pulp from Crown forests in the far southeast of the state, an area covering some 250,000 ha. Serviced by the port at Eden, these were largely dry sclerophyll forests of relatively low productivity. There were two main reasons for initiating this program. An export market for the low quality products of the forest helped make it economic to harvest the relatively small sawlog component – a useful contribution to State wood supply at a time of impending deficit. Secondly, foresters saw the operation as an opportunity to convert low quality or fire-degraded forest to a more productive state by harvesting, in the one operation, both the sawlog and non-sawlog components of the forest. The harvesting of the forests began in 1969, and the first woodchips were exported in 1971.

The early integrated logging was based on clearfelling, the only major program of this type in NSW. There was at this time no limit on coupe size, and no post-harvest burning of logging debris, or use of any other deliberate form of site preparation. However, adequate regeneration did establish through most of the area. This included new seedlings developing on soil disturbed by harvesting machines, lignotuberous and other advance growth, and coppice developing on cut stumps. Environmental standards were not prescribed in the early years, a factor which was to generate considerable opposition to the program and, eventually lead to changes in forest practice.

Sawlog/pulpwood Production in the Eden Management Area: 1969 to 2000

Sawlog and pulpwood yields from the Eden Management Area, for the three decades, 1970 to 2000 are presented in Table 4. There was, beyond the start-up period, a consistent production (and export) of pulpwood from Crown land between 1975 and 1995 of 500,000 to 600,000 t yr^{-1}. The subsequent decline (1995 to 2000) is associated with the withdrawal of forest from wood production and its transfer to National Park. There was a progressive decline in the sawlog harvest after 1980.

Pulpwood Production Outside the Eden Management Area

The production of pulpwood and timber for masonite manufacture is recorded in the Forestry Commission Annual Reports from 1950/51. They were itemised separately for a number of years, but later given as a single figure. They are presented as a single entity here. From 1950 to 1975 most of the pulpwood was drawn from the Metropolitan, Newcastle and Taree Districts to supply the masonite industry at Raymond Terrace. Annual extraction was around 10,000 t in the early 1950s, rising to 45,000 t in the 1960s, and 75,000 t between 1970 and 1975.

Table 4. Sawlog and pulpwood (woodchip) production per year from public lands within the Eden Management Area – from 1969/70 when woodchip export began. Note that sawlog volumes are also incorporated in the State sawlog summary (Table 1).

Years	Sawlog production (m^3) net volume	Pulpwood (t) from public land
1969/70 to 1974/75	87,400	205,400
1975/76 to 1979/80	89,400	506,600
1980/81 to 1984/85	80,500	584,300
1985/86 to 1989/90	62,700	551,906
1990/91 to 1994/95	43,100	552,700
1995/96 to 1999/00	33,500	375,000

Until 1982, production and export of woodchip had been limited to the Eden Management Area. During 1982/83 the Government approved the sale of sawmill wastes and logging residues from other Management Areas for the production of pulpwood chips. Operations were initiated in Bulahdelah and Chichester Management Areas based on thinnings from eucalypt plantations, the residual 'heads and butts' from sawlog operations, and salvage of material from areas scheduled for silvicultural treatment.

Harvesting of silvicultural residues such as non-commercial timber and defective trees was extended to the Wyong Management Area within the Newcastle region in 1984/85. Sale of residues also began in the Batemans Bay and Murray Management areas. These operations can create large savings by removing the need for non-commercial silvicultural treatment. However a sale ceiling (by market or regulation or both) can limit the usefulness of this as a silvicultural tool. The export woodchip operation extended to the Coffs Harbour region in 1989/90.

An average of 113,000 t of pulpwood was harvested per year between 1984 and 1990; this increased to 156,000 t between 1990 and 1994, and 167,000 t in 1996/97. This reflects the increasing management intensity within the regrowth forests, particularly the potential to commercially thin young stands.

In addition to the coastal forests, there was a pulpwood harvest in the Glen Innes district between 1987/88 and 1991/92, and from the 'Western region' in 1992/93 and 1993/94. This averaged 12,000 t yr^{-1}, with a peak of 25,000 t in 1992/93.

4.9 HARVESTING RAINFOREST

There are 266,000 ha of rainforest in NSW which, soon after World War II, were supplying more than 10 per cent of NSW sawlog production. By 1985-86 the rainforests were supplying only 0.4 per cent of the State's sawlogs.

Research into the silviculture of natural rainforest stands (commenced during the 1940s and intensified during the 1950s) showed that most of the commercial rainforest types in NSW were quite amenable to sustained management for timber (Baur, 1991). 'General purpose' harvesting of the Subtropical Rainforest was selective, removing around one third of the basal area (or 50 per cent of the canopy). In this case, a period of 30 to 60 years was needed to reconstitute the overstorey. Logging within the Warm Temperate Rainforest tended to be much heavier, removing virtually all merchantable stems and creating a dense 'thicket' of regeneration. Heavy logging was imposed because there is generally dieback of many of the residual trees when the canopy is opened up.

The wood volume yield from rainforest in public land from 1950 to 1992 is given in Table 5. There was an increase in extraction from 118,000 m^3 yr^{-1} during 1950-55 to a peak of 121,900 m^3 yr^{-1} during 1966-1970. There was an all time high of 141,000 m^3 removed in 1947/48. The rate of rainforest logging was substantially reduced in 1982 when the Government began to phase out rainforest logging on the public land. Rainforest logging ceased entirely in 1992/93.

The yield from privately owned rainforest was always much smaller than that from public land (Table 5). It declined progressively over the four decades from the early 1950s (23,900 m^3 yr^{-1}) to about 2,000 m^3 yr^{-1} during the late 1980s.

4.10 HARVESTING AND TREATING THE CYPRESS PINE FORESTS

Cypress Pine (*Callitris glaucophylla*) is widely distributed west of the 700 mm isohyet in NSW and Queensland.

In 1987 *C. glaucophylla* forest in NSW was estimated to cover 1,819,000 ha (Forest Resources Committee of the Australian Forestry Council, 1987). There were 398,000 ha on public land managed for multiple use including wood production (State forests); 731,000 ha of Crown land or land occupied under lease on which wood harvesting could be carried out under government control; 58,000 ha on land where wood production was excluded (e.g. National Park); and 632,000 ha on private property.

In the early 1950s it became possible for the first time to see the *C. glaucophylla* forests as a sustainable resource, rather than one progressively liquidated by harvesting. Thus it is appropriate to present, as part of the 'dynamic decades', a brief account of the revitalised management of these forests.

Before 1950, the *C. glaucophylla* forest contained remnant old-growth cypress and hardwood trees and regrowth cypress which had originated as a massive wave of regeneration throughout the eucalypt-cypress forests and woodlands around 1880.

There was, however, no further *C. glaucophylla* regeneration because of the rabbit plague that spread through the country. The Forestry Commission continued to harvest the 'old pine' and later, to commercially thin the 1880s regrowth with the expectation that milling was a prolonged

Table 5. Volumes (m^3) of rainforest species and conifer veneer (Hoop Pine) harvested annually from public and private land, 1950 to 1992/93.

5-year period	Public land Rainforest	Hoop Pine veneer	Private land Rainforest
1950/51 to 1954/55	87,000		24,000
1955/56 to 1959/60	112,000		22,000
1960/61 to 1964/65	118,400		18,000
1965/66 to 1969/70	122,000		14,000
1970/71 to 1974/75	112,000		11,000
1975/76 to 1979/80	84,000		6,000
1980/81 to 1984/85	31,000	15,000[A]	4,000
1985/86 to 1989/90	3,000	14,000[B]	2,000
1990/91 to 1992/93	2,000		1,000

[A]Average for 3 years. [B]Average for 4 years 'controlled liquidation'. Unlike eucalypts, *C. glaucophylla* can survive in dense stands for long periods while making negligible growth, and then respond well to release. In this way the regrowth resource could contribute to sawlog supply over very many decades.

A new wave of regeneration did eventually develop following rabbit control by the myxomatosis virus around 1950, so that sustainable management of the forests became possible. Silvicultural treatment of the forests began in the late 1950s, encouraging regeneration of *C. glaucophylla* by harvesting mature trees and ringbarking competing hardwoods. In several districts, rotary hoeing was used to thin exceptionally dense regeneration to prevent stand stagnation over extensive areas.

A summary of sawlog production in both public and private forests, and silvicultural treatment of public forests is given in Table 6. There has been a fairly consistent harvest of *C. glaucophylla* on public lands during the past 50 years - a volume production in the range 90,000 to 110,000 $m^3 yr^{-1}$. Reduced harvests during the years 1956 to 1959, and 1985 to 1987, both recession periods, account for the lower yields in their respective five-year periods.

The harvest of *C. glaucophylla* from private property has not been so consistent. It was considerably greater than that on public lands during the 1950s, but declined rapidly and progressively thereafter – from a peak of 156,000 $m^3 yr^{-1}$ during 1955/60 to only 9,000 $m^3 yr^{-1}$ during 1990/95. This decline in yield from private lands mirrors that from privately owned eucalypt forests.

The silvicultural treatment of *C. glaucophylla* forests (including spacing of the wheatfield regeneration) was first recorded as a separate entity in the Annual Report for 1960/61. It reached a peak at 13,800 ha yr^{-1} during 1965/70 (Table 6), declining thereafter to 2,200 ha yr^{-1} during 1985/90. No silvicultural treatment is recorded beyond 1990/91.

Table 6. Log harvest ($m^3 yr^{-1}$) and silvicultural improvement treatment (ha) within the NSW Cypress Pine forests, 1950 to 2000.

	Log volume harvested		Improvement treatment
5-year periods	**Public land**	**Private land**	**Public land only**
1950/51 to 1954/55	91,700	128,200	(A)
1955/56 to 1959/60	77,600	156,360	(A)
1960/61 to 1964/65	103,000	110,000	9,000
1965/66 to 1969/70	103,400	70,400	13,800
1970/71 to 1974/75	112,600	34,800	8,400
1975/76 to 1979/80	97,100	27,000	6,200
1980/81 to 1984/85	90,500	20,200	3,400
1985/86 to 1989/90	85,300	15,800	2,200
1990/91 to 1994/95	94,100	9,100	1,500
1995/96 to 1999/00	99,800	10,400	–

[A] Silvicultural treatment records within eucalypt and cypress pine forests were not differentiated until 1960/61.

5. REVIEWING FOREST STRATEGIES: THE INDIGENOUS FOREST POLICY OF 1976

5.1 BACKGROUND TO THE POLICY

By the late 1960s, some foresters were questioning the trend towards heavier forest cutting, the proliferation of jiffy pot nurseries and eucalypt planting, and the felling and planting of previously treated forest. Resource inventories and projections of wood supply and demand were highlighting a critical shortage of sawlogs until the yield from the softwood plantations would increase appreciably towards the end of the century. It was argued that NSW could not afford to waste the potential future volume of sawlogs where forest was clearfelled, particularly where it had been silviculturally treated in the past. Further, site preparation or planting was expensive, and could be justified only where there was a market for a full range of harvested trees, including thinnings. It was argued that long-term wood production targets would be better met by according financial priority to the softwood program.

Legislation in 1972 confirmed the Forestry Commission's timber production role, but required, for the first time, that greater emphasis be placed on the conservation of wildlife, promotion of the recreational use of the forests, and protection of the environment generally.

Against this background, it was essential that the Forestry Commission prepare a statement of policy and practice which would:

1. Establish the priorities accorded to wood production;
2. Rationalise the silvicultural and other management practices which had been evolving within the State; and
3. Provide a framework within which the management planning for individual regions might proceed.

The Indigenous Forest Policy of 1976 was designed to serve this role. The Policy continued to guide forest practice until 1992 when it was withdrawn in response to changes in community perceptions of forest practice, and advances in concepts of multiple-use forest management.

Under the Policy, wood supply was based on the designation of seven zones with different priorities and practices. Within two of these zones, logging was based on a 'one-off' harvest of all available commercial trees (the 'Mountain' and 'Tablelands' zones). Silvicultural practice in another three zones focused on conserving the more productive component of the existing growing stock in order to maintain supply for the next 30 years (accessible coastal forests, Cypress Pine forests and River Red Gum forests). The Policy phased out general purpose logging in rainforests but accepted continued selection harvesting of specialty timbers. It limited eucalypt planting to specified areas.

5.2 FOREST ZONES WHERE HARVESTING OF ALL COMMERCIAL TREES WOULD APPLY

Mountain Zone Forests

The Indigenous Forest Policy concluded that at rates of log supply which were economic, logging of old-growth mountain forests on a sustained yield basis was unrealistic. Because of the strong pressures to maintain sawlog supply, the nature of the growing stock, the difficulties and costs of log extraction, and limited financial resources, the forests were to be "logged to the limit of economic accessibility", that is, all trees of commercial size and quality were to be harvested. In many areas of the State, most of the immediate wood commitment to industry was to come from these forests.

The Mountain Zone forests were not considered a 'multiple-use resource'. They fell within that category where "there is a clear practical and economic case (for wood production) to seriously preempt other forest uses" (Indigenous Forest Policy, 1976). Moreover, little or no post-harvest treatment was to be applied to them. Natural regeneration was relied upon or, where this was in doubt, a burn could be used to assist regeneration. However, the outstanding emphasis was on maximising wood supply with minimum financial input. Indeed, where attainment of a forest cover after logging would require additional investment, some existing trees might be retained as an alternative.

Tableland Zone Forests

With the exception of the *E. delegatensis* forests in the Bago-Maragle Management Area, and some *E. fastigata* (Brown Barrel) and *E. nitens* (Shining Gum) communities, the Southern Tablelands forests were not considered to have good investment potential for continuing hardwood timber production.

Within the Northern Tablelands, some tree species were not favoured as sawlogs until fairly recently, and natural stands carried a high percentage of stems too defective for sawlogs. The Indigenous Forest Policy stipulated that where softwood planting was planned on cleared native forest sites, the aim should be to harvest hardwood sawlogs and other products at a rate consistent with the plantation program. Where softwood planting was not planned, the existing crop was to be logged to the limit of economic accessibility at a rate which could be sustained under extensive management, but and there was to be no investment in silvicultural treatment.

5.3 FOREST ZONES WHERE CONSERVATION AND STIMULATION OF EXISTING GROWING STOCK WOULD APPLY

Coastal Regrowth Zone Forests

As it relates to the coastal forests, the Indigenous Forest Policy placed principles of 'sustained yield' and 'multiple use' firmly in the public arena. Nevertheless, it was clear that short-term wood production had priority. The coastal forests had the primary role of maintaining wood supply for the next 30 years or so (that is, until beyond 2000). In order to achieve this, conservation and stimulation of existing growing stock would take precedence over regeneration operations designed to improve wood production for the longer term. This was based on the premise that there was already sufficient regrowth, not only to replace the existing crop, but also to make the forest more vigorous and productive in the future.

Silvicultural guidelines called for:

1. The retention of all healthy stems of merchantable or near merchantable size for further increment;
2. Treatment to release or promote increment on stems capable of making sawlogs in the next 30 years;
3. Some, but minimal regeneration treatments, and only where exacting location, topographic and economic criteria were met; and
4. Silvicultural practice to ensure perpetuation of existing forest types and species.

The importance of the coastal forests for recreation and wildlife conservation was stressed in the Policy. However, it was generally anticipated that requirements for maintaining or developing non-timber uses and values would be largely met through a system of management which would make use of natural silvicultural processes aimed at maintaining a forest comprising a diversity of natural species and age classes with a future production capacity as well as potential in other roles (Indigenous Forest Policy 1976).

Cypress Pine Zone Forests

The role of the Cypress Pine forests was to be similar to that of the coastal forests in maintaining sawlog supply for the next 30 years. This was to be achieved by maximising merchantable increment over this period. Quite apart from the expected state-wide shortage of sawlogs, this period would be critical in bridging the gap between the late 19th century growing stock and the post-1950 regrowth. This objective was to be achieved by:

1. Thinning stands capable of acceptable increment to a residual basal area of about 10 m^2 ha^{-1} (or as lightly as economically feasible), and logging overmature stands as frequently as practicable to minimise loss of sawlog volume; and
2. Silvicultural treatment (non-merchantable thinning and removal of competing hardwood) aimed at increasing increment in stands which would provide merchantable volume over the next 30 years.

River Red Gum Zone Forests

The management of *E. camaldulensis* forest was to continue on a multiple use basis, taking account of flood buffer areas, conservation of wildlife habitat, fish feeding and breeding grounds, and recreation. Although yields might diminish as river regulation reduced growth rates, commitments to industry would continue to be met through selection logging. Any drop in demand was to be used to reduce yields to a level which could be sustained indefinitely.

5.4 HARDWOOD PLANTATIONS

As part of the restrictions on regeneration treatment, the Indigenous Forest Policy confined eucalypt planting to projects designed specifically for the production of smallwood, such as mining timber and pulpwood. These plantations were generally located on land with little potentially useful growing stock. These programs were mainly in the Coffs Harbour and Newcastle Districts on previously cutout moist hardwood and rainforest sites. The Policy projected, for both major programs, the planting of 15,000 ha of forest land located on good terrain within an acceptable haulage range of a processing centre, and providing a yield of some 200,000 m^3 or more per annum.

It was recognised that both programs would involve clearfelling of forests, some of which, despite low current productivity, would have significant environmental values.

5.5 THE RAINFOREST STRATEGY

The Indigenous Forest Policy required the phasing out of general purpose timber harvesting in most rainforest areas (Section 4.9). Harvesting was now to be based on selective felling for specialty logs only in order to maintain canopy and rainforest structure. However, where intensive felling could be carried out without destroying the ecological viability of the rainforest, this might be continued to meet current market commitments.

Where market commitments or the nature of the forest type forced a continuation of intensive felling in rainforests (notably the Warm Temperate Rainforest), rehabilitation was to be carried out by planting openings at a stocking rate sufficient to provide an acceptable tree cover. In types which originally carried *Araucaria cunninghamii* (Hoop Pine), this species could be used, otherwise eucalypts suitable to the site were to be planted.

6. FOREST PRACTICE THROUGH THE 1970S AND 1980S: PROGRESSIVE TRANSITION TO REGROWTH FORESTS

Demand for wood from native forests remained strong during the 1970s and 80s. On a number of occasions the Forestry Commission affirmed its legislative commitment to meeting the demand, as far as possible, from State resources. At the same time the Commission enunciated a policy of gradual transfer of general purpose timber production from native forests to softwood plantations, and a commitment to bringing supply and demand into balance in the forest, *wherever this could be effected without undue social and industrial disruption*. The Commission recognised that environmental activities in the early 1980s, including, for example, denying access to overseas resources such as veneer logs from Indonesia, would place enormous demands on State plantations and native forests to supply equivalent materials (Forest Commission NSW Annual Report, 1980/81).

The Indigenous Forest Policy continued to underpin forest management through the 1980s together with progressive adjustments to sawlog removals to achieve sustainable (implies long term) levels. Much management effort was also being directed towards the inevitable shift of wood supply from old-growth to regrowth forests. This involved regrowth assessments in many forest districts.

6.1 THE WOOD SUPPLY STRATEGY

During much of the 1970s and 1980s harvesting focused on the escarpment and mountain forests, permitting a build up in tree sizes and log volumes within the coastal forests. The relative production roles of the mountain and coastal forests differed from region to region. For example, the Forestry Commission was able to state in its 1984/85 Annual Report that the Coffs Harbour Management Area would be one of the first in the State to phase out reliance on harvest of mature natural forest, and to base management wholly on harvest of regrowth forest derived from past logging and silvicultural treatment. The old-growth resources of the 'upriver' Bellinger forests were nearly exhausted by 1985. A reduced sawlog commitment to industry now relied on coastal forests, including Pine Creek State Forest within the Urunga Management Area.

Elsewhere, the mountain forests were scheduled to sustain supply to industry well into the 21st century. For example, old-growth logging within the Kempsey-Wauchope Management Areas was scheduled to continue until 2020. The Environmental Impact Statement for this Area (Truyard Pty Ltd, 1993) scheduled the harvest of 17,620 ha of old-growth forest at an average rate of 1,175 ha yr^{-1} until the end of 2008, and 6,425 ha at an average rate of about 515 ha yr^{-1} from 2008 to the end of the cutting cycle in 2020.

6.2 MANAGEMENT PRACTICE WITHIN THE COASTAL FORESTS

Harvesting Prescriptions, Markets and Products

The 1970s and 80s saw a continuing transition in harvesting from old-growth to utilisation of uneven-aged regrowth forests. New products and markets meant it was possible to commercially thin regrowth at different growth stages, thus utilising more of the non-sawlog component of the forest.

A wider and more flexible market for a range of forest products was an important factor contributing to the development of more vigorous and productive coastal regrowth forests through the 1980s. It was possible to sell a great diversity of forest products, including pulpwood, mining timber, small sawlogs, both durable and non-durable poles, girders and, in some regions, veneer logs. Use of eucalypts for veneer and plywood production was possible after the (1982) withdrawal of rainforest logging, and research had resolved many of the problems of eucalypt gluing technology. Moreover, it was now possible to 'clean up' much of the accumulation of low quality trees, particularly of the shade tolerant species. This helped service a demand for dense and durable wood, for example, for small poles, pallets and fencing.

Silvicultural practice differed appreciably from that in the 1960s. Consistent with the Indigenous Forest Policy, tree-marking could now focus on 'quality stem retention' through a range of size classes, rather than simply harvesting conventional sawlogs and associated durable poles and piles.

In well stocked uneven-aged regrowth stands with low defect levels, the quality stem retention prescription might be simplified by seeing it primarily as a 'thinning' from below within patches of regrowth constituting different size classes. The tree marker could retain 50-120 stems ha^{-1} in the pole to sawlog range by "freeing up codominants in fully stocked even-aged or irregular stands resulting from past management" (Curtin *et. al.*, 1991).

Regeneration was not necessarily sought in these circumstances, rather, in vigorous stands, small canopy openings would quickly close through expansion of the crowns of trees adjacent to the openings.

Silvicultural Treatment of Coastal Forests

The Indigenous Forest Policy had restricted silvicultural treatment for regeneration and other purposes. Nevertheless, some treatment was consistent with the primary objective of stimulating increment on trees which would make sawlogs in the next 30 years. Thus the 1983/84 Annual Report advised that where harvesting was not sufficient to improve growth of potentially valuable trees and ensure adequate useful regeneration, unwanted non-saleable trees could be removed and natural regeneration encouraged or seedlings planted. Post-harvest burning was still practiced, especially in moister forest types, and enrichment planting could be done where it was considered the cheapest means of ensuring adequate regeneration. However, hardwood plantation establishment as a specific objective was no longer considered necessary or appropriate and was phased out.

The general decline in regeneration treatment, enrichment planting and planting has been shown in the statewide summary of silvicultural treatment (Table 3, Section 4.6). Under the provisions of the Indigenous Forest Policy, hardwood planting declined from 1,600 ha yr^{-1} during 1970-75 to around 100 ha yr^{-1} during 1990-95. Enrichment planting declined from a peak 1,480 ha yr^{-1} during 1975-80 to only 70 ha yr^{-1} in 1990-95; and regeneration establishment from 3,400 ha yr^{-1} (1955 to 1965) to around 100 ha yr^{-1} during 1980. This was to create a dilemma for foresters seeking to maintain productivity. An attempt was made in the early 1990s to reconsider the need for proactive efforts to ensure regeneration.

A New Emphasis on Regeneration: the 'Gaps and Clusters' Technique

By the early 1990s, a statewide concern about lack of forest regeneration and the consequences for long-term wood supply had developed. A basic premise of the Indigenous Forest Policy was also under challenge – which envisaged future wood supply would be obtained mainly from softwood plantations, with a greatly reduced demand for hardwood being met from continuing extensive (low input) management of the native forests. However, the demand for hardwood was not declining appreciably, indeed there was a growing appreciation of the value-adding potential of hardwood, and a continuing demand for saw and veneer logs and other products to service domestic and export markets. It was essential once again to emphasise stand regeneration in order to meet future demand. This led to the examination of a new silvicultural method called 'Gaps and Clusters'.

Horne (1993) set out a relatively sophisticated approach to the method. This involved recognition of a number of zones within which:

- Forest would be protected from logging;
- Forest would be logged relatively conservatively, creating only small canopy openings;
- Harvesting so that there would be larger openings, though retaining some component of the pre-harvest growing stock; and
- Forest with little or no effective growing stock might be clearfelled and regenerated.

Horne envisaged that both structural and species diversity would be maintained by working towards an 'optimal' pattern which integrated effective regeneration into a structurally diverse forest. However, as applied, the method came to be interpreted more in terms of a mosaic of even-aged regenerating groups, and retained habitat patches or 'clusters'. The regenerating groups could be 80 to 100 m in diameter creating, over three cutting cycles, even-aged regrowth patches covering about

70 to 75 per cent of the net available area (Nicholson, 1999). It is understandable that after some 15 years of fairly benign silvicultural practice under the Indigenous Forest Policy, there was opposition to the method on visual, ecological and other environmental grounds.

In 1996 the Government, under environmentalist pressure, placed a moratorium on the use of the method. A review concluded that it did not provide a single and adequate statewide approach for ecologically variable forest types, and questioned the maintenance of sustainability of all forest values. Continuing harvesting was to be based on single tree and group selection harvesting, but with canopy openings averaging no more than 40 m in diameter. Such a prescription is considered to be too inflexible to be able to balance growing stock levels, structural diversity and stand regeneration.

The Influence of Pressures to Maintain Wood Supply and of Changing Product Values

Following the withdrawal of rainforest logging in 1982, the environmental focus shifted to the logging of old-growth forest. In 1990 the NSW Forestry Commission responded with a strategy which deferred operations in strategic areas pending completion of environmental impact statements (EIS) over the State's forest management areas. This placed greater supply pressures on some of the coastal forests in order to maintain commitments to industry.

Financial performance and changing product values also began to influence forest practice in the late 1980s. *The Forestry Amendment Bill 1988* allowed financial restructuring of the Commission on a commercial basis. This meant that each multiple use management area became "a profit centre insofar as commercial use is concerned" (NSW Forestry Commission Annual Report 1987/88). In 1989/90, the Forestry Commission paid, for the first time, a dividend of $10 million to the State Treasury – a logical outcome of increased government emphasis on commercial performance.

Against this background, the Commission was committed to obtaining the highest economic return in the market for all timber products, and encouraging the use of wood for the highest value end product. At this time, logs suitable for veneer and girders were attracting a greater stumpage than the conventional sawlog. Hence trees which had the potential to make future quota sawlogs might be harvested early, as ex-quota girder logs, veneer logs and treatable poles.

The sawlog industry expressed concern that the harvest of chemically treatable poles, small logs, veneer logs and girder logs was jeopardising prospects for a continuing and sustainable yield of quota sawlog (R.L. Newman and Partners, 1996).

6.3 PLANTATIONS ON STATE FORESTS

Despite the restrictions on establishment of hardwood plantations under the Indigenous Forest Policy, there were, by the early 1990s, some 25,000 ha of hardwood plantation within the State forests (dating from 1940). There are two principal reasons for this relatively large area.

1. In 1983/84 the Forestry Commission purchased the bulk of the hardwood forest and plantation areas of APM Forests Pty Ltd., located near Coffs Harbour. Approximately 5,000 ha of the 15,000 ha of farmland and forest were plantation which had been established as part of a resource for a projected pulp mill. Following the 1982 decision to withdraw rainforest logging, the purchase was designed to reassure the timber industry of the Government's determination to safeguard its resource base and to help compensate for substantial loss of commercial resources transferred to National Park (NSW Forestry Commission Annual Report, 1983/84); and

2. In its 1990/91 Annual Report the Commission broadened the term 'plantation' to include even-aged forest created through intensive site preparation and direct seeding. Regenerated areas could be regarded as 'plantation' where

significant site preparation had been undertaken, and where new trees had been established, either by seeding or planting. This brought onto the plantation register significant areas of even-aged regrowth in the Coffs Harbour area that had been established through clearfelling, burning and direct seeding.

6.4 CHANGES IN MANAGEMENT PRACTICE IN THE EDEN MANAGEMENT AREA

The reasons for initiating the integrated sawlog-woodchip program in the late 1960s and the early operations and product yields have been described in Section 4.8.

A number of important changes were made in the 1970s and 80s to enhance the environmental acceptability of the program. In 1973, the original clearfelling units of up to 800 ha were reduced to 200 ha, and in 1976 an 'alternate small coupe logging system' was adopted with an average coupe size of around 15 ha. The change to small coupe logging was a response both to concerns about the environmental effects of clearfelling in large coupes, and the perceived need for more intensive pre-planning of operations. The result was a checkerboard pattern of logged and unlogged areas varying in size. The change was seen to be beneficial in terms of wildlife management, water protection and the visual impacts of harvesting.

At about the time the small coupe system was introduced, there was a significant change in wood production objectives. Initially forests were seen as producing only pulpwood beyond the first cutting cycle, which would be harvested on a short rotation of about 40-50 years. However, there was a strengthening perception during the 1970s that the forest should be managed on a multi-product basis, providing a future supply of sawlogs, poles, mining timber and pulpwood. This helped counter continuing environmental criticism of clearfelling by retaining a range of stand components, and by adopting a longer sawlog rotation.

A severe wildfire in 1980 led to yet another modification to the clearfelling regime. Slash burning was introduced to reduce the accumulation of logging debris. In order to facilitate this, it was necessary to use larger coupes (50 to 100 ha), though still in an alternate pattern. The slash burns were relatively light, essentially burning the dried heads of felled trees under moderate weather conditions. This was designed to conserve as much as possible of the lignotuber growth and new seedlings, and to minimise nutrient loss on inherently infertile soils.

The harvested coupes may contain a wide range of components, including advance growth (saplings, poles and larger-boled trees capable of growing into sawlogs), seed trees (to compensate for seedlings and advance growth lost in the burn),

Table 7. Numbers of stems per hectare removed, and number remaining, following harvest of an old-growth Blue Gum - Tallowwood (moist) and a New England Blackbutt (Dry) forest in the Wauchope Management Area.

Size class (cm DBHOB)	10-30	30-50	50-80	80+
Moist				
Removed	0	2.0	5.0	17.0
Remaining merchantable	0	0.3	1.4	0.5
Remaining unmerchantable	0	4.0	7.0	8.0
Dry				
Removed	0	0	2	13
Remaining merchantable	16	9	8	1
Remaining unmerchantable	3	7	5	1

wildlife habitat trees, gully retention strips and wildlife corridors. Current practice has moved a long way from its clearfelling origins and, to some, might better be described as selection or shelterwood management.

6.5 HARVESTING WITHIN MOUNTAIN AND TABLELANDS FORESTS

The old-growth forests of the mountains and tablelands remained a critical source of sawlogs during the 1970s and 80s. The harvest of all commercial growing stock had a variable impact on the forest – depending on bole quality and the size distribution of trees. At one end of the spectrum the operation may have approached clearfelling in high quality stands, and at the other harvesting might be better described in terms of selection management. Two examples ('Moist' and 'Dry' Hardwoods) are cited from the Kempsey-Wauchope Environmental Impact Statement (Truyard Pty Ltd, 1993).

The impact of harvesting on old-growth wet sclerophyll forest (Blue Gum-Tallowwood Type) at Mount Boss in the Wauchope Management Area is shown in Table 7 based on the number of stems removed from, and the number of merchantable and unmerchantable stems remaining in two compartments. There were on average 39 stems ha^{-1} in the original forest, 25.5 of which were greater than 80 cm DBHOB. In total, 21 of the original 39 stems ha^{-1} were retained, a good basis for ultimate restoration of this complex ecosystem.

Assuming that the average size of the 80 cm+ stems was 120 cm, the stand basal area was around 34 m^2 ha^{-1}. Thus, logging removed ~65 per cent of the stand basal area. Very little of the remaining basal area was of merchantable quality.

The establishment of regeneration in this forest would depend on the distribution pattern of the residual growing stock, whether a post-harvest burn was carried out, and the extent to which regrowth was able to establish on soils disturbed by tractor operations.

A Forestry Commission study (van Loon, 1966) established that mechanically disturbed soil makes a satisfactory seedbed for *E. microcorys* (Tallowwood) regeneration within this forest type, and that this has operational advantages over the use of fire. From a survey of 23 Moist Hardwoods sites, King (1985) concluded that irrespective of treatment, most areas had enough regrowth to replace the sclerophyll overstorey, and all overstorey species present before harvesting were present in the regrowth. Thus, while many such stands may not be fully stocked in terms of conventional regrowth expectations, the natural Tallowwood-Blue Gum overstorey should eventually recover.

A similar analysis of a New England Blackbutt (*E. andrewsii*) forest shows a greater range of tree sizes in the original forest, possibly reflecting the effect of past fires within more open forest (Table 7, compartment 2). There were 15 stems ha^{-1} >80 cm DBHOB in the original forest; most of these were of commercial quality, and only 2 were retained. There were 15 stems ha^{-1} in the 50-80 cm range, of which only two were harvested; eight of the remainder were of commercial quality. There were also 35 stems ha^{-1} below 50 cm DBHOB, presumably a consequence of earlier wildfires.

Assuming that the average size of the 80 cm+ stems was 100 cm, 50 per cent of the stand basal area of 22 m^2 (a lower quality site than compartment 1) was removed in logging. The residual merchantable stocking, together with the regrowth which should develop readily on this site, should ensure a continuing productive forest.

Following the withdrawal of wood production from a large part of the old-growth mountain and tablelands resource (Section 7), maintenance of log supply in some areas has depended on an integrated 'recut' logging of forest first harvested only 20-30 years before. The latter harvest has included a wider range of products - including pulpwood (from thinnings), and sawlogs which were regarded as non-commerical at the first harvest.

7. THE 1990S: ENVIRONMENTALISM AND ITS CONSEQUENCES FOR FOREST MANAGEMENT

In 1996, the State forest management agency signalled a significant change in policy direction. An operational circular acknowledged that the management of forests primarily for wood production was at an end, to be replaced by integrated resource management at a landscape level. This was based on the concept that all key values in the forest are reflected in the objectives of management. For example, conserving wildlife habitat was to be a 'co-equal' objective of management, and no longer to be seen simply as a constraint on timber production.

The development of modern integrated resource management in NSW followed several decades of social conflict over the role and management of public forests. A brief account is given of the environmental review process in NSW, the transfer of forest from State Forest to National Park, and of integrated forest practice including protocols for conserving biodiversity within the wood production forests.

7.1 ENVIRONMENTAL PROCESSES IN NEW SOUTH WALES

The withdrawal, in 1982, of harvesting from a substantial part of the rainforest resource was the first of a series of government initiatives which were to radically alter the balance between the respective roles of the State forests for wood production and conservation of biodiversity.

The Environmental Planning and Assessment Act 1979 became, for the native forests, the cornerstone of environmental policy in NSW. The Act required preparation of Environmental Impact Statements (EISs), and the Forestry Commission initially agreed to prepare five of these. However, there were critical limits as to what the EIS could achieve. Most notably, there was no provision for modern review of land use – although this (reservation versus harvesting) was at the heart of the forest conflict. In the early stages of the process, State Forests was its own determining authority.

Social conflict over harvesting continued to develop, related mainly to old-growth forests and wilderness. The Government in 1991 placed a moratorium on further harvesting in the most sensitive old-growth forests and, in accordance with the *Environmental Planning and Assessment Act 1979* and the *Timber Industry (Interim Protection) Act 1992*, the Forestry Commission commenced an intensive program to prepare 16 EISs and associated Fauna Impact Statements (the latter required under the *Endangered Fauna (Interim Protection) Act 1991*.)

The regulation of forest practice was also transferred from State Forests to other public agencies. By 1994 the Environment Protection Agency was issuing and auditing licences under the Clean Waters Act. The National Parks and Wildlife Service was responsible for assessing Fauna Impact Statements and issuing logging licences under Section 120 of the *National Parks and Wildlife Act 1974*, in relation to protection of endangered species. The Department of Urban Affairs and Planning undertook the assessment and monitoring of the implementation of activities covered by EISs, and the Department of Land and Water Conservation provided input and external advice on practices which could impact on soil conservation.

The joint Commonwealth-State Comprehensive Regional Assessment (CRA) began in 1994/95. The NSW Government Forestry Reform Package of June 1995 acknowledged that prior to completion of the CRAs it was necessary to define areas available for timber harvesting, and to identify on a regional basis those forests that might be included in a Comprehensive, Adequate and Representative (CAR) Reserve system. This was done according to an 'Interim Assessment Process'.

In January 1996 a 'Deferred Forestry Agreement' was signed with the Commonwealth. This took account of current reservations and State harvesting moratoria, old-growth, biodiversity, wilderness values and Commonwealth criteria for CAR

Reserves. The full CRA-RFA (Regional Forest Agreement) process was then able to proceed on this basis. The RFA for the Eden Area forests was completed during 1997/98, that for the Northeast regions in 1998/99, and that for the Southern region in 2001.

The NSW Government's forestry initiative also provided for the development of protocols for the protection of old-growth forest, rainforest, rare non-commercial forest types, threatened species and special sites. The substance of these protocols, particularly the provisions for conservation of biodiversity within the wood production forests, is examined in Section 8.3.

The following describes the areas of forest which have been transferred from State forest to National Park, and the processes to conserve biodiversity within the residual wood production forests.

7.2 TRANSFER OF STATE FOREST TO NATIONAL PARK

Of the 230,000 ha of rainforest in State forests, around 100,000 ha were transferred to National Park as a consequence of the Government's rainforest decision of October 1982. The remaining 130,000 ha were zoned for multiple use management, though in reality only about 90,000 ha were available for continuing wood production. All rainforest logging ceased in 1992.

Statistics on the transfer of eucalypt forest from State forest to National Park is provided for four regions: Lower North-East and Upper North-East, Southern, and South-East (the Eden Area forests).

Northeast Regions. Information on changes in land tenure within the northern region of the state is derived from a brochure produced by Northern NSW Forestry Services (*The State Forest Resource in Northern NSW Following the 1998 Forestry Decision),* based on data provided by State Forests.

The combined Lower North-East (LNE) and Upper North-East (UNE) Regions extend from about Gosford north to the Queensland border and west to the forests around Muswellbrook, Armidale, Glen Innes and Tenterfield.

Prior to the commencement of the Interim Assessment and Comprehensive Regional Assessment processes in 1996, there were 1,625,908 ha of State forest in these two regions, including plantations and Flora Reserves. Following the completion of the RFA, the total area within State forest was 1,056,159 ha, a reduction of 569,749 ha.

Of the total area of State forest in the region, the actual area available for multiple use management is 923,474 ha. However, of this area, 518,041 ha are excluded from timber production. The excluded area includes rainforest, areas for riparian protection, rare and non-commercial forest types, steep and inaccessible areas, and other areas such as rock and unmerchantable forest.

The remaining area (405,433 ha) is the total area available for timber production, and represents only about 15 per cent of the combined area of forest in National Parks and State forests. This area will further decrease due to silvicultural prescriptions and threatened species protection zones.

Southern Region. Within the southern region 156,000 ha of forest has been transferred to National Park management.

Southeast Region. Several areas of State forest land have been withdrawn from wood production and transferred to National Park since the integrated sawlog-woodchip export operation began. In 1990 there were about 245,000 ha in State forests, 104,000 ha within National Parks and nature reserves, and 8,000 ha in Crown timber land.
As a result of the Eden Region Forest Agreement (signed in 1993) and the Regional Forest Agreement, there are now 163,000 ha within State forest, and 255,000 ha within the National Park and nature reserve systems. In addition to the area protected within National Parks and nature reserves, Informal Reserves (within State forests) cover 4,600 ha.

Thus the Dedicated Reserve and Informal Reserve components of the Reserve System together cover approximately 260,000 ha, about 56 per cent of the public land in the region or 33 per cent of the entire region. Conservation is further enhanced through special management prescriptions applying to 7,900 ha of State forest.

7.3 CONSERVING BIODIVERSITY WITHIN WOOD PRODUCTION FOREST

Conservation of biodiversity within wood production forests is achieved in three principal ways: through the system of Forest Preserves and Flora Reserves, a Forest Management Zoning System, and integrated (multiple use) management within wood production forests.

Forest Preserves, Flora Reserves and the Forest Management Zoning System

NSW has long had an active program of native forest preservation which sets aside examples of forest to be retained with minimal human disturbance. The system of Forest Preserves and Flora Reserves complements those forests managed as National Parks, especially by preserving forest types and naturally coexisting groups of types not sampled by the National Parks system.

Since 1981 the Forestry Commission has also used a system of management classification called the Preferred Management Priority system (PMP). State Forests has recently reviewed the zoning system to better reflect current initiatives in forest management. The Forest Management Zoning System establishes 7 classifications with associated protective measures that prohibit or allow specified forest practices. The classifications or zones are:

- Special Protection Forest
- Special Management Forest
- Special Prescription Forest
- General Management Forest
- Hardwood Plantation
- Softwood Plantation and
- Non-Forest Areas.

Ecologically Sustainable Forest Management

The Regional Forest Agreement process commits NSW to management of the State's forests in a way which is consistent with established ESFM (ecologically sustainable forest management) principles. From a silvicultural viewpoint, the critical principles are those relating to the conservation of biodiversity, and maintenance of the productive capacity, health and vitality of forest ecosystems. These principles must underpin all silvicultural practice, whatever the silvicultural method or combinations of methods used to achieve the objectives of management.

The following account of selection practice in coastal eucalypt forests is drawn largely from Nicholson (1999), and integrates decisions relating to both wood production and conservation of biodiversity as equal objectives. A more complete account of wildlife conservation practice follows.

The silvicultural regime applied to the net harvestable areas can be broadly classified as 'flexible selection practice'. Short and long-term wood supply are taken into account in tree-marking, wildlife values are conserved by retaining habitat and recruitment trees, and species and structural diversity are maintained as far as possible. Silvicultural systems which produce essentially even-aged stands, such as clearfelling and seedtree systems have been excluded from NSW, and this now also includes the Eden Area forests.

Depending on the forest structure and environmental objectives, stands may be thinned or harvested, with harvesting based on a single tree or group selection regime, with canopy openings no greater than 50 m diameter. Tree-marking seeks to retain all trees judged capable of growing to a more valuable size during the next cutting cycle, and to harvest older and slower-growing trees that have reached commercial maturity, and those which are in decline or are suppressed, or have unacceptable levels of defect. Removals are made from even-aged stands or patches of regrowth by thinning from below to concentrate growth on vigorous trees. Site treatment to encourage regeneration may be carried out where necessary.

As stand structure can be highly variable, it is not unusual to have all silvicultural methods applied within very small areas, that is, specific site silviculture can create a complex structural mosaic within an individual compartment. Provision of refugia and conservation of other forest values within net harvestable areas can and does have a significant effect on timber yields.

Continuing management of Cypress Pine forest is based on thinning the 1880s overwood trees to a wide spacing, enabling the 1950s regrowth to develop as a secondary stratum. A conservative single tree selection system will minimise harvesting impact within the existing River Red Gum forest though, at some stage, wider canopy opening will be needed to encourage development of regeneration.

Integrating Timber and Wildlife Management

The integration of timber and wildlife management represents one of the most substantial changes in forest practice during the past 50 years. Specified forestry activities must comply with the protective measures outlined in the Conservation Protocols negotiated between State Forests and the National Parks and Wildlife Service. These are now prescribed by the 'Integrated Forestry Operations Approvals' (IFOAs).

It is inappropriate here to present a comprehensive account of these protocols, but a summary is given of the general measures for habitat conservation within wood production forests and of prescriptions for threatened species.

General Measures for Habitat Conservation

Tree retention: Within 'non-regrowth' forests, 10 hollow-bearing trees and 10 recruitment trees must be retained per 2 hectares. Recruitment trees must show potential for developing into hollow-bearing trees, and represent the range of species in the area.

A similar number of hollow-bearing and recruitment trees must be retained in the 'regrowth zone'. Where this density is not available, any hollow-bearing trees present must be retained. In this case, one recruitment tree must be retained for each hollow-bearing tree.

Significant food trees are to be retained.
For example, prescriptions relate to:

- The protection of stands where She Oak (Allocasuarina spp) dominates the canopy, sub-canopy and understorey;
- The retention of at least four mature trees ha^{-1} of any set of specified eucalypt species;
- Avoidance of damage to banksias and Grass Trees (Xanthorrhoea spp); and
- Minimising damage to all trees with incisions made by Yellow-bellied gliders.

Riparian Buffers and Connection corridors: The Protocol prescribes the width of riparian buffer strips for first, second, third and higher order streams and, with limited exception, excludes forestry activities from them. Standards are also set for connection corridors linking different drainage systems.

Wetlands, heaths, rocky outcrops, caves, tunnels and disused mineshafts: Prescriptions cover the width of buffer zones around all features which have significant habitat values, and the exclusion of all forestry activities from them.

Ground habitat protection: The protocols require that reasonable measures be taken to protect ground habitat (understorey, ground cover, large logs on the forest floor) from specified forestry activities.

Nest and roost sites: Buffers are prescribed around nest and roost sites for a number of Owl species, Lyrebirds, Glossy Black-Cockatoos, Turquoise Parrots, Ospreys and the Square-tailed Kite. These range from 20 to 100 m in width.

Burning: State Forests is to ensure that prescribed burning regimes take account of wildfire history and the ecological requirements of threatened species, and be conducted in a manner which promotes and maintains an understorey mosaic, including significant areas of dense understorey vegetation, particularly within the habitat of listed ground-dwelling species. Burning is to be varied by season, intensity and interval.

Prescriptions for Threatened Species

Actions under the NSW Biodiversity Strategy, the *Threatened Species Conservation Act 1995* (NSW), the *Endangered Species Protection Act 1992* (Commonwealth), the *National Parks Estate Act 1998*, and a range of management strategies, management plans and the Integrated Forestry Operations Approval process, provide for the protection of rare and threatened species and ecological communities.

A brief summary is given of prescriptions for a number of threatened animal species in order to indicate the range of actions required, and their likely influence on wood production. Prescriptions also apply to threatened frogs, bats and birds.

Powerful and Masked Owls: A large area (300 ha) must be permanently retained within a two kilometre radius of a recording. Where there is more than one Greater Glider per hectare within two kilometres of Powerful and Masked Owl records, sixteen habitat trees per two hectares are to be retained within the net logging area (the Greater Glider is a significant food source for the Owls).

Squirrel glider: Where there is a Squirrel Glider record in a compartment or within 400 m of the compartment boundary, specified forestry activities must be excluded from an 8 ha area which includes the Squirrel Glider records.

Yellow-bellied Glider: Fifty ha of potential habitat must be permanently retained around records of Yellow-bellied Glider. Areas of potential habitat are to be selected in terms of a defined order of priority.

Critical Weight Range Vertebrates (CWRV - animals in a defined weight range which are susceptible to feral predators). Where there is a record of a CWRV in the compartment or within two kilometres of the compartment boundary (or for the Tiger Quoll within five kilometres), commercial and private firewood licenses should specify that fallen hollow logs over 40 cm DBHOB must not be removed. Moreover, feral predator surveys must be conducted within three months of completion of harvesting, and species-specific control measures taken to remove predators. The area covered by fuel reduction burning should not exceed 75 per cent of the net logging area within any one compartment.

More specific prescriptions apply for individual species, including the Tiger Quoll, Long-nosed Potoroo and Brush-tailed Phascogale.

More Specialist Silvicultural Regimes: Case Study of Koala Management

A good example of the integration of wildlife and timber management is the current management of Pine Creek State Forest (State Forests of NSW, 1997). Despite being a relatively small forest (5,890 ha) with a history of logging and treatment over some 120 years, and incorporating 2,000 ha of eucalypt plantation, the Pine Creek forest has an estimated koala population of 350 to 400 animals, which is considered to be a regionally significant resource. In order to maintain this population within a wood production framework, six management zones have been designated, based on koala habitat potential. Separate silvicultural strategies have been developed for each zone. These include a wood priority zone based on more or less even-aged stands; a single tree and small gap selection zone within Mixed species and structurally diverse forest (designed to preserve structural diversity and a range of koala habitat trees); a zone where a moratorium is placed on logging for the time being; and a zone where high quality koala habitat areas are to be completely preserved.

Nicholson (1999) suggests that concepts and systems like this will continue to set the context for future forest management decisions, including silvicultural directions.

8. NEW SOUTH WALES PRIVATE PROPERTY FORESTS

There are 8.3 million ha of forest in NSW of which 2.8 million ha are in private ownership.

Private property native forests have been important for wood production. In the early post-war period privately owned forests provided as much wood (all products) as the public forests (around 750,000 m^3 yr^{-1}). The private harvest had declined steeply to around 200,000 m^3 yr^{-1} between 1995 and 2000. The harvest from public land was 550,000 m^3 yr^{-1} at this time (Table 1).

There is limited knowledge of the private resource, including the volume harvested, management practices, forest condition and potential productivity. Consequently, some Regional Forest Agreements included commitments to improve knowledge of these forests. Ryan *et. al.*, (2002) suggest that silvicultural practices in private native forests have tended to closely reflect those in State forests. In southern NSW these range from heavy selection to seed tree operations where there is a market for pulpwood, through to gap selection and light selective harvesting. In northern NSW, gap selection has been the main method used, resulting in stands dominated by young to semi-mature regrowth. A fairly consistent pattern of late winter and spring burning to control undergrowth and promote native pasture and grazing has resulted in more open stands than those under public ownership.

Against this background, and in the absence of better information, it is appropriate that the data tables based on operations within public forests might also be taken to represent the private forests.

The private sector forests are now subject to regulation by the Department of Land and Water Conservation through the *Native Vegetation Conservation Act 1997*, and Regional Vegetation Committees. It is unclear at the present time just what the continuing contribution of the private native forests to wood production will be.

9. DISCUSSION

The following is a broad perspective of the impact of forest practices in NSW on the forest growing stock, carbon storage and carbon flux during the past 50 years. This perspective is based on the forest policies, strategies and practices described above, and on the information provided in the Appendix to this report (Procedures for recording information on the forests and management practices), and the accompanying data tables. The Appendix describes the forest zones and forest types used to construct the data tables, management practices within each of a number of time periods, and the assumptions made in compiling the information recorded in the tables. Key considerations are:

Forest vegetation: An analysis of the effects of forest management practice on carbon storage and carbon flux must start with an appreciation of vegetational complexity within the forests. Distinctive eucalypt communities exhibit very different silvicultural responses in terms of the growth characteristics of harvestable species, notably their relative tolerance to shade, inherent vigour, stand productivity and regeneration potential. Hence, in assessing carbon stocks and carbon flux it has been essential to report separately on these distinctive forest types.

The focus on short-term wood supply objectives: Native forest practice in NSW has not set out to maximise wood production nor, as it follows, carbon storage and carbon uptake. Rather, forest practice reflected efforts by the State government to maintain essential wood supply for the short term, to avoid high levels of wood imports (and the effect this would have on timber prices), and to help maintain rural communities and employment. Moreover, it was concluded that long-term wood production objectives might be more effectively realised where financial priority was accorded to the rapid development of a softwood plantation resource.

Forest yield: There has recently been a marked decline in hardwood harvest in NSW. Hardwood harvest (sawlogs, poles, piles, girders, mining timber and hewn timber and sleepers) on public land increased from about 800,000 m^3 yr^{-1} during the early 1950s to a peak of about 1,150,000 m^3 yr^{-1} during the 1970s. This was greater than the sustainable harvest, and has contributed to a progressive decline in growing stock and biomass carbon pools.

There was a subsequent reduction in the harvest volume to just over 1,000,000 m^3 yr^{-1} in the late 1980s, and to 555,200 m^3 yr^{-1} during the second half of the 1990s. This latter figure reflects the deferring of large forest areas from harvesting during the Comprehensive Regional Assessment process, the subsequent transfer of State Forest to National Park, and elsewhere, the reduction in wood harvest to sustainable levels. The rainforest harvest declined from 140,000 m^3 yr^{-1} to 84,000 m^3 yr^{-1} during the late 1970s, and effectively ceased from 1982.

The volume of wood harvested from private land has experienced an even steeper decline, from around 600,000 m^3 yr^{-1} during the 1950s to less than 200,000 m^3 yr^{-1} during the second half of the 1990s. This reflects a reduction in the sawlog resource where logging has been more exploitive, and in recent years, a more stringent regulation of harvesting of private forest. Little is known about the condition of the private property forests, though much of it is likely to be in a rundown condition

The public Cypress Pine forest has been the only sector to maintain a more or less even sawlog flow during the past five decades. Apart from a reduction during the late 1980s, the Cypress Pine yield has been in the range 90,000 to 110,000 m^3 yr^{-1}. The private property harvest has declined sharply from a peak of 156,000 m^3 yr^{-1} during the early 1950s to around 10,000 m^3 yr^{-1} during the 1990s.

The decline in total wood production from all native forests (public and private) in NSW has been very substantial. Between 1960/61 and 1965/70, 2,220,000 m^3 yr^{-1} of wood was harvested. This was before the advent of the Eden sawlog-woodchip export program, and largely represents the harvest of sawlog, poles, piles, girders and sleepers. Between 1995 and 2000, the comparable figure was only around 850,000 m^3 yr^{-1}, though 540,000 t yr^{-1} of pulpwood from all sources can be added to this.

Silvicultural practice: The wood supply strategy in NSW has been based on:

1. Conservative selection practice within Coastal Regrowth, Alpine Ash, River Red Gum and Cypress Pine Zones; and
2. Complete logging of all commercial product within the mountain and foothill forests of the east coast, the Eden Management Area, and parts of the Tablelands forests.

The impact of selection practice has varied. Within the Coastal Regrowth Zone, it was associated with ringbarking and reject felling treatments until the mid-1970s (with moderate to more extensive levels of canopy disturbance), and thereafter, has been more conservative (with minimal or limited canopy disturbance). Current silvicultural practice integrates wood production with management for other values.

The different management strategies applied to forests are reflected in yields. The greatest yields are recorded where near-complete harvest of all commercial product occurred, for example, 140 t ha^{-1} from sawlog-pulpwood operations within the Messmate-Brown Barrel Type (Eden Management Area), and 90 t ha^{-1} from sawlog only operations within high quality mountain forests.

At the other end of the spectrum, yields have been in the range 6 t ha^{-1} for Cypress Pine forests, and 15 to 20 t ha^{-1} for logging in the Dry Hardwoods and New England Blackbutt Types.

Average sawlog removal based on selection logging within the Blackbutt Type are within the range 20 to 30 t ha^{-1} depending on the level of canopy opening. These yields are affected by suboptimal growing stock levels and poor tree quality, particularly in mixed-species stands. Harvest removals from the Alpine Ash Type are somewhat greater at 30 to 40 t ha^{-1}, reflecting the inherently higher productivity of this species and its occurrence in near monocultures.

Forest condition: Given the philosophies and policies which have underpinned the management of NSW forests, it is understandable there is now much variation in the present forest condition and hence, carbon stocks. The emphasis on selection management means that much of the forest is in a 'semi-natural' condition with a good level of species and structural diversity. The loss of large-boled trees will have reduced habitat quality for hollow-dwelling species, though present tree-retention policies and practices aim to eventually overcome this problem.

The forests of NSW can be categorised based on stocking and structural attributes, and the impact of prior harvesting on the carbon stock.

1. *Unharvested old-growth forest:* The bulk of residual old-growth forest formerly within State forest has been transferred to conservation reserves following completion of Regional Forest Agreements.

2. *Old-growth forest which has been 'logged to the limits of economic accessibility' since the late 1950s.* The impact of this harvesting has been illustrated in Section 6.5. This showed that around 65 per cent of the basal area of a Moist Hardwoods forest had been removed leaving mainly unmerchantable larger-boled trees.

   Moreover, eucalypt regrowth may be inadequate in the face of strong competition from rainforest elements. It follows that carbon stocks will have been depleted, and, for part of the forest, natural recovery will be a lengthy process. On the other hand, much of the Moist Hardwoods forest will be structurally diverse with good habitat values.

   It is likely there would have been adequate natural regeneration within the lower quality New England Blackbutt forest, and that the residual trees, together with the regrowth, will help re-establish C stocks. While the effective stocking and wood volume increment may be less than optimum, good recovery of carbon stocks can be anticipated.

3. *Well-stocked forest within the Coastal Regrowth Zone.* The condition and productivity of the coastal zone forests vary widely. This can reflect the proportion of the more productive Blackbutt Type within the forest, its location with respect to markets, the time since management was imposed, and the intensity of harvesting and post-harvest treatment.

   Some growing stock information for more accessible and better-stocked forests is provided in Horne and Carter (1992) for the Kendall Management Area, and in the Environmental Impact Statement for the Coffs Harbour and Urunga Management Areas (State Forests of NSW, 1995). When compared with the 'ideal' stocking for uneven-aged *E. pilularis* forest (Curtin, 1963), these forests are seen to be moderately well stocked, though still skewed towards the smaller diameter classes. This reflects the limited regrowth which developed following some of the earlier selection harvests, for example before 1955.

   It should be possible, with careful management, to work towards fully stocked stands, a balanced distribution of size classes, and carbon stocks which are close to that present in un-harvested uneven-aged forest.

4. *Forest with lower effective stocking within the Coastal Regrowth Zone.* These forests may contain a smaller proportion of the Blackbutt Type, and a greater proportion of Rainforest, Dry Hardwoods, Moist Hardwoods or Spotted Gum Types. Data presented in Environmental Impact Statements for Management Areas in the northeast of the State (Murwillimbah, Casino) show much of the forest is understocked, particularly in larger tree sizes. Forest composed of Dry Hardwoods and Moist Hardwoods Types (e.g. Urbenville Management Area) may have a greater residual stocking in larger sizes, but a high proportion of these stems would not be of commercial quality.

   There are technical difficulties in maintaining Dry Hardwoods forest at optimum productivity. The species are not as inherently vigorous as *E. pilularis*, and while classified as 'tolerant', often accumulate in stands in a 'growth restricted' condition. This adversely affects stand increment and the build up of carbon stocks. This also applies to lower quality Spotted Gum Type forests.

   Stocking levels and carbon stocks may be particularly low in some Moist Hardwoods areas where post-harvest regeneration treatments were not carried out, and there is now a strong development of rainforest elements. However, because of site factors it is unlikely that this rainforest element will form a fully developed self-perpetuating rainforest. The element is currently contributing to biomass accumulation but not at the level associated with a full stocking of emergent eucalypts.

5. *The Eden Management Area forests.* The Eden Management Area forests contain a range of tree components – habitat trees, seed trees and potential sawlog trees, sapling-pole advance growth from the original forest, and regrowth developing following harvest. While there is, for the most part, full site stocking, site quality has a significant influence on regrowth vigour and stand and carbon increment.

6. *Alpine Ash, River Red Gum and Western Hardwoods.* These communities have regenerated well following harvesting, particularly where canopies were more heavily disturbed during the 1950s and 1960s. Subsequently, more conservative selection/thinning practice will have helped maintain moderate to good stocking levels and carbon stocks.

7. *Cypress Pine forests.* Stocking level is not generally a problem in these forests, though overstocking can result in general stand stagnation. Hence, much effort has gone into releasing and thinning regrowth, particularly that which developed in the 1950s. The maintenance of carbon stocks and carbon increment will depend on a successful transition from harvesting the older (1880s) regrowth to harvesting and stimulating the development of 1950s regeneration.

The forests: a carbon perspective: It will be apparent that apart from unharvested old-growth forest in National Parks, and well-stocked uneven-aged stands and plantations, carbon stocks are below site carrying capacity. Where uneven-aged forests are well stocked – though skewed towards smaller sizes, there is potential for the carbon stock to build up in the short term. However, this might not happen given the continuing wood supply pressures on a much-reduced wood production estate in NSW. In this case, there may continue to be a decline in the average tree size within the forests. Where forests are currently understocked, particularly where this is related to limited post-harvest regrowth within wet sclerophyll forest, a substantial forest restoration program will be needed to restore carbon stocks and carbon increment.

The case for restoration programs: Both State and Commonwealth Governments have benefited greatly, in socio-economic terms, from the short-term wood supply strategies and low financial input practices adopted for the native forests of NSW. The strategies and forest practices have played a fundamental role in achieving ample wood supply through the softwood program, a relatively seamless transition from a hardwood to a softwood dominant forest economy, and the opportunity to establish a more socially acceptable balance between conservation and wood production in native forests. Governments may not fully appreciate the contribution of past native forest policies and strategies to these outcomes.

Many foresters have been concerned at the environmental consequences of wood supply strategies and practices, particularly those affecting wood production potential of high quality wet sclerophyll forests. However, they believed there would be ample opportunity to restore full sitestocking and productivity of these forests as the softwood program entered its 'mature phase' and generated positive financial flows. Unfortunately, there has been only limited finance directed to restoration programs.

10. CONCLUSIONS

The NSW forests are more environmentally and vegetationally diverse than those of other States. This has greatly influenced management strategies and practices. Native forests have been managed primarily to maintain wood supply to industry while building up an alternative and more productive softwood resource. This has been achieved through conservative selection logging designed to retain trees for continuing harvest within the Coastal Region, Alpine Ash, River Red Gum, and Cypress Pine forests, and through complete harvest of all commercial product within the Mountain and Tablelands forests and those of the Eden Management Area.

As a consequence of these strategies and practices, and limited post-harvest improvement treatment, the forests are now in a variable condition, and generally below optimum in terms of growing stock and wood increment levels. Much of the forest is in a 'semi-natural' condition.

In a socio-economic context, past strategies and practices have served the State and nation well. However, the NSW Government is now committed under Ecologically Sustainable Forest Management principles to restore the stocking, community patterns and biodiversity of the forests, and through this their carbon increment and stocks.

11. ACKNOWLEDGEMENTS

A range of information has been used to compile this report. A major source has been the Annual Reports of the Forestry Commission of New South Wales (later State Forests of NSW) for the years 1950 to 2000.

An appreciation of management practices and other matters was developed from the following representative 1980s management plans:

Coastal forests

Kendall
Coopernook
Casino
Murwillimbah
Grafton
Taree
Wingham
Gloucester
Bellingen
Narooma

Tablelands forests

Bago-Maragle
Glen Innes
Styx River
Walcha-Nundle
Queanbeyan
Chichester

Western forests

Narrandera
Gilgandra
Walgett
Dubbo
Griffith
Cobar
Gunnedah
Murrimbidgee
Mildura

The following EIS documents were consulted

Kempsey-Wauchope 1993
Casino 1995
Gloucester-Chichester 1995
Dorrigo 1995
Coffs Harbour 1995

Much of the information on forest yields and growth was obtained from management plans and discussions with NSW foresters. I am indebted to the following for assistance in this way.

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13. APPENDICES

13.1 APPENDIX 1

BACKGROUND TO AND ASSUMPTIONS USED IN ASSEMBLING THE DATA

The management of the native forests in New South Wales has been 'extensive' rather than 'intensive' and, for the most part, practice has been motivated by pressure to maintain wood supply at a minimal cost. Because there has been little application of classical silvicultural systems, a given logging prescription could have a variable impact on forest structure. Moreover, there is limited recorded data according to forest type, creating additional difficulties in recording management information.

Against this background, the Appendix develops the framework for the native forest data tables. It examines:

1. The preparation of tables specific to a number of forest zones;
2. The most suitable forest type structure;
3. The management practices applicable to each forest type and time period; and
4. The problems in compiling sets of management information, and the assumptions made in doing so.

Defining Forest Zones

In NSW, distinctly different practices have applied to the one forest type. For example, the Blackbutt Type within the coastal regions has been logged conservatively and silviculturally treated for a century or more. In contrast, the Blackbutt Type within the steeper terrain of the mountains has been subject to a one-off harvest of all commercial product only since the late 1950s.

The delineation of the Coastal Regrowth, Mountain-Tablelands and other Zones are presented in Figures 1-3. The map was prepared during the CRA process, and is available on a NSW GIS data base.

The following zones provide a basis for reporting on management practices:

- The Coastal Regrowth Zone
- The Eden Management Area Zone
- The Mountain-Tablelands Zone
- The Alpine Ash Zone
- The Cypress Pine-River Red Gum-Western Hardwoods Zone

An approximate delineation of the 'Coastal Regrowth Zone' and the 'Mountain-Tablelands' and 'Alpine Ash' zones is shown on Figures 1-3. The Cypress Pine forests are shown on Figure 4, west of the 700 mm isohyet.

Forest Types

The temperate and subtropical forests of NSW are more vegetationally complex than the temperate forests of the southern States. A rich mosaic of forest types reflects the presence of both eucalypt forest and rainforest and their transition zones, and within the eucalypt forests, the 'ecological sifting' of a large number of species by site factors.

While any one of the 235 forest types defined in the Forestry Commission Research Note 17 (Forestry Commission of NSW, 1989) may be characterised by one or two dominant tree species, there may be several other species associated with each type. Where these individual types are aggregated into broader community groupings for purposes of reporting on management practices and forest yields, large numbers of species may be involved. There can also be a great deal of overlap in species composition between otherwise distinctive forest types.

For purposes of this project it may be appropriate to simplify the definition of community groupings.

The Blackbutt Type incorporates any community with a *Eucalyptus pilularis* component. It may also be associated with *E. microcorys* (Tallowwood), *E. propinqua* (Grey Gum), *E. acmenioides* (White Mahogany), *E. siderophloia/paniculata* (Grey Ironbark), *E. resinifera* (Red Mahogany), *Corymbia maculata* (Spotted Gum), *C. intermedia/gummifera* (Red / Pink Bloodwood), and others. The Dry Hardwoods Type might incorporate all these species, with the exception of *E. pilularis*.

Along the vegetational gradient towards rainforest, both Blackbutt and Dry Hardwoods Types will develop an increasingly mesophytic understorey. *E. pilularis*, and some Dry Hardwoods species will be replaced by *E. grandis* (Flooded Gum) and *E. saligna* (Sydney Blue Gum), and an increasing component of *E. microcorys*, *Syncarpia glomulifera* (Turpentine) and *Lophostemon confertus* (Brush Box). This is the Moist Hardwoods Type.

In a number of areas the Spotted Gum Type will have an *E. pilularis* component. In order to avoid 'double recording' of an area, it will be appropriate to designate any community with *C. maculata* (or *C. variegata* or *C. henryi*) as a Spotted Gum Type.

Given the vegetational complexity of NSW forests, the spatial definition of forest types from satellite images and the National Vegetation Data Base may be problematic. An alternative option would be to use the 13 broad community groupings digitised by State Forests of NSW. These differ only marginally from the forest type structure used in compiling the data tables, for example, within the Tablelands Zone, the New England Blackbutt and Messmate-Brown Barrel Types are amalgamated, despite distinct differences in productivity.

The following 'forest types' are recognised in preparing the data tables.

Coastal Regrowth Zone

The typical coastal forest may consist of a complex mosaic of distinctive forest types based on various combinations of the following:

Rainforest: There are two main types within the Coastal Regrowth and Mountain Zones – the more complex Subtropical Rainforest and the vegetationally and structurally simpler

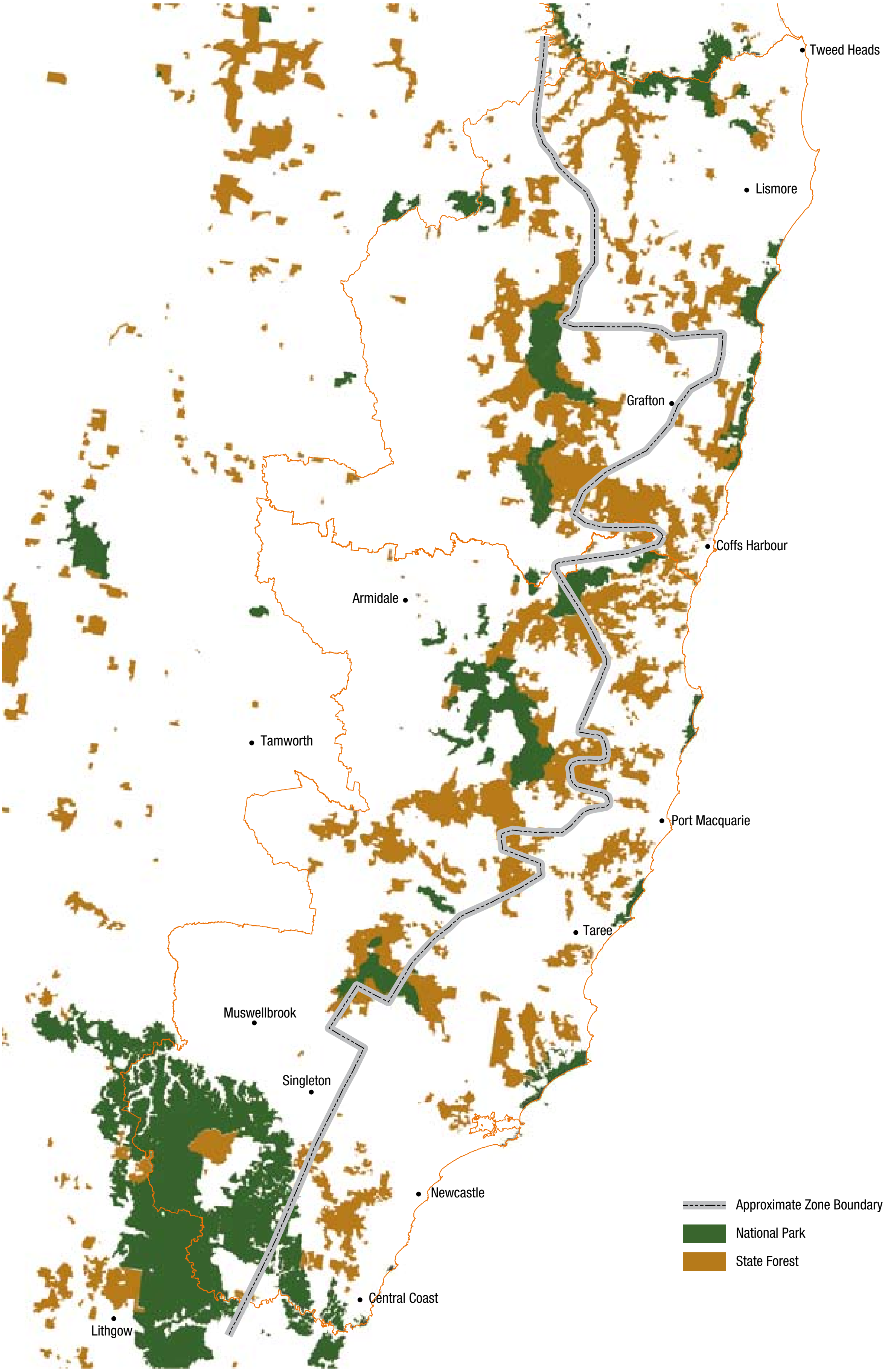


Figure 1. Approximate delineation of the Coastal Regrowth and Mountain Tablelands Zones in northern New South Wales

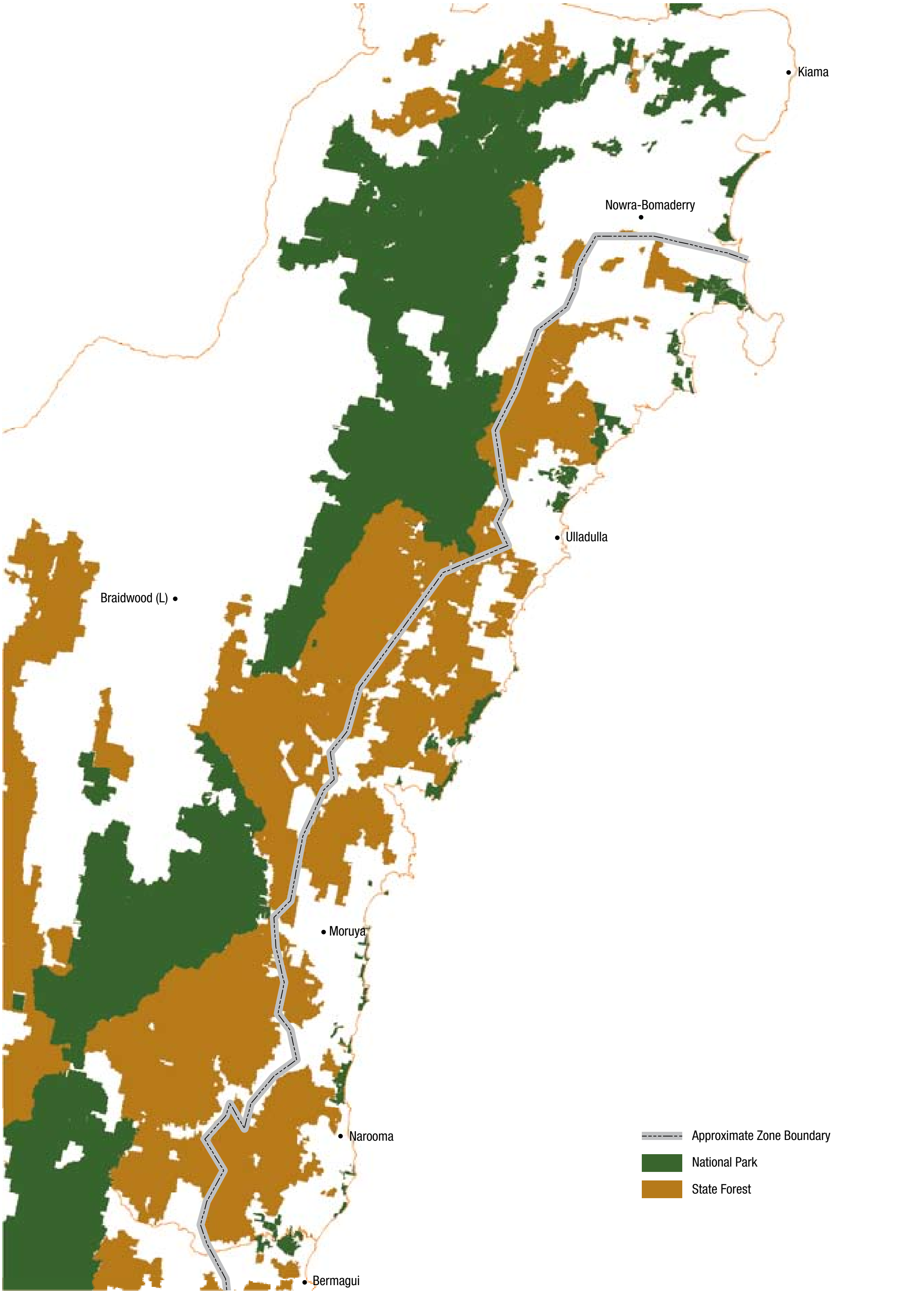


Figure 2. Approximate delineation of the Coastal Regrowth and Mountain Tablelands Zones in southern New South Wales.

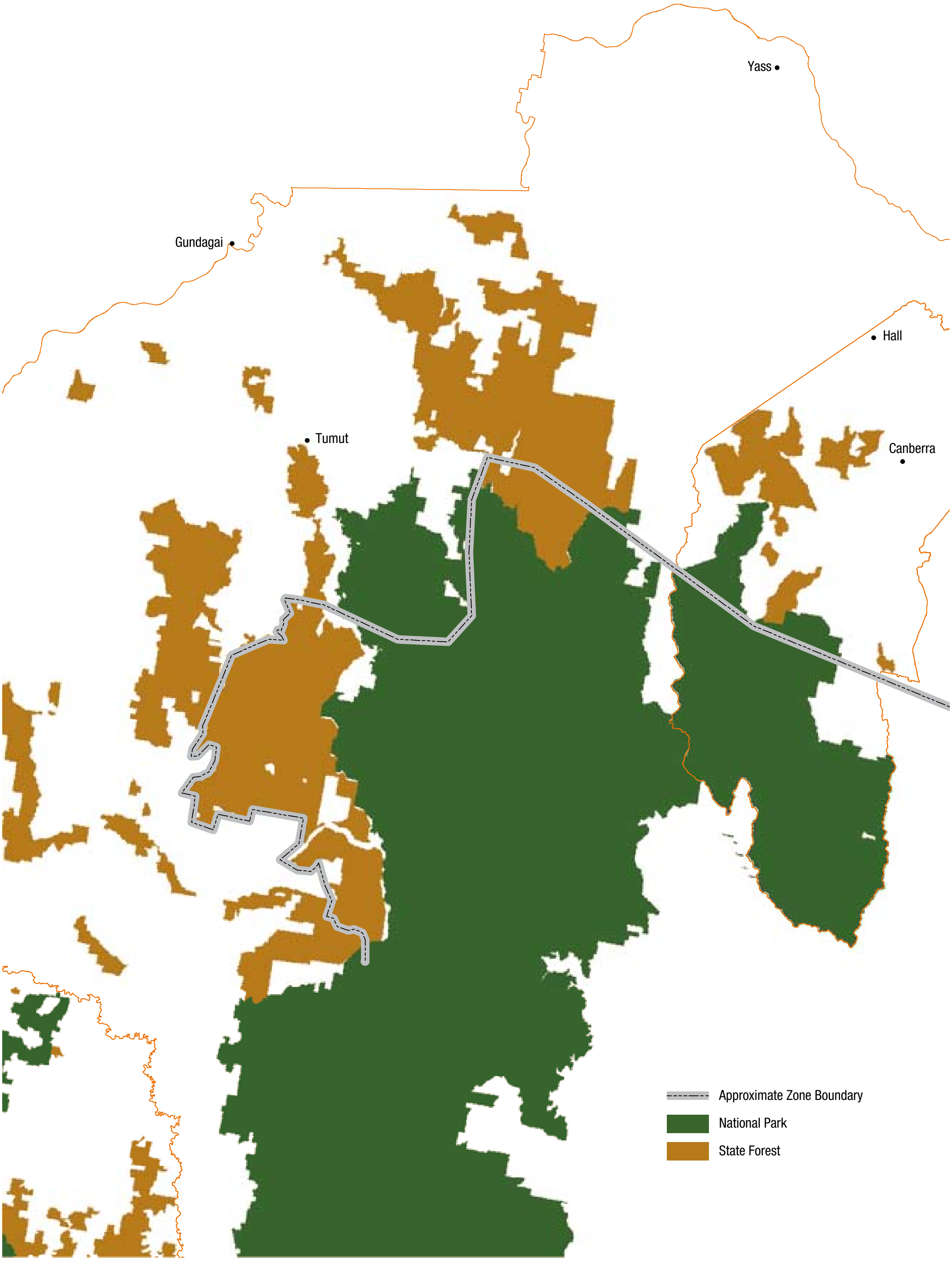


Figure 3. Approximate delineation of the Coastal Regrowth and Alpine Ash Zones in southern New South Wales.

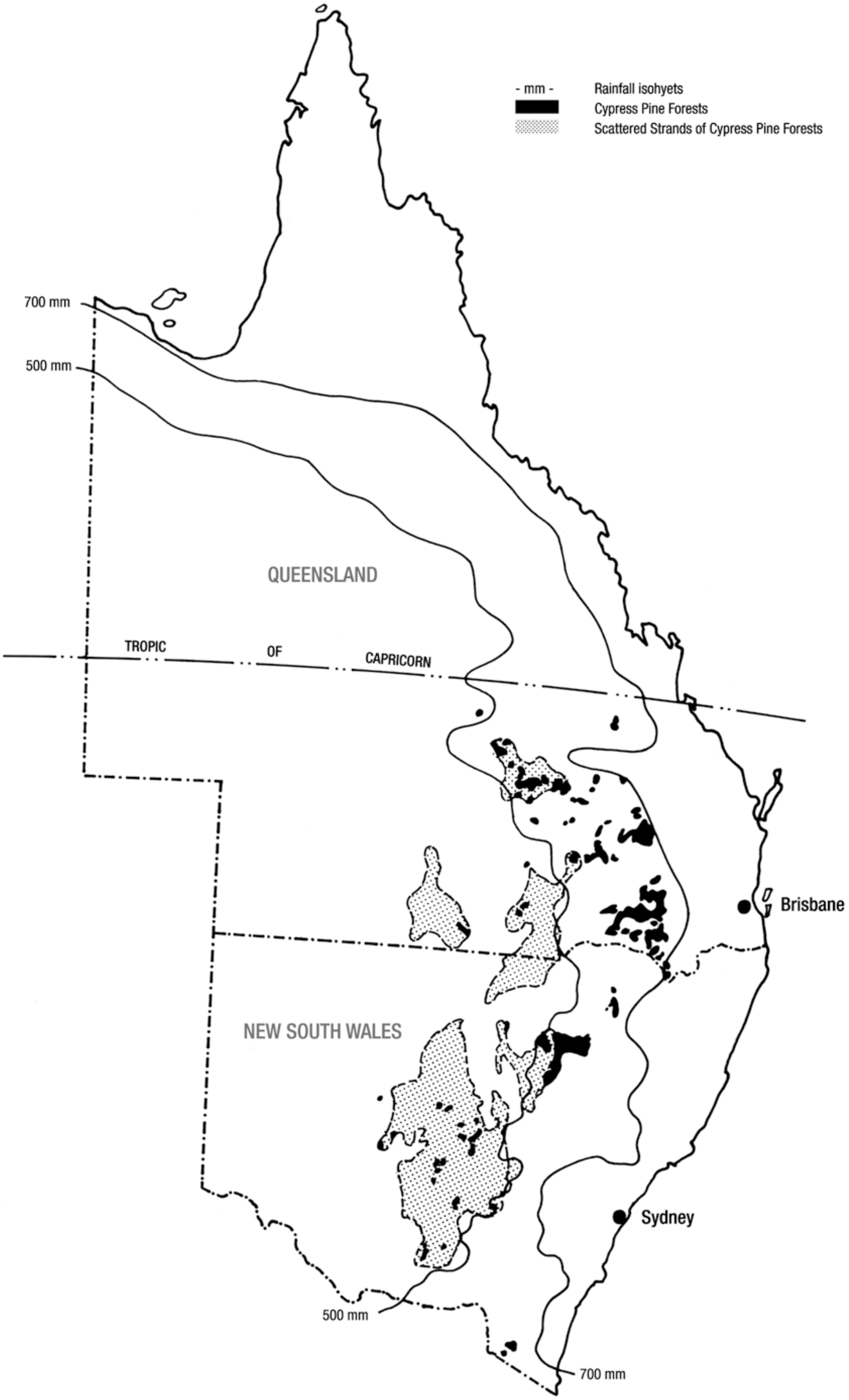


Figure 4. Distribution of Cypress pine forests in NSW and Queensland (source: Johnston and Jennings, 1991).

Warm Temperate Rainforest. Other types of less commercial importance are the Cool Temperate Rainforest and the Dry and Depauperate Rainforest. 'Rainforest' is treated as a single community grouping for this project.

Blackbutt Type: Ecologically, the type occurs as both dry sclerophyll and wet sclerophyll forest and ranges from near-pure stands to those in which *E. pilularis* maintains dominance but in association with a wide range of species (for example, those listed for the Dry Hardwoods Type). The understorey component can range from grasses and scattered sclerophyll shrubs, to a stratum of ferns and rainforest species. For purposes of this exercise the Type may be taken as any community with an *E. pilularis* component.

Dry Hardwood Type: This is the most widely occurring type within the coastal forests, and like the Blackbutt Type, has both dry and wet sclerophyll forms. However, it is rarely dominated by a single tree species, rather, it is a Mixed species forest with varying proportions of *E. propinqua, E. siderophloia/paniculata, E. acmenoides, E. microcorys, E. resinifera, S. glomulifera, L. confertus,* and others. The understorey may be grassy with sclerophyll shrubs, or the same tree species may dominate a wet sclerophyll or rainforest element understorey.

Moist Hardwood Type: This is a broad community type made up of 10 individual forest types (Forestry Commission of NSW, 1989). It often represents the final stage in the transition from eucalypt forest to rainforest. Hence, the forest will normally have a well developed understorey or one with rainforest elements, and an overstorey with various combinations of *E. saligna, E. microcorys, L. confertus, E. grandis, S. glomulifera, E. dunnii* (Dunns White Gum), *E. botryoides* (Bangalay), as well as many of the species listed in the Dry Hardwoods Type.

The Spotted Gum Type: The Spotted Gum forest occurs throughout the coastal districts as the main component in a number of formations. It may be appropriate to characterise any community with a Spotted Gum component as the Spotted Gum Type – although this type can separate the southern and northern Spotted Gum forests: 'Spotted Gum – Southern' Type and 'Spotted Gum-Northern' Type. A recent taxonomic revision divides the former *C. maculata* (syn *E. maculata*) into a number of species – including *C. variegata, C. henryi and C. citriodora* in northern NSW and Queensland, and *C. maculata* in southern and central NSW (Hill and Johnson, 1995).

The Grey Box-Grey Ironbark Type: This is a diverse grouping of types throughout coastal districts – including, for example, the *E. siderophloia/E. bosistoana* (Coastal Grey Box) and *E. bosistoana/E. propinqua* associations of northern NSW (both have associations with rainforest); and the *E. bosistoana/E. longifolia* (Woollybutt) and *E. bosistoana/E. tereticornis* (Blakely's Red Gum) associations on the south coast. There are many associated species, representing an overlap with other types, including *E. melliodora* (Yellow Box), *E. gummifera, E. acmenoides, E. propinqua, C. maculata* and a number of Stringybarks (including *E. globoidea and E. agglomerata*).

For purposes of this project, the Grey Box-Grey Ironbark Type is not differentiated in a management sense from associated types, particularly the Spotted Gum Type. The Grey Box-Grey Ironbark Type is a relatively small component of many forests on the south coast, occurring, for example, on black soils associated with diorite intrusions on 6 per cent of Narooma State Forest.

The Eden Management Area Zone

Silvertop Ash-Stringybark Type: Research Note 17 presents Silvertop Ash-Stringybark as a complex 'League'. For purposes of this project it is best to define a Type by this name which includes the more commercially significant Silvertop Ash and related communities within the Eden Management Area. Thus component species include *E. sieberi* (Silvertop Ash), species of Stringybark (*E. globoidea, E. agglomerata*), *E. consideniana* (Yertchuk), and, in moister gullies and sheltered aspects of the coastal ranges and peaks, *E. cypellocarpa*

(Mountain Grey Gum), *E. obliqua* (Messmate Stringybark) and, in places, *E. muelleriana* (Yellow Stringybark).

For purposes of this project the Silvertop-Stringybark Type includes the Grey Box-Grey Ironbark Type within the Management Area.

Messmate-Brown Barrel Type: This type in the Eden Management Area merges with the Silvertop Ash-Stringybark Type along an altitudinal gradient. Its component species are as described for the Tablelands Zone.

Other types: These include any other coastal Zone dry sclerophyll and largely non-commercial forest not identified above – including, for example, the Scribbly Gum Type (with *E. haemastoma*/*E. signata*/ *E. racemosa*); the Sydney Peppermint/White Stringybark Type (*E. piperita*/*E. globoidea*); the Smooth-barked Apple/Sydney Peppermint/ Stringybark Type (*Angophora costata*/ *E. piperita*/*E. globoidea*), and various types with *Corymbia gummifera* and *C. intermedia* in coastal regions.

The Mountain-Tablelands Zone

This zone incorporates mid-elevation occurrences of forest types within the Coastal Regrowth Zone (Rainforest, Blackbutt, Dry Hardwoods and Moist Hardwoods Types), as well as distinctive types at higher elevations (the Tablelands). There are individual data tables for the Blackbutt, Dry Hardwoods and Moist Hardwoods Types in the Coastal Regrowth and Mountain-Tablelands Zones, respectively. While Rainforest occurs in both Zones, data are recorded only for the Coastal Regrowth Zone. The distinctive Tablelands Types are:

Messmate-Brown Barrel Type: This is often described in Management Plans as 'High Quality Tableland Hardwood'. Some 20 individual types are recognised within the broader League; these are variable in composition and may contain *E. laevopinea* (Silvertop Stringybark), *E. dalrympleana* (Mountain Gum), *E. cypellocarpa, E. maidenii* (Maiden's Gum), *E. nitens, E. radiata* (Narrow Leaved Peppermint), *E. fraxinoides* (White Ash), *E. andrewsii, E. bicostata* (Southern Blue Gum), *E. viminalis* (Ribbon Gum) and *E. rubida* (Candlebark).

The New England Blackbutt Type: This is recorded in Research Note 17 as part of the Messmate-Brown Barrel League. However, it is commonly recorded as a separate type within management plans. This type varies from wet sclerophyll forest to dry sclerophyll forest, and tends to replace the Grey Gum-Grey Ironbark League on shallow-soiled ridges in generally moist, higher altitude sites in northern regions of the State. Thus the type may contain a range of coastal species.

Other Types: Again, these aggregate generally non-commercial forests including the *E. rossii*/ *E. mannifera* (Scribbly Gum/Brittle Gum), and *E. radiata*/*E. dalrympleana*/*E. viminalis* forests of the Central and Southern Tablelands, and a wide range of Stringybark communities.

Alpine Ash Zone

While the Alpine Ash (*E. delegatensis)* forest is part of the Tablelands Zone, it is more productive and has been managed more intensively than Tablelands forests elsewhere, and is treated here as a separate zone.

Alpine Ash Type: This is best defined as any forest with an *E. delegatensis* component. It is a Tall Open forest with a mainly sclerophyll understorey. *E. delegatensis* will normally be the clear dominant - although *E. dalrympleana*, and less commonly, *E. viminalis* may also be dominants. Other associated species may be *E. radiata, E. pauciflora* (snow gum) and *E. cypellocarpa*. The type is replaced at higher altitudes by the Snow Gum Type and at lower altitudes by the Messmate-Brown Barrel Type.

The Cypress Pine Zone

This zone incorporates the White Cypress Pine and Western Box-Ironbark Leagues described in Research Note 17.

Within the Cypress Pine Zone it is appropriate to distinguish between:

The Cypress Pine Type: This is limited to stands of near pure *Callitris glaucophylla*; and

Cypress Pine-Hardwood Type: This includes stands where *C. glaucophylla* is associated with a wide range of other species – including *E. melanophloia* (Silver-leaved Ironbark); *E. crebra* (Narrow-leaved Ironbark); *E. fibrosa* (Broad-leaved Ironbark); *E. trachyphloia* (Brown Bloodwood); a number of box species (*E. melliodora, E. woolsiana ssp microcarpa, E. woolsiana, E. albens, E. pilligaensis, and E. intertexta*); *Allocasuarina luehmannii* (Bull Oak); *E. blakelyi* (Blakely's Red Gum); and others. Research Note 17 recognises the White Cypress Pine Type and 7 other Cypress League Types, depending on associated hardwood species.

Hardwood Type: a further broad community grouping can be characterised as the Western Box-Ironbark League of Research Note 17. It may co-occur with the Cypress Pine Types, and incorporate a considerable number of Box species, *E. microtheca* (Coolabah), various Ironbarks and *E. camaldulensis* (River Red Gum).

The River Red Gum-Black Box/ Coolabah Zone

Near pure *E. camaldulensis* forests with an understorey of grasses, sedges, rushes and other herbs occur in the flood plains of the Murray, Murrumbidgee and other western rivers. Where environmental conditions become less favourable for *E. camaldulensis*, it tends to be replaced by *E. largiflorens* (for example where there is less regular flooding), and subsequently by *E. largiflorens*, *Corymbia tesselaris* (Carbeen) and other species.

Management Practices and Time Periods

A general account of forest policies, strategies and management practice has been given in the main report. More specific management prescriptions are summarised below based on 30 Management Plans prepared during the 1980s, and discussions with Dr R.A. Curtin and State Forests personnel throughout the State. These are described below.

Management practice in NSW cannot be usefully described in terms of classical silvicultural terminology. Rather, practices are best described in terms of management objectives and their impact on the forest canopy. It must be appreciated any one practice can be variable in terms of the level and pattern of canopy disturbance it creates.

In presenting the management practices, it is also appropriate to indicate the time periods in which they have operated.

The Rainforests

Rainforests occur within both the Coastal Regrowth and Mountain-Tablelands Zones. The following management practices apply to both.

Small to moderate canopy gaps: General purpose harvesting within the Subtropical Rainforests was based on the selective removal of around one third of the basal area or 50 per cent of the canopy. This continued until 1975.

Limited canopy disturbance: The Indigenous Forest Policy required that logging in Subtropical Rainforest be for specialty logs only, and this applied from 1975 until the bulk of harvesting was withdrawn from rainforest in 1982, and the remainder in 1992.

Heavy disturbance of the upper canopy stratum: Logging in Warm Temperate Rainforest virtually removed all merchantable stems, exposing a lower stratum of thicket type saplings.

Coastal Regrowth Forest

Selection logging with minimal gaps: From about 1975 to 1995 conservative management practice focused on improving average tree quality within uneven-aged regrowth forest by retaining trees with good increment potential, and thinning within the different age classes. Constraints were placed on regeneration operations, with no formal provision made for creating regeneration openings. There may be difficulties in detecting this level of canopy disturbance on satellite images. Extensive areas of coastal regrowth forest were harvested in this way.

Selection logging with small canopy gaps: Creation of small canopy gaps typified practice in two time periods:

1. During the early post-war period before the advent of chainsaws (1945 to 1955), when typical gap size would be around 30 to 40 m in diameter; and

2. Following completion of the CRA-RFA process in 1998 the RFA determined that for coastal regrowth forests, flexible silvicultural practice would be based on a mix of single tree and group selection logging with maximum permitted canopy gaps of 50 m. Moreover, during this period there has been more rigorous retention of uncut forest (gully strips, wildlife corridors) and wildlife habitat within logging areas.

Variable-sized canopy gaps: More extensive canopy disturbance (50 to 80 m openings) were associated with more complete harvest of mature and overmature trees, ringbarking, and felling to waste of non-commercial growing stock. The irregular (variable) post-logging structure depended on the mix of mature/overmature and regrowth components within the uncut forest. This practice applied generally from 1955 to 1975.

Clearfelling to create largely even-aged stands: This involved two main practices:

1. Clearfelling with seed trees within higher quality or previously harvested mature forest, and clearfelling followed by site disturbance (fire, mechanical disturbance) and sowing or planting. Coupe size was variable, for example, from 10 to 80 ha. This practice applied primarily from about 1955 to 1975, sometimes on previously cutover wet sclerophyll forest. The clearfelling of remnant or old-growth forest ceased in most regions after 1976 but was maintained in the Coffs Harbour and Newcastle regions.

2. Clearfelling of even-aged regrowth stands developed as in (1) above. This applied from the 1990s, sometimes where thinning had been delayed and stand productivity was declining.

Thinning of even-aged regrowth stands: This applies to even-aged logging regrowth and with more extensive areas of even-aged natural (fire) regeneration. These stands are widely scattered through the forests – including Mountain and Tableland Zone forests. The volumes presented in the data tables are an attempt to present average data for a wide range of species and stand conditions.

There was a period in the early 1990s when quite substantial canopy openings were created (the 'Gaps and Clusters' methodology), but this was discontinued following a State Government Inquiry. The general sense in the regions has been that on a statewide basis, the impact was too limited and localised to nominate Gaps and Clusters as a separate management practice.

Eden Management Area (Sawlog/woodchip Export) Forests

Clearfelling: Near total clearfelling applied from the commencement of the operation in 1969 until 1975. This was carried out as a continuous harvest over very large areas rather than on a small coupe scale.

Modified clearfelling in an alternate small coupe (12-15 ha) pattern: This applied mainly to the Silvertop Ash-Stringybark forests (Coastal Regrowth Zone) and to a lesser extent to the Brown Barrel-Messmate (Mountain-Tablelands Zone) forests from 1975 to 1983. The operation entailed retention of a range of stand components, including useful saplings and poles, trees likely to develop into future sawlogs, and wildlife habitat trees. Alternate (logged/unlogged) coupes were 10 to 15 ha in size. There was no post-harvest slash reduction burning or seedbed preparation at this time.

Modified clearfelling as above, but with larger alternate coupes (50 to 100 ha), and low to moderate-intensity post-harvest slash burning. This has continued from 1983 to 2000, though with increasing emphasis on tree retention within coupes (up to 30 per cent of basal area). This practice also included retention of gully strips and wildlife corridors. Indeed, some harvests might now be better described as selection-shelterwood systems.

Mountain and Tablelands Forests

Small canopy gaps: Early harvesting within the Tablelands forests (to the mid-1970s) was based on highly selective logging, or logging based on diameter limit control. The typical canopy gap may have been about 30 m diameter.

Canopy removal approaching clearfelling in some circumstances: This applied from the late 1950s to high quality Blackbutt and Moist Hardwoods Types within the mountainous terrain – a practice described in the Indigenous Forest Policy as 'logging to the limits of economic accessibility'. The practice on a large scale ceased when most old-growth forest was withdrawn from wood production in the 1990s.

Variable canopy openings (small/moderate gaps 30 to 80 m in diameter): This again reflects logging to the limits of economic accessibility, but in lower quality forest with a greater proportion of non-commercial trees (either because of defect or size). This would apply to the Dry Hardwoods Type within the mountains from the late 1950s to the 1990s; and to the Tablelands types from the 1970s when utilisation standards improved and prescriptions called for complete harvesting of all commercial product above a prescribed diameter.

Recut harvesting: This may equate to small/moderate canopy openings (e.g. less than 50 m). It applies to the harvest of residual logs from old-growth forest which had previously been subjected to the logging regime described above. Recut harvesting has been necessary following the substantial withdrawal of old-growth logging from the early 1990s, and has been possible because of improved utilisation capability. Recut harvesting currently provides the main wood supply in some areas.

Alpine Ash Forests

Moderate to more extensive gap creation: This applied from 1955 to 1972. While the term 'group selection' has been applied to this operation, a substantial proportion of the canopy could be removed as sawlogs and in follow-up TSI (canopy gaps to 70 or so metres). Note also that the forests were subject to severe phasmatid attack between 1953 and 1963.

Small gap creation: This involved single tree selection based on quality stem retention, that is, retention of vigorous trees irrespective of size (canopy gaps 20 to 30 m). This applied from 1972 and is consistent with provisions of the Indigenous Forest Policy

Clearfelling: This applied from 1968 only to the previously unlogged Maragle State Forest – based on harvest or culling of all mature and overmature trees. Clearfelling ceased in 1988 when thinning of older stands began.

Thinning: This refers to thinning of stands which had been regenerated early in the 20th century (sometimes referred to as 'Shelterwood-type' harvesting). Thinning was light until 1980 (20 per cent canopy removed) and heavier thereafter (40 per cent removed).

Cypress Pine Forests

There is considerable variation in the composition, structure and condition of the Cypress Pine-Hardwood forests – including mature/overmature (19th century) sawlog stands, most of which are currently being logged; submerchantable stands of similar age, and the 1950s regrowth component in varying stages of release. Moreover, in some areas (e.g. the Pilliga), as much as one half to one third of the basal area may be of non-commercial material, that is, neither *Callitris glaucophylla* nor commercial hardwood.

The following practices apply.

Small to moderate canopy openings: From 1950 to 1970 management practice involved commercial thinning of the 19th century *C. glaucophylla* regrowth and its release from mainly hardwood competition. Ringbarking of competing hardwood reached a peak in the late 1960s, and declined thereafter, ceasing in some forests as early as 1972. At this time continuing treatment involved non-commercial thinning of 1950s regrowth; some non-commercial thinning of stagnant 19th century regrowth was also carried out.

This silvicultural description also applies to the Cypress/Hardwood and Hardwood/Cypress Types where there has been a focus on both the harvesting (sleepers and poles) and culling of the hardwood to release the 19th century *C. glaucophylla* regrowth. The sleeper market has declined since 1990 and the current hardwood market is mainly for posts, landscape material and firewood. Where culling has been inadequate, highgrading may have left a stocking of badly formed and defective eucalypts.

Yet again, the description applies to Hardwood forest where there has been selective logging for sleepers, posts, poles, landscape material and fuelwood.

Thinning/Shelterwood harvesting: Logging in the more pure *C. glaucophylla* forests has been based on progressive harvest of the mature 19th century stratum which overtops the 1950s regeneration. Initially this was based on progressive thinning but in the 1990s regrowth has been released more rapidly, creating shelterwood-type stands with wide spaced trees overtopping the 1950s regrowth.

Low intensity selection: This has been used to describe harvesting within the more western (drier region) *C. glaucophylla* forests where only a limited component of the stocking may be of commercial quality.

River Red Gum Forests

Moderate canopy openings (to 70 m diameter): This description applies to operations in the *E. camaldulensis* forests from 1950 to around 1975. It involved harvesting of mature/overmature trees with ringbarking and reject tree felling to release developing regrowth. Operations were more intensive on the Murray than on the Murrumbidgee-Lachlan River forests.

Conservative selection: Following the Indigenous Forest Policy there was an increasing emphasis on multiple use values. From 1975 there was some harvesting of mature and overmature trees, but the focus was now on retaining and releasing trees with continuing increment potential, including thinning of the regrowth which had developed early in the century.

There is little information for the Black Box/Coolabah forests. *E. largiflorens* and *E. microtheca*, together with associated *C. glaucophylla* and *Casuarina cristata* (Belah) have durable woods and have been cut in low volumes for posts, fencing timber and fuelwood. However, harvesting in these forests would have little quantitative effect on wood flows and forest carbon balance.

Quantitative Information on Forest Practices

Percentage of Basal Area Removed in Harvesting

Most selection practices described in this report remove a variable proportion of stand basal area. While a percentage basal area removed is presented for each treatment, this is an average applying broadly to the practice, but not necessarily to specific parts of the harvested area. For the same reasons, and because of a lack of relevant records, it is not possible to indicate the proportion of a forest subjected to different levels of canopy disturbance.

Timber Stand Improvement (TSI)

In early operations, TSI (ringbarking of old trees, and felling of trees of marginal sawlog quality) was often incomplete, and any given stand may have been treated several times. Because there are no records of the amount of wood removed from a stand in this way (it would have been highly variable both between and within forest types) no objective data can be given in this report. Rather, an estimate of its impact on canopy cover is included in the data tables, and provision is made for ringbarked and felled trees in estimating harvesting residues (see Forest Residues).

Harvesting Volume Estimates

The project calls for information on product volumes harvested by forest type and time periods. While some Management Plans do indicate gross volumes harvested per ha, this may or may not be presented on a forest type basis. Management information has been collected and published in Annual Reports on an administrative area basis and thus may incorporate harvest and other information from two zones (e.g. the Coastal Regrowth and the Mountain-Tablelands Zones), or from several forest types within each zone. Even if it were possible to gain access to individual harvesting area reports, the data would probably cover several forest types.

Sawlog volumes: Against the above background, most of the information needed to complete the data tables has been based on 'professional judgement' and informed estimates backed up by relevant (though limited) information in some management plans. Despite a wide range in harvest volumes, there was good agreement, from region to region, on 'typical' sawlog volumes by forest types and management practices. For example, the Chichester Area Management Plan shows an average 87 m^3 ha^{-1} harvested from nine areas which broadly fall within the Moist Hardwoods Type. Quite independently, the regional concensus reached for this type was an average 90 m^3 ha^{-1}. Similarly, the average harvested volume for Dry New England Blackbutt and Dry Hardwoods Types within the Chichester Plan was 26 m^3 ha^{-1}, again consistent with the consensus yields.

Pole-pile-girder-sleeper-mining timber volumes: Information based on the Spotted Gum Type in the Batemans Bay region shows that about 5000 m^3 of poles, piles and girders were harvested annually between 1970 and 1993. This represents 5 per cent of the total volume harvested in the region. Pole/pile/girder harvests presented in the data tables for the Spotted Gum Type-Southern Zone are based on this. The harvest reached a greater peak at an earlier time (about 10 per cent of total volume). Account is taken of this in compiling the data tables.

Estimates of the pole/pile/girder harvest for the north of the State have been derived from information supplied in SFNSW Annual Reports. There was a sharp decline in the relative production of poles/piles/girders from 6 to 8 per cent of sawlog production during the 1960s, 70s and 80s, to around 3.5 per cent from 1990 to 1995, and only 1 per cent in the late 1990s. These percentages have been used to estimate pole/pile/girder volumes for the different time periods. A greater part of the volumes has been subjectively allocated to the Dry Hardwoods Type which has been the prime source of durable poles, piles and girders.

Pulpwood: Most pulpwood in NSW has come from the Eden Area forests. Data on the pulpwood harvest (t ha^{-1} yr^{-1}) have been provided by State Forests of NSW for both the Silvertop Ash-Stringybark, and Messmate-Brown Barrel Types.

Pulpwood production elsewhere commenced around 1982/3 (Buladelah/Chichester), 1984/85 (Wyong, Batemans Bay, Murray Management Area) and 1989/90 (Coffs Harbour).

Local foresters advised that in the Batemans Bay region yields of quota sawlogs, salvage logs and pulpwood are in the approximate ratio of 1:1:1. This provides a good basis for completing the data tables for the Spotted Gum Type in the southern region.

Pulpwood production in the regions north of Sydney (based on Newcastle, Wauchope and Coffs Harbour) was around 170,000 t yr^{-1} in 1996/97. The Newcastle and Wauchope regions each extracted around 70,000 t yr^{-1}, half from salvage material drawn from native forests, and half from plantations. Pulpwood was derived from all forest types, including thinning of regrowth within the Messmate-Brown Barrel forest of the Tablelands. Pulpwood has not been extracted from natural forests in the northern sector of the State (Coffs Harbour region), but has been harvested from plantations since 1989 (around 25,000 t yr^{-1}).

The current pulpwood estimates for the regions north of Sydney are based on the assumption that 50 per cent of natural forest within the Coastal Regrowth and Mountain-Tablelands Zones have been subject to pulpwood harvest. Pulpwood yields are based on sawlog: pulpwood: slash relationships for high quality moist forest, and dry lower quality forest, respectively, in north-east NSW (from Snowdon *et. al.*, 2000, based on original NSW data). The relationships differ for forests subject to single tree selection and patch cutting, respectively. The pulpwood harvest from forests north of Sydney commenced around 1985, and the data have been further modified to take account of the progressive build up in yield from this time.

Firewood: There has not been a great demand for firewood from State forests, and the limited production shown in Annual Reports could be reasonable, though it is generally agreed that there has been some unrecorded firewood removal. The best information on firewood harvest came from Batemans Bay region where some 10,000 t are sold per year. This is equivalent to one-tenth of one t ha^{-1} overall, or about 2 t ha^{-1} from an individual logging area. Elsewhere, it is difficult to show how the 50,000 t of firewood per year might be apportioned to forest types on a per hectare basis.

Foresters in northern (subtropical) NSW see firewood as a relatively minor product. There is no firewood production on a recordable scale from the Eden Area forests. However, it is an important product in western regions (mainly River Red Gum forests and hardwood species associated with Cypress Pine forest).

Conversion of Volumes per ha to tonnes per ha

Harvest volumes are presented in the data tables as tonnes per ha-1 AD (air-dry). The conversion has been based on wood density information given in Boas (1947) for a range of eucalypt species, rainforest species and Cypress Pine. For example, the AD weight of Blackbutt is approximately 0.9 t m^{-3}, 1.05 for species of the Dry Hardwoods Type, and 0.68 for Cypress Pine.

Post-harvest Production Estimates

Work is currently being undertaken by SFNSW to improve estimates of the mean annual wood production associated with different forest types and practices. However, for the present, post-harvest productivity estimates are derived from published State Forests data for a number of coastal eucalypt forests, rainforests and Cypress Pine forests (Curtin *et. al.*, 1991; Baur, 1991). Estimates for all forest types and management practices were discussed with Dr Curtin and regional and planning managers, and a reasonable consensus reached.

Post-harvest productivity, expressed in m^3 ha^{-1} yr^{-1} is relatively low in NSW forests. Thereare several reasons for this: full site production has rarely been an objective of management; the structure of selectively harvested forest will often limit stand productivity; the forests are variably understocked; and not all growing stock will be in a vigorous condition.

It is difficult to estimate total biomass increment with any confidence, particularly where stocking of the uneven-aged forest is variable, part of the growing stock is in a non-vigorous condition, or there is a substantial understorey. This is a matter which will need to be considered further.

Percentage Adequately Regenerated/ Percentage of Full Site Stocking

The 'adequacy of regeneration' is not necessarily relevant to a selectively harvested forest, for example, where conservation and stimulation of existing growing stock is the most important objective of management. Hence the 'percentage adequacy of regeneration' is taken to represent the completeness of the stocking as it relates to the stand as a whole. Under extensive management regimes this is inevitably below 100 per cent. Thus 70 per cent is a typical figure for the Blackbutt Type, and as low as 20 to 30 per cent for the Moist Hardwood Type where there has often been limited post-harvest regeneration.

Forest Residues

Biomass and residue data for the Eden Management Area (subject to clearfelling, or 'modified clearfelling') have been derived from biomass information for the Mixed species forests of East Gippsland (Flinn *et. al.*, 2007). It is assumed that residue levels within broadly similar forest will be correlated with the harvested biomass with consideration also given to the degree of pulpwood removal. Flinn *et. al.*, (2007) give a harvest biomass of 155 t ha^{-1} for mature Mixed species forest of medium to high quality; the estimated harvest biomass from the Eden forests is 105 and 140 t ha^{-1}, respectively, for the Silvertop Ash-Stringybark and Messmate-Brown Barrel Types. Residue levels for the Eden Area forests have been determined on a proportional basis using the Victorian estimates.

Several approaches were taken for estimating slash residue in selectively harvested forest. The most appropriate appeared to be that based on the weight of harvested sawlog, and the proportions of the total biomass which might be allocated to sawlog, pulpwood and slash residues, respectively, within the northern NSW forests (Snowdon *et. al.*, 2000). The amount of residue varies with the biomass harvested, site quality, the availability of a pulp market, and the silvicultural practice (single tree selection, patch cutting/clearfelling).

In the absence of realistic guidelines for a very wide range of forest communities and harvesting intensities, estimates of *total* slash residue only are presented in the data tables.

Prescribed Burning in NSW

Two types of fuel reduction burning apply to New South Wales:

1. **Pre-harvest or post-harvest slash burning:** This is usually of low to moderate intensity designed to reduce fine fuel weights up to 75 per cent on 30 to 60 per cent of the gross area so treated. After such fires the fine fuel weight may recover to 70 to 80 per cent of the pre-burn weight in 2 to 3 years; and
2. **Low intensity broadacre prescribed burning:** designed to reduce fine fuel weight on 35 to 60 per cent of the area treated.

Pre- or post-harvest slash burning and broader prescribed burning have not been used in any consistent way in NSW. Where used, the post-harvest burn has been mild or, of moderate intensity, contrasting with the intense slash burns routinely used in the southern States to reduce fuel loads, create receptive seedbeds and establish even-aged forest stands.

There are no consistent or readily available records on the extent of either slash reduction or prescribed burning in the northern part of the state. The main reasons for the conservative use of fire lie in the greater vegetation complexity in New South Wales, the use of the selection harvest system, and the competition which can be generated by fire successional species in a subtropical, summer rainfall environment.

The following account of burning practice is derived from discussions within the regions.

Lower and Upper North-east regions: Currently there is only limited post-harvest slash reduction burning in forests north of Sydney. Indeed, some recent coastal regrowth harvesting plans stipulate that post-harvest burning will be necessary only where less than one-quarter of the soil is disturbed in small patches distributed evenly over the gap. Similarly, a Tablelands management plan recommends the use of post-harvest fire only 'where desirable and practical'.

It was suggested in discussion that 50 per cent of logged coastal regrowth areas may have received a light to moderate slash reduction burn before 1970, and 60 to 70 per cent of the logged areas during 1970 to 1985 (following the severe wildfires of 1968). However, during the last decade the figure would be closer to 20 per cent, and within that 20 per cent, less than 50 per cent of the net harvested area would have been burnt. The low level of slash burning reflects climatic factors within the subtropics, availability of labour, costs, conservation considerations and general social concerns about smoke pollution.

Post-harvest burning may have been used more consistently within wet sclerophyll forest in mountainous terrain. It was suggested that around 50 per cent of old-growth (mountain) forests have probably received a post-harvest burn. Around 10 per cent of these burns would have been 'hot', others moderate. A higher percentage may have applied to Moist Hardwood forest where regeneration is more critically dependent on fire.

Broader prescribed (protection) burning has also declined in the northern regions of the State. For example, while the mid-North Coast Region has a general policy of burning about 2 per cent of the forest area per year, this is rarely achieved. During 1997 to 2000 there was no prescribed burning at all in this region. A recent survey has indicated that the percentage of forest actually burnt in a typical prescribed burn is very low. This reflects particularly, the increasingly mesophytic understorey beyond upper slopes. At most, the region now aims to burn around high value assets. This would also apply to the North East Region.

The Southern region (based on Batemans Bay): Fire is used more widely in this region – 80 per cent of all logged area receive a post-harvest burn (contrasting with the estimated 20 per cent in the northern regions). Annual prescribed burning covers 13,000 ha – around 6 per cent of the total forest.

Eden region: Post-logging burning was not carried out in the Eden region until 1982, following the severe wildfire of 1981. This is regarded as a high risk area because of climatic factors, the dry sclerophyll vegetation, the large areas harvested, and the intensity of harvesting. Eighty per cent of all harvested areas are now post-log burnt, and there is a regular program of fuel reduction burning.

Western region: Neither post-harvest slash reduction nor broadacre hazard reduction burning are used in western region forests, including the Cypress Pine and River Red Gum forests. Fire is not generally used in the Alpine Ash forests, though there was a period during the 1980s when some post-log burning was carried out.

Burning Efficiency

In the absence of experimental data on burning efficiency in NSW, it was assumed that 80 per cent of the fine fuel would be consumed in a moderate slash reduction/regeneration burn, and 50 per cent of the coarse woody fuels. The percentages are increased to 90 and 60 per cent, respectively, for fine and coarse fuels in the Moist Hardwood Type. These percentages have been applied to the burn efficiency formula used by Flinn *et. al.*, (2007).

Thus for the southern Spotted Gum Type, burning efficiency would be:

Fine fuels: 80% loss over 60% of coupe area over 80 % of coupes = (approx.) 40%

Coarse fuels: 50% loss over 60% of coupe area over 80% of coupes= 24%

Burning efficiency (i.e. fraction of available fuel actually burnt) would be much less in northern NSW. For example, during the past decade, burning efficiency would be around 10 per cent for fine fuels, and for coarse fuels only, 6 per cent.

SECTION 3

Victoria

David Flinn

Ross Squire

Kevin Wareing

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

VICTORIA

SUMMARY

Changes in forest management practices in Victoria's public native forests since 1945 have been reviewed and the potential implications for forest carbon (C) stocks have been discussed. Privately owned native forest has not been included in the review as the quantity of timber harvested is relatively small and management records are poor.

The history of Victoria's forests over the last 150 years has been closely correlated with the changing needs and values of the community. The forests have been variously perceived as a virtually inexhaustible resource to be heavily exploited for mining timbers and fuelwood, as a barrier to agricultural development, and as a resource to be managed for a range of uses and values.

By 1945 the rate of alienation of Crown Land had declined and in the immediate post war years the focus of forest management was primarily on meeting the increased demand for building timber, expanding plantations to reduce the cost of timber imports, and improving the protection of forests from fire.

Emerging concerns commencing in the 1960s, about the management of native forests and the priority being given to timber production over other forest uses, have led to significant changes in forest land use and forest management. These changes have included cessation of the conversion of public forest to agriculture, a ban on the clearing of native forest for plantations, establishment of a comprehensive, adequate and representative system of parks and reserves, and the adoption of ecologically sustainable forest management principles.

For the purpose of the review it was decided to adopt the following four forest types:

- Ash (*E. regnans* and *E. delegatensis*).
- Mixed species.
- River Red Gum.
- Box-Ironbark.

Annual Reports by successive Departments responsible for State forests since 1945 have consistently reported forest production and forest management data according to these four forest types.

The floristics and management of each of the forest types is described and detailed information on biomass removals, residue management and growth rates of regrowth forests following harvesting are given for each five-year interval from 1945 to 2000. This information is used as the basis for discussing the implications of past management practices on forest carbon stocks.

Amongst other things, the review highlights changes in silvicultural practice in response to research and development, the consistent annual removal of about 2 million m^3 of sawlogs, firewood, pulpwood, sleepers and fence posts, and the extensive use of fire for regeneration. It also highlights the high priority given to regeneration success in Victoria following timber harvesting.

1. INTRODUCTION

This review is part of a national project being undertaken by the Australian Greenhouse Office (AGO) to develop a system for tracking and forecasting carbon (C) stocks and fluxes in Australian forests. In order to make reasonable forecasts of future C balance for forests, it is necessary to have knowledge of forest management practices and their impacts over approximately the past half century. The major impacts, excluding changes in forest area, relate to biomass removal (i.e. harvested products), treatment of logging residues (e.g. heaping and burning), and different growth rates of the newly regenerated forests.

The purpose of this review is to describe temporal changes in forest management practices, and to discuss the potential implications of such changes for forest C balance. The emphasis is on management practices with the potential to cause significant changes in C stocks, such as the widespread adoption of intensive harvesting (e.g. clearfelling) and regeneration burning since the 1960s and 1970s. A detailed quantitative assessment of C balance for part or all of the forest estate is beyond the scope of this review.

2. THE FOREST ESTATE

Early Victorian governments were indifferent to the management and conservation of Victoria's forests. In 1883 a State Forests and Nurseries Branch was established and, until 1907, this Branch was shifted around between the Departments of Lands and Survey, Agriculture and Mines.

Pressure on successive governments to implement more effective controls over the alienation and use of forests, which commenced in the latter part of the nineteenth century eventually led to the passing of legislation in 1907 that established the State Forests Department. The new Department and its successor, the Forests Commission, Victoria, strove to limit the alienation of high value areas of forested Crown Land, establish forest reserves for timber production and implement measures to improve the management and protection of the forest resource.

By 1945 the rate of alienation of Crown Land had declined and in the immediate post war years the focus of forest management was primarily on meeting the increased demand for building timber, expanding plantations to reduce the cost of timber imports, and improving the protection of forests from fire. Timber production from native forest on private land has been limited and consequently, has not been included in the review.

By the 1960s concerns were emerging about the quality of Victoria's forest environment and the priority being given to timber production over other forest uses. These concerns led to the formation in 1970 of the Land Conservation Council, which was constituted to make recommendations on the balanced use of public land in Victoria.

The formation of the Land Conservation Council and acceptance by successive Governments of the vast majority of its recommendations has resulted in major changes in the use of public land in Victoria. These changes include the cessation of the alienation of public land for agriculture and a substantial increase in the area of public land reserved for National and State parks.

Some 38 per cent (8.51 million ha) of the total area of Victoria (22.74 million ha) is public land and predominantly native forest and woodland. Changes in the use of public land between 1970 and 1997 are shown in Table 1.

Table 1. Public land use in Victoria for the periods 1970 and 1997.

Land use 1970	% of public land	Land use 1997	% of public land
National parks	2.2	National and State parks, wilderness	34.8
Conservation reserves	0.5	Conservation reserves	10.0
Reserved forest	25.7	State forest	41.8
Unreserved Crown Land	58.1		
Other reserves	6.0	Other reserves	6.1
Services and utilities	7.5	Services and utilities	7.3

Source: Land Conservation Council (1997).

Notwithstanding the progress made by Victoria in addressing the competing demands of conservation and industry on native forests, the Commonwealth and Victorian Governments have entered into a series of Regional Forest Agreements (RFAs) over part of the forest estate that aim to:

- Establish and manage a comprehensive, adequate and representative (CAR) forest reserve system.
- Establish ecologically sustainable management of the entire forest estate.
- Develop an efficient, internationally competitive timber industry.

The Regional Forest Agreements signed for the East Gippsland, Central Highlands, North East, Gippsland and West Regions have been principally concerned with the management of State forests for a range of uses and values. The principal instrument for integrating forest values such as timber production, conservation of biodiversity, water quality and yield, recreation and tourism and the management of historic and cultural sites, is the development of Forest Management Plans (described later).

2.1 BACKGROUND TO VICTORIAN FORESTRY

Preamble

There have been some excellent books written on the history of Victoria's forests (e.g. 'Secrets of the Forest: Discovering history in Melbourne's Ash Range' by Tom Griffiths). There have also been Royal Commissions into the use of the forests and the impacts of wildfire, and a number of formal timber inquiries have taken place in the last century. The common thread in all of these accounts is a series of crucial historical events that have had profound impacts on Victoria's forests.

The main historical and contemporary factors that have shaped the condition of Victoria's forests presently available for commercial forestry include:

- Discovery of gold.
- Use of wood as a major energy source from the 1850s to the 1950s.
- Major wildfire events in 1851, 1898, 1919, 1926, 1932, 1939, 1983, 1985 and 2003.
- Post-war housing boom leading to access to the alpine and eastern forests.
- Research into regeneration practices, particularly for the Ash species.
- Environmental concerns leading to the expansion of National parks and reserves.

In more recent times the major influences have included:

- The commissioning of the standard gauge railway line from Melbourne to Albury in the early 1960s, with a concomitant increase in sleeper production from the Mixed species, Box-Ironbark and River Red Gum forests. Sleeper production peaked at around 100,000 $m^3 y^{-1}$ in this period compared with less than 4,000 $m^3 y^{-1}$ today, reflecting amongst other things the closure of many country railway lines in recent times.
- The 1986 Timber Industry Strategy (Gov, 1986), leading *inter alia* to a new Code of Forest Practices for Timber Production and an early commitment to the concept of sustainable forest management, recognising the importance of the social, cultural, economic and environmental values of forests.
- Expansion in the sale of residual logs in the 1990s.

Today, most publicly owned native forest in Victoria is managed within a framework of Regional Forest Agreements signed off by the Victorian and Federal Governments. These Agreements attempt to strike a careful balance between jobs and industry development and conservation and cultural values.

The supply of wood products from the native forests of Victoria was crucial to the development of the State. Victoria relied very heavily on the forests as an energy source for industry and households via fuelwood production, and a source of timber - particularly structural timbers - to facilitate post-war economic development including house construction and infrastructure. As an example of the reliance on the native forests for energy, an average of 1.34 million $m^3 y^{-1}$ of firewood was harvested during the period 1946 - 1950. Similarly, by 1955 the annual sawlog cut was also 1.34 million m^3 compared with a present day harvest of around 800,000 $m^3 y^{-1}$.

Historical Perspective

In 1824, Victoria was mainly forested land (Figure 1). There was no widespread clearing of the forests until the gold rushes in the 1850s. The early colonists favoured natural clearings and woodlands that could be grazed and ploughed easily. Their grazing runs had few fences. Timber was mainly used for homesteads and outbuildings.

Huge amounts of timber were required to provide fuel for the numerous company gold mines operating in Victoria in the second half of the nineteenth century. The miners stripped the vegetation from the land above and around alluvial gold deposits, and clearfelled nearby forests for timber and fuel. Timber cutting for the mines, however, was not the cause of forest clearing depicted in Figure 1, because the forests regenerated in most instances. When the shallow alluvial gold ran out, many of the miners turned to farming small selections developed by felling or ringbarking the trees in open forests. Clearing for agriculture, not timber production, was therefore the primary cause of forest destruction.

Vast quantities of the timber felled by squatters and selectors were wasted, and a Royal Commission was established in 1897 to examine the State's forests and timber reserves. The Commission warned of the need to reserve and protect the forests from indiscriminate clearing for agriculture, and an urgent requirement for better forest management to ensure future supplies of timber.

The need for effective control of early exploitation led to the establishment of the Forests Commission in 1918. This initiative signalled many strategic changes, including the reservation of forests to restrict alienation for agricultural development, the expanded proclamation of areas of forest as water reserves, the regulation of yield and sale of timber, and the development of a credible fire protection capacity. Little was known about the natural processes controlling regeneration and healthy growth of the dominant eucalypts. In general, regeneration depended on the retention of seed trees. Only scant attention was given to seedbed preparation, which mainly consisted of soil disturbance during harvesting (e.g. mountain forests) or a form of slash burning in the coastal and foothill forests which also had a dual fire prevention objective. During this time, the forest estate continued to decrease as more land was cleared for agriculture.

Fortunately, most of the forest in and around the goldfields regenerated either by seedling, coppice or lignotuberous growth. These regrowth forests subsequently became an important source of timber. As an example, the Wombat Forest was declared a 'ruined forest' by the end of the nineteenth century, yet it has supplied high quality sawlogs to industry for the past few decades.

As noted earlier, there have been many devastating wildfires since european settlement. Perhaps the best known are the 1939 fires. Early in January 1939, bushfires swept out of control across the State, reaching their climax on Black Friday, 13 January. About 1.3 million ha of forest land were burnt. Work began at once to salvage timber from the burned areas. The salvage program supplied most of the heavy war-time demand for timber and continued for a number of years after the war. More than 4.5 million m^3 of timber had been salvaged by 1950.

The end of World War II resulted in unprecedented demands on Victoria's forest resources. Over 300 hardwood mills were established to satisfy the increased demand for timber for public construction as well as private housing.

As salvage logging was phased out, major access roads were constructed into the alpine forests of north-east and north-central Gippsland. These forests became the main source of high quality timber. In 1949, the Forests Commission began a large scale program to reforest derelict farmland in the Strzelecki Ranges. In the 1960s, East Gippsland became another major source of hardwood logs.

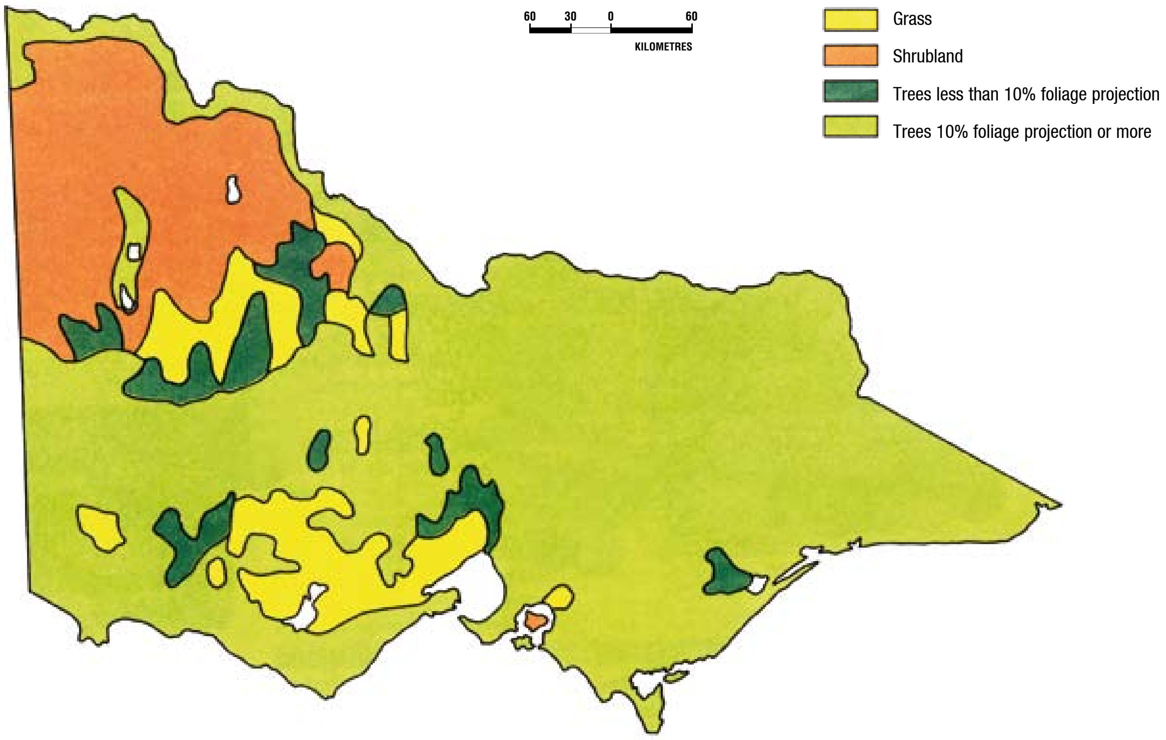
Overview of Forest Ecology

An excellent account of the ecology of Victoria's commercially important forest types is provided by Campbell *et. al.,* (1984). Over 90 per cent of the land surface of Victoria was originally occupied by eucalypts, including a wide variety of species and an extraordinarily wide range of plant associations. The eucalypts invariably dominate the plant associations in which they occur, but they form only one component of the ecosystem. Since the arrival of Hume and Hovel in 1824, much of the tree covered area on the flat lands and foothills has been cleared for agriculture. Forested land is now restricted to about 36 per cent of the land surface (Figure 1). The map *Forests of Victoria* (Figure 2) shows the present extent of the forests, classified according to principal tree species. It is recognised that the Department of Sustainability and Environment has a more detailed and up-to-date floristic map of the State, but the 1984 map has been adopted for this review as it is consistant with the forest types used in providing data on silvicultural operations in past Annual Reports. These data are crucial to the current review.

The presence of fire in the Australian environment is thought to have given the eucalypts a competitive advantage in the evolutionary processes (Jackson, 1968) and is reflected in many adaptive characteristics (e.g. epicormic shoots and development of lignotubers) and, in some cases (e.g. wet sclerophyll eucalypts), an apparent dependence on fire for long-term survival. The survival and proliferation of eucalypts following fire is ensured by the storage of large quantities of seeds in the canopy that are protected from fire by resistant capsules (Ashton, 1981) and then subsequently released onto the fire-prepared seedbed where they germinate and grow rapidly.

Adaptations of the eucalypts to low soil fertility (particularly phosphorus availability) and high moisture stress during periods of drought have also contributed to their evolutionary success. The eucalypts are capable of relatively high production of biomass on soils of limited fertility through adaptations such as withdrawal of nutrients prior to leaf fall (Florence, 1981) and highly efficient mechanisms for nutrient uptake (Jackson, 1968). Adaptations to drought include the ability to promote leaf fall and restrict biomass production under conditions of moisture stress (Florence, 1981) and development of xeromorphic leaf characteristics. Soil phosphorus appears to have been particularly important in determining species composition and production capacity of the vast array of Australian floristic communities.

Victoria's commercially important native forests are found in the mountains, foothills and plains, and exhibit great floristic and structural diversity. They range from the pure forests of *Eucalyptus camaldulensis* (River Red Gum) along the middle reaches of the River Murray to the highly productive forests of *E. regnans* (Mountain Ash) in the Central Highlands, the tallest flowering plant in the world. For the purpose of this review, Victoria's forests have been subdivided into a number of main forest types. The details and rationale for this subdivision are given later, along with a brief description of each forest type in terms of floristics, structure and management history.



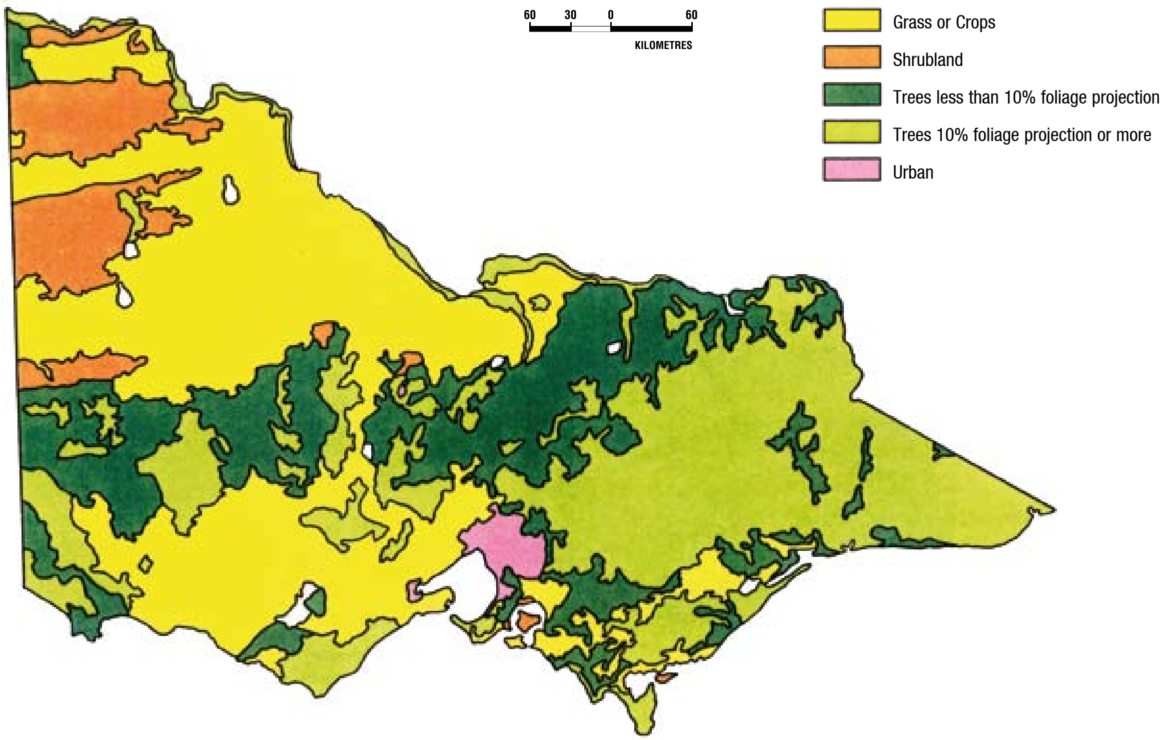


Figure 1. Victoria - (top) Vegetation prior to European Settlement (from Atlas of Australian Resources); and (bottom) Vegetation in 1980 (source: Institute of Foresters of Australia Inc., 1980).

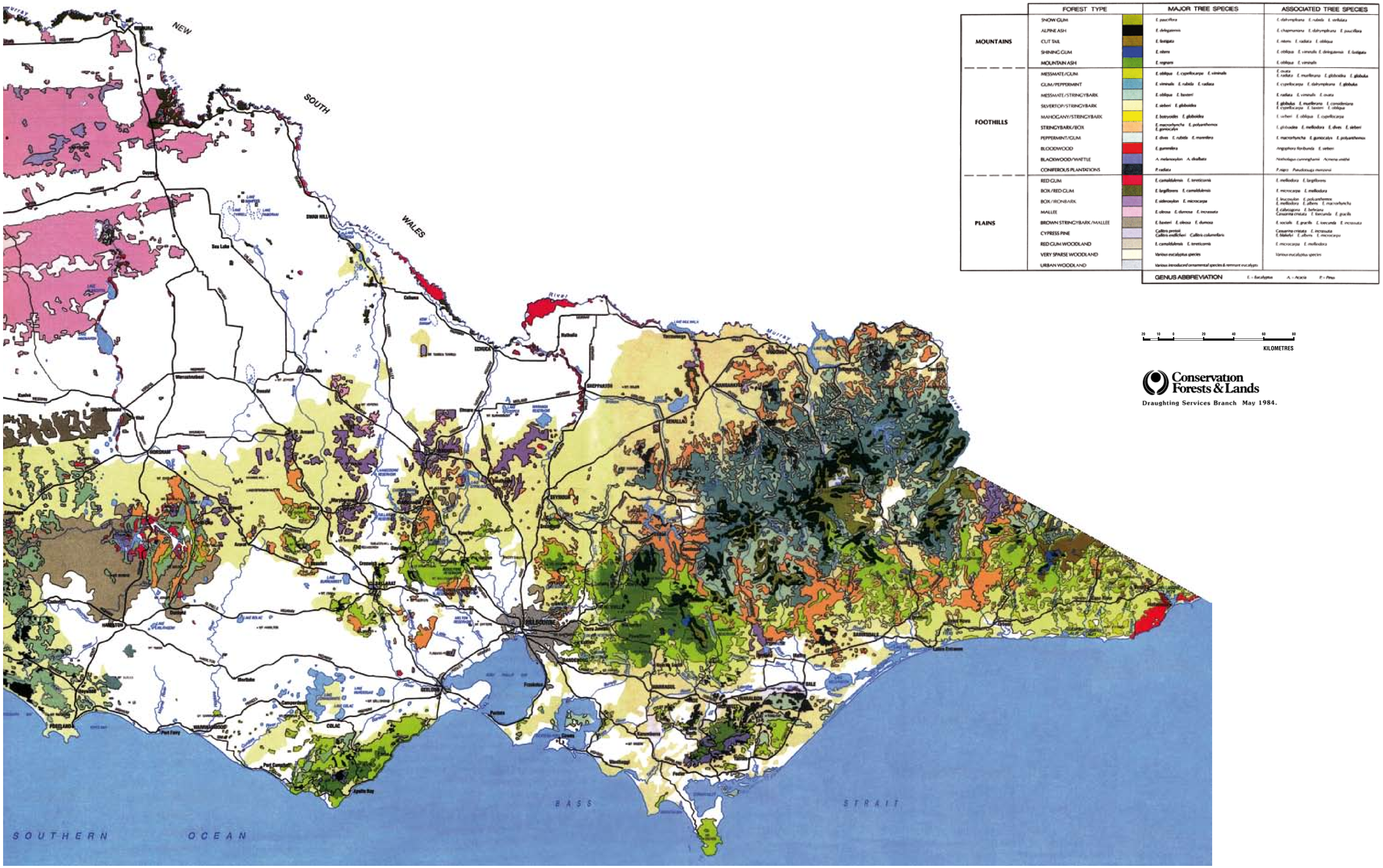


Figure 2. Forests of Victoria.

Establishment of Softwood Plantations

Following the success of species trials, State-owned plantations of *Pinus radiata* (Radiata Pine) were established in the early 1900s in locations such as Ballarat, Creswick and Macedon, and later in the Ovens Valley and the Otways. Planting lapsed during World War II, and little was done in the immediate post-War years. By the early 1960s, the total area of State plantations in Victoria was about 20,000 ha, comprising widely dispersed units, all under 5,000 ha.

In 1960, Victoria initiated a plantation extension (PX) program with new plantings commencing at Kentbruck, Koetong and other localities. In 1964, following lobbying by the States, the Commonwealth Government adopted a policy of achieving self-sufficiency in the majority of forest products by the year 2000. This led to a rapid expansion in the establishment of softwood plantations. The *Softwood Forestry Agreement Act 1967*, provided additional finance from the Commonwealth Government to enable the Forests Commission to undertake a major expansion of softwood plantations. By 1990, the State-owned plantation area had increased to about 100,000 ha, and *P. radiata* comprised 98 per cent of the plantings. Victoria's State-owned plantations were privatised in the late 1990s.

As well as public sector plantings, the private sector also played a major role in expanding the softwood plantation resource in Victoria. Most of the planting was undertaken by companies such as APM Forests (in Gippsland) and Softwood Holdings and Sapfor (in south-west Victoria), along with a large number of smaller companies and individual landholders.

Whilst large tracts of predominantly Mixed species native forest on largely undulating foothill and coastal land were cleared to facilitate this expansion in the softwood plantation estate, it is important to note that a significant portion of the estate has been established on land previously cleared for agriculture. For example, up until 1992 around 15 per cent of the State-owned softwood plantation estate had been established on previously cleared land (mainly pasture land). Clearing of native forest for the establishment of plantations ceased in Victoria in 1987. Table 2 summarises the location and tenure of the softwood plantation estate in Victoria in 1993.

In the past decade, there has been an exponential increase in the establishment of hardwood plantations (mainly Blue Gum, *E.globulus*) by the private sector. With few exceptions, this activity has been confined to fully cleared agricultural land.

Table 2. Softwood plantation areas (ha) in Victoria to 30 June 1993.

Region	Public Sector	Private Sector	Total
Central	4,955	5,148	10,103
North–East	45,181	7,540	52,721
Latrobe	20,728	44,792	65,520
Western	39,193	52,014	88,207
Total	**109,057**	**107,494**	**216,551**

Source: DCNR (1993).

Towards Sustainable Forest Management

In the latter half of the twentieth century, there was an increased public awareness of the finite nature of Victoria's native forest resource and the diverse benefits that it can provide. The establishment of the Land Conservation Council in 1970 provided a means of addressing the political problems associated with the allocation of these benefits (e.g. water versus wood) between competing demands. There was a concomitant upsurge of interest in studies of the interaction between forest management and forest ecosystems (Craig, 1984). As a result, research expanded from an initial emphasis on wood production (e.g. regeneration methods and thinning to maximise timber yields) to include other values such as flora and fauna, site wfertility, water quality and streamflow (see Campbell *et. al.*, 1984).

Since the early 1970s, there has been increasing community concern over whether wood production should continue in native forests, with the environmental impacts of management practices such as clearfelling and slash burning, and the adequacy of conservation reserves being of most concern. Several high-level inquiries were mounted in an attempt to resolve this conflict (e.g. Resource Assessment Commission 1990, Ecologically Sustainable Development Working Group 1991). However, real progress in conflict resolution and implementation of sustainability principles can be traced to two key initiatives:

- The 1986 Timber Industry Strategy set new directions for the management of Victoria's natural forests and plantations. One of the many initiatives introduced in the Strategy was the Code of Forest Practices for Timber Production which was ratified by the State Government in May 1989. Other key initiatives included the introduction of regional sustainable yields and a ban on the clearing of native forest for softwood plantations.
- The National Forest Policy Statement (NFPS) (Commonwealth of Australia, 1992) agreed by the Commonwealth, States and Territories in 1992. The obligations of each State include a requirement to establish a comprehensive, adequate and representative (CAR) reserve system as a prerequisite to the signing of an RFA.

2.2 CURRENT MANAGEMENT

The current planning framework for the management of Victoria's public native forests is highly developed. It involves extensive public consultation in the detailed consideration of the cultural, social, environmental and economic aspects of forest management. The process conforms with all Victorian land and natural resources legislation (e.g. *Forests Act 1958, Flora and Fauna Guarantee Act 1988*) and takes full account of other relevant legislation, policies and plans, along with commitments in the NFPS.

Within this framework, the Forest Management Plan (FMP) is the primary planning instrument. Such plans divide State forest into the following three zones:

- Special Protection Zone - managed for conservation.
- Special Management Zone - managed to conserve specific features, while catering for sustainable timber production under certain conditions.
- General Management Zone - managed for a range of uses and values, with sustainable timber production as a major use.

The productive area of forest (i.e. the area available for sustained sawlog production after taking account of Forest Management Plan zoning, harvesting exclusions due to the Code of Forest Practices for Timber Production and areas considered to be unproductive for sawlog production) varies from plan to plan. However it is generally about 20-30 per cent of the total area of State forest.

The Department of Sustainability and Environment is responsible for implementing FMPs across the State. The FMPs are comprehensive documents addressing, *inter alia*, biodiversity conservation, water management, hardwood production, forest protection (both fire and pest, plants and animals), cultural heritage, and recreation. The FMPs make an important contribution to achieving sustainable forest management principles and other commitments contained in RFAs. As an example, the RFA for the North East region of the State provides for:

- Development and monitoring of sustainability indicators.
- Publishing future reports of audits of compliance with the Code of Forest Practices for Timber Production.
- Implementing a continuing quality assurance program within three years.
- Publishing regional prescriptions for timber production, the Central Highlands Forest Management Plan and management plans for National and State Parks by the end of 1998.
- Developing Statewide guidelines for the management of cultural heritage values in forests, parks and reserves.
- Encouraging private forest owners to comply with the Code of Forest Practice for Timber Production.
- Establishing research priorities and priorities for the management of vegetation communities and endangered species.
- Completion of a review of pricing and allocation policies for government owned commercial forestry operations.

Finally, Wood Utilisation Plans (WUPs) and Forest Coupe Plans are extremely important elements of the planning process in terms of on-ground implementation of timber harvesting operations which are conducted according to the legislated Code of Forest Practices for Timber Production. WUPs specify the individual coupes of State forest that are approved for harvesting under the FMP guidelines to meet license requirements. Coupe Plans then provide detailed information on how logging will be conducted on individual coupes, including location of roads and log landings.

2.3 SILVICULTURAL PRACTICES

Preamble

For the purpose of this review, the set of management practices applied to an area of forest is really synonymous with the forestry concept of a silvicultural system, namely a set of cultural treatments aimed at achieving specified objectives of management.

At the coupe level, silviculture is usually based on a single system defined in terms of the felling method, that is the spatial and temporal distribution of tree removal (e.g. clearfell or selection), methods of seedbed preparation (e.g. fire or mechanical disturbance) and methods of seeding or seedling supply (e.g. natural/applied seed or planting). The name of the felling method is commonly applied to the silvicultural system. At the forest level (e.g. Forest Management Area), silviculture may consist of a single system interspersed with reserves (e.g. clearfell and CAR reserve system). This review is primarily concerned with cultural/management practices at the coupe level.

Harvesting and Regeneration Method

The harvesting and regeneration method is that part of the silvicultural system concerned with felling type, seedbed preparation and seed supply.

Felling types lie on one of two continuums related to the size of opening (selection or clearfell) or the density of the retained trees (shelterwood to seedtree to clearfell) (Campbell, 1997a, b). The use of this terminology does not proscribe the use of an innovative approach to management that may be necessary to achieve specific benefits, such as conservation of specific flora and fauna.

Clearfell

Intensive silvicultural research in mountain forests in the late 1950s (Cunningham, 1960; Grose, 1960) led to the development (Grose *et. al.*, 1964) of a regeneration method involving clearfelling and slashburning. The method has been used extensively in Victoria's Ash and Mixed species forests because it provided forest managers with a regeneration method that was comparatively simple, easily supervised and, most importantly, that consistently produced a new forest following harvesting. The felling method involves removal of all commercial trees from a predefined coupe, usually in one integrated operation. Selected trees are retained for fauna habitat. Seed supply for eucalypt regeneration is either from the habitat-trees, heads of felled trees, direct seeding or planting where seed is scarce or the seedbed is poor. Other plant species regenerate naturally from the below-ground store of seed, rootstock or propagules, or seed and/or spores carried onto the site by wind, water or animals. Seedbed preparation may be by burning slash, broadscale mechanical disturbance or selective disturbance by hand or machine.

Burning is very much the preferred method of seedbed preparation. Coupes are prepared for burning in late summer and regeneration burns are carried out where possible in late February or early March. Coupes should ideally have logical burning boundaries because, where fuel and weather permit, high intensity burning is the usual objective.

This method involves major disturbance of the site only once during a single rotation (i.e. at least 80 years). The eucalypts on a single coupe are basically even-aged, but at the forest level the method will produce a series of even-aged stands from zero to rotation age. Detailed prescriptions for the existing clearfell systems are defined in Operational Prescriptions and the Code of Forest Practices for Timber Production (DNRE, 1996).

Seedtree

The felling method involves removing all but a carefully selected set of trees on the coupe to provide an above-ground seed source for the eucalypts, and fauna habitat. Usually, a regeneration burn is used to induce seedfall and prepare the seedbed. Burning is very much the preferred method of seedbed preparation and is implemented in a similar way to that for the clearfell method. Ideally, burning is followed by rapid removal of commercially valuable (i.e. merchantable) seedtrees prior to the eucalypts germinating. In reality, seedtree removal may be delayed for several years, during which there is a risk that some of the retained trees may deteriorate due to exposure and windthrow.

Regeneration of other plant species and fauna conservation is catered for in a similar way to that for the clearfell method. In common with clearfelling, the seedtree method with rapid removal of most seedtrees effectively involves only one major disturbance of an individual site during a single rotation of the dominant eucalypts, and at the forest level it generates a mosaic of ages and areas similar to clearfell.

Shelterwood

The felling method involves removing trees on a coupe in two or more fellings during a regeneration period when mature trees are retained for shelter, seed or other purposes (e.g. aesthetics). In the fire-sensitive Ash forest type, seed supply would normally be by natural seedfall onto a mechanically prepared seedbed. Seed supply may be supplemented by direct seeding if there is insufficient seed in the canopy of standing trees.

Regeneration of other plant species, and conservation of critical fauna habitat, using a shelterwood method can be catered for in a similar manner to that described for clearfell. A two-stage shelterwood method involves a major disturbance of the site twice during the rotation, with the area of forest being disturbed in a given year being around twice that of the clearfell method producing similar wood volumes. The period between the two fellings (regeneration and final) may be varied to suit the objectives of management and the biology of the species, but would normally be expected to be within the 5-20 year range. Following the final felling, the method produces an even-aged stand at the coupe level and a mosaic of ages at the forest level. The accumulation of slash associated with mechanical seedbed preparation (e.g. Ash forest type) may increase the risk of wildfire during the first few years after each felling.

Selection

The felling method/type differs fundamentally from the preceding methods in that within an individual coupe, trees are removed sequentially at regular intervals (felling cycle) throughout the whole life of the stand. Trees may be removed individually or as small groups, the size and shape of which may vary to meet the particular needs of the forest (e.g. biological/silvical or seedfall characteristics) or particular management objectives (e.g. aesthetics). Seed supply would normally be by natural seedfall from surrounding trees, with the maximum distance of effective seedfall (usually up to 1.5 x tree height) setting the upper limits to the size and shape of the opening (i.e. about 2 x tree height).

With fire-sensitive species such as *E. regnans* (Mountain Ash), the standard technique of seedbed preparation would be mechanical disturbance, although a carefully controlled regeneration burn may be used depending on the size and shape of the forest opening. The use of mechanical disturbance carries with it a similar burning risk to that associated with the shelterwood method.

Selection methods involve disturbing an individual coupe (logging unit) several times during a single rotation period, and a greatly extended area of disturbed forest in any single year to sustain a steady flow of wood products. For example, a selection method with a 15-year felling cycle and a 90-year rotation would involve entry into the coupe six times during the rotation. This would produce an intricate mosaic of age classes and structures within small areas of a single coupe, and a relatively homogeneous pattern across all areas of harvested forest when used on a broad scale.

Coppice with Standards

Coppice is the term for shoots that grow from dormant buds on the stumps of felled trees. The stumps from which coppice shoots develop are called 'stools'. The great majority of eucalypts produce coppice shoots. *E. regnans* and *E. delegatensis* (Alpine Ash) are notable exceptions.

In this method, selected trees arising from either seedlings or coppice are maintained as standards or for fauna habitat above a simple coppice stand (Smith, 1962).

The understorey of coppice is managed on a short rotation, usually from 25-40 years (Jacobs, 1955), to produce timber for firewood, posts and poles. The felling method for the coppice component of the forest is clearfell. It involves felling all trees except for those chosen as standards or for habitat. The trees retained as standards are of good form and vigour. Natural regeneration is almost entirely of coppice origin. However, stools will eventually die, and it is necessary to introduce new seedlings into the crop from time to time using, for example, direct seeding onto a seedbed mechanically prepared following a coppice clearfell. Survival and growth of seedlings may be severely restricted by competition with faster-growing coppice shoots drawing on established root systems. Regeneration of other plant species is catered for in a similar way to that described for the clearfell method.

The overstorey of standards is managed on a rotation of at least 80 years to produce timber for sawlogs and a range of other products. The felling method for the standards component of the forest is selection. Some standards are felled and further recruitments are made to their number each time the coppice is felled. The presence of several age classes of standards means that there is no or very restricted use of fire either for seedbed preparation or fuel reduction purposes.

The method produces a forest structure consisting of an uneven-aged selection component (standards) superimposed on an entirely even-aged clearfell component (coppice), with the former varying in age and size, and each age class being a multiple of the coppice rotation.

In reality, the method has been implemented in a very *ad hoc* way in Victoria, where it was practiced in some Box-Ironbark and lower quality Mixed species forests in the central part of the State. It appears that very little attention was given to systematic planning and recording with respect to recruitment of standards, introduction of new seedling regeneration or even to the frequency and location of coppice harvesting operations, when this system was practiced.

Other Silvicultural Practices

Partial Cut

This term is used to describe an improvised felling method involving removal of all or most merchantable trees on a coupe. It is not a harvesting and regeneration method because no attempt is made to obtain regeneration. It is simply a term that describes a very flexible felling method without any other silvicultural connotations. The partial cut method typically harvested about 45 per cent of the standing basal area, but application of the method was highly variable and influenced strongly by topography, distance of forest from mills and the quality of the forest itself. The latter was influenced by past history including extent and severity of wildfires.

A variant of the partial cut method is the so called Sawmillers' Selection System which, like the classical Selection System, involved removing trees individually or as small groups. However, this is where the similarity ends. The Sawmillers' Selection System involved only limited entries into the forests to harvest only the best quality trees, with regeneration being left to chance. The resultant forest structure will be described later in this review.

Thinning

Fellings that are made in immature stands in order to improve the growth rate and/or health of the trees that remain are termed thinnings. If the thinnings (i.e. felled trees) can be extracted and sold, the operation is called commercial or production thinning. Conversely, if the thinnings are left to decompose on the forest floor, the operation is often termed thinning to waste. Thinning is further described in terms of the development or position of the crowns of the individual trees that are felled. In Victoria, the traditional thinning method that has been used almost invariably, is 'thinning from below'. In this method, trees are removed from the lower crown classes leaving, in the heaviest application, only the dominants and best co-dominants. However, much lighter applications were very much the norm.

Thinning has been applied sporadically in Victoria's native forests, and has often been limited by the availability of markets for the thinnings. Thinning was used extensively in regrowth Mixed species, Box-Ironbark and River Red Gum forests for the production of firewood prior to and immediately following World War II. The practice declined with the reduction in the demand for fuelwood. In the 1939 *E. regnans* regrowth, thinning peaked during the 1960s and 1970s. For fully stocked stands, up to 40 per cent of the initial basal area was removed, depending on stand age at the time of thinning. The purpose was to provide pulpwood and reduce the production time for sawlogs.

Timber Stand Improvement

Timber Stand Improvement (TSI) is likely to have somewhat different meanings in different parts of the country. From a C dynamics perspective, the important common feature of TSI will be that the practice/treatment results in substantial biomass of standing dead trees.

From a Victorian viewpoint, TSI is defined as the practice of killing cull trees[1] by ringbarking or with herbicides, to stimulate the growth of the remaining trees which, depending on previous management/harvesting practices, could represent many stages of stand development but, most usually, the regeneration and sapling stages. Killed culls are left standing, and the above-ground biomass will gradually fall to the ground (leaves first, stem last) over a period, which depending on forest type, could be 50 to 100 years.

In effect, TSI is a form of thinning. Whilst TSI could result in the establishment of new regeneration, this would be an unintended outcome.

In Victoria, TSI was often used to release young regeneration usually less than 10 years old. This regeneration had generally established following a wildfire in stands that had previously been cut over using the Sawmillers' Selection System. Under this system, sawmillers selected and removed the best trees for their purpose and left the rest. Eventually, mainly culls remained. These so called degraded stands were often burnt by a wildfire that led to the establishment of regeneration but did not kill the older trees. Soon after the fire, the stands were logged to remove/salvage the few remaining merchantable trees. TSI was then applied a few years later to release the regeneration. Most recent TSI work in Victoria was focused on Mixed species forests, particularly the coastal forests of East Gippsland.

In the 1940s and 1950s, a major effort was directed at 'liberation fellings' in partially cut-over or fire-damaged Mixed species forests in several parts of the State. The objectives were to salvage any merchantable logs and to remove overwood competition. The trees (culls) were felled rather than ringbarked to reduce the fire hazard and to ensure that all merchantable logs were salvaged.

Approach Adopted for the Victorian Review

A floristic description of each forest type was an important requirement of the brief. Their distribution is shown in Figure 2. The most important requirement, however, was to enter quantitative information about each forest type onto standard tables (prepared by the AGO) for each forest type for the period 1945 - 2000 using 5-year time intervals. These tabulated data focused on biomass removals, residue management and growth of the new forests. The product classes to be adopted in estimating total biomass removals in harvested products were specified, though some flexibility was given in this regard. Victoria adopted the following product classes:

- Sawlogs (including veneer logs).
- Pulp logs and residual logs.
- Firewood.
- Sleepers.
- Round timbers (e.g. poles, posts).

The main data sources used in this review were Departmental Annual Reports, Forest Management Plans, Regional Forest Agreements and research and resource assessment reports.

2.4 MAJOR FINDINGS

The average annual quantities of forest produce harvested for each 5-year period by forest type are summarised in Table 3. Assumptions used in deriving all tabulated data are detailed in Appendix 1. Table 3 reflects the impacts of both historical events (e.g. successive wildfires, past utilisation practices stretching back to the early gold rush days, establishment of a major paper mill at Maryvale in Gippsland, housing booms and world wars), changes in market demand (reflecting the changing needs over time of society for different

[1] A cull is usually a large-crowned mature tree that has no commercial potential and, through competition, is significantly reducing the commercial value/potential of neighbouring trees.

forest products), on the type and quantities of forest produce harvested and on the type of forest used to source this produce. Amongst other things, Table 3 shows that an estimated total of 110 million m^3 (equivalent to about 2 million m^3 yr^{-1}) of forest produce were removed from Victoria's forests between 1945 and 2000, with the bulk of this coming from Mixed species forests and the Ash forests. It can also be seen that sawlogs have been a significant output of the forest over a sustained period, whereas the output of products like sleepers has been much more variable. Fuelwood production was substantial in the immediate post World War II era. The high annual volumes of firewood shown in the Table for this period are consistent with comments in the early Annual Reports, which referred to the establishment of firewood camps to supply the State with much-needed energy.

The main findings of this review will be presented separately for each of the four forest types, commencing with a broad floristic description of the forest type followed by its management history and the impacts of this on carbon stocks.

The floristic descriptions given in this review are intended to provide the necessary information to enable the AGO to link individual forest types to a national vegetation system based on the National Vegetation Information System (NVIS).

The floristic descriptions have two parts:

- First, a general description covering distribution, dominant eucalypts and vertical structure (i.e. tree, shrub and ground layer components).
- Secondly, the major tree species and the associated tree species that occur within the forest type are expressed in terms of the groupings given in Figure 2. These groupings, when aggregated, define the spatial distribution of the forest type and will be the key link to the NVIS.

Ash (*E. regnans and E. delegatensis*)

Floristics

The Ash forest type is widely distributed in the mountain land in the central and eastern highlands, the Otway Ranges and South Gippsland. It occurs at altitudes of 120-1,400 m and with increasing altitude snowfalls range from light to moderately heavy. The land, particularly at lower altitudes, is of high quality with deep friable soils. Rainfall usually exceeds 1,000 mm yr^{-1}

The forest typically forms pure, even-aged stands of either *E. regnans* (Mountain Ash) at lower elevations or *E. delegatensis* (Alpine Ash) at higher elevations, although on the margins these species occur in mixture with others such as *E. obliqua* (Messmate) in the case of *E. regnans*, and *E. dalrympleana* (Mountain Gum) in the case of *E. delegatensis*. The dominant trees commonly attain heights of 45-60 m. The understorey vegetation varies with altitude. In the Mountain Ash community, the understorey is luxuriant and may be present in one or more of three horizontal strata, including trees (e.g. *Atherosperma moschatum* (Southern Sassafrass), *Nothofagus cunninghamii* (Myrtle Beech), *Acacia melanoxylon* (Blackwood), shrubs (e.g. *Bedfordia salicina* (Blanket Leaf), *Pomaderris aspera* (Hazel), *Oleria argophylla* (Musk Daisy Bush)), and ground flora (ferns). In the Alpine Ash community, the understorey varies considerably with elevation, aspect, soils and fire history. Generally, it consists of a scattered tree layer (e.g. *Acacias*), a tall shrub layer (e.g. *Pomaderris*) overtopping tree ferns, and ferns dominating the ground layer. Detailed descriptions of the floristics can be found in Gullen *et. al.*, (1979) for *E. regnans* and in Chesterfield (1978) and Land Conservation Council (1977) for *E. delegatensis* forests.

The ash eucalypts are fire sensitive and are usually killed by fires that scorch more than 50-75 per cent of leaves in the crown. The natural processes of eucalypt regeneration are initiated by an intense wildfire that removes the understorey, provides

Table 3. Summary of the average annual production of timber products from Victorian State forests for 5-year time periods from 1945 to 2000.

Forest Type	Products		Time Periods											Total Production
			1945/46 to 1949/50	1950/51 to 1954/55	1955/56 to 1959/60	1960/61 to 1964/65	1965/66 to 1969/70	1970/71 to 1974/75	1975/76 to 1979/80	1980/81 to 1984/85	1985/86 to 1989/90	1990/91 to 1994/95	1995/96 to 1999/00	
Ash	Sawlogs	% of prod'n	45	35	35	35	35	35	35	35	37.5	41	41	
		Volume (m^3)	365,000	390,000	469,000	436,000	428,000	436,000	384,000	370,000	393,000	379,000	362,000	22,060,000
	Pulpwood	% of prod'n	85	70	70	70	70	70	70	70	70	60	55	
		Volume (m^3)	61,000	55,000	133,000	153,000	206,000	213,000	223,000	230,000	330,000	500,000	640,000	13,720,000
	Other	% of prod'n	0	0	0	0	0	0	0	0	0	0	0	
		Volume (m^3)	0	0	0	0	0	0	0	0	0	0	0	
													Sub–total	35,780,000
Mixed	Sawlogs	% of prod'n	52	63	63	63	63	64	64	64	64	58	58	
Species		Volume (m^3)	422,000	702,000	845,000	785,000	770,000	800,000	700,000	675,000	670,000	536,000	512,000	37,085,000
	Pulpwood	% of prod'n	15	30	30	30	30	30	30	30	30	40	45	
		Volume (m^3)	11,000	23,000	60,000	66,000	90,000	90,000	95,000	100,000	140,000	335,000	520,000	7,650,000
	Firewood	% of prod'n	71	71	66	62	60	50	33	41	54	53	38	
		Volume (m^3)	950,000	750,000	390,000	260,000	180,000	90,000	30,000	50,000	110,000	100,000	53,000	,481,500
	Poles/posts	% of prod'n	30	30	30	30	30	30	25	20	20	10	0	1
		Volume (m^3)	7,300	13,100	11,900	10,800	10,000	8,250	4,100	2,200	2,200	800	0	353,250
	Sleepers	% of prod'n	40	51	61	54	54	42	22	20	17	0	0	
		Volume (m^3)	18,500	40,500	59,500	44,000	37,500	18,000	6,000	4,000	2,200	0	0	1,151,000
													Sub–total	61,054,250
Red Gum	Sawlogs	% of prod'n	3	2	2	2	2	1	1	1	1	1	1	
		Volume (m^3)	25,000	25,000	25,000	20,000	20,000	15,000	15,000	10,000	10,000	10,000	10,000	925,000
	Pulpwood	% of prod'n	0	0	0	0	0	0	0	0	0	0	0	
		Volume (m^3)	0	0	0	0	0	0	0	0	0	0	0	
	Firewood	% of prod'n	15	14	17	19	20	25	34	30	25	29	36	0
.		Volume (m^3)	200,000	150,000	100,000	80,000	60,000	45,000	32,000	37,000	50,000	50,000	50,000	4,270,000
	Poles/posts	% of prod'n	20	20	20	20	20	20	25	25	25	20	0	
		Volume (m^3)	4,900	8,700	8,000	7,200	6,700	5,500	4,100	2,750	2,750	1,600	0	261,000
	Sleepers	% of prod'n	51	44	36	43	43	58	73	75	78	91	83	
		Volume (m^3)	25,000	35,000	35,000	35,000	30,000	25,000	20,000	15,000	10,000	6,200	3.000	1,196,000
													Sub–total	6,652,000

Table 3. Summary of the average annual production of timber products from Victorian State forest for 5-year time periods from 1945 to 2000.

Forest Type	Products		Time Periods											Total Production
			1945/46 to 1949/50	1950/51 to 1954/55	1955/56 to 1959/60	1960/61 to 1964/65	1965/66 to 1969/70	1970/71 to 1974/75	1975/76 to 1979/80	1980/81 to 1984/85	1985/86 to 1989/90	1990/91 to 1994/95	1995/96 to 1999/00	
Box-	Sawlogs	% of prod'n	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Ironbark		Volume (m^3)	700	700	700	700	700	700	700	700	700	700	700	38,500
	Pulpwood	% of prod'n	0	0	0	0	0	0	0	0	0	0	0	
		Volume (m^3)	0	0	0	0	0	0	0	0	0	0	0	
	Firewood	% of prod'n	15	14	17	19	20	25	33	29	18	20	26	0
		Volume (m^3)	200,000	150,000	100,000	80,000	60,000	45,000	30,000	35,000	37,000	37,000	37,000	4,055,000
	Poles/posts	% of prod'n	50	50	50	50	50	50	50	55	55	70	100	
		Volume (m^3)	12,200	21,850	19,900	18,000	16,750	13,750	8,250	6,000	6,000	5,700	2,500	654,500
	Sleepers	% of prod'n	5	4	4	4	4	5	5	5	5	9	20	
		Volume (m^3)	2,500	3,000	3,500	3,000	2,500	2,000	1,500	1,000	600	600	600	104,000
													Sub–total	4,852,000
Total	Sawlogs	% of prod'n	100	100	100	100	100	100	100	100	100	100	100	
		Volume (m^3)	812,000	1,115,000	1,341,000	1,245,000	1,233,000	1,246,000	1,097,000	1,054,000	1,047,000	925,000	883,000	59,990,000
	Pulpwood	% of prod'n	100	100	100	100	100	100	100	100	100	100	100	
		Volume (m^3)	72,000	78,000	190,000	219,000	206,000	304,000	318,000	332,000	471,000	839,000	1,158,000	20,935,000
	Firewood	% of prod'n	100	100	100	100	100	100	100	100	100	100	100	
		Volume (m^3)	1,343,000	1,050,000	587,000	418,000	299,000	183,000	92,000	122,000	204,000	189,000	140,000*	22,435,000
	Poles/posts	% of prod'n	100	100	100	100	100	100	100	100	100	100	100	
		Volume (m^3)	24,400	43,700	39,800	36,000	33,500	27,500	16,500	11,000	11,000	8,100	2,500	1,270,000
	Sleepers	% of prod'n	100	100	100	100	100	100	100	100	100	100	100	
		Volume (m^3)	46,000	79,000	98,000	82,000	70,000	43,000	27,500	20,000	12,800	6,800	3,600*	2,425,500
													Grand total	107,055,500

Footnotes:
* estimate by authors
Poles/posts includes piles

Conversion factors used:

1 lineal foot =.3048 Lin. metres
1 super foot HLV =.003 cubic metres
1 cubic foot true =.0283 cubic metres
20 lin.metres of poles =1 cubic metre
125 posts equate to approx. 1 cubic metre

a bare seedbed and induces a fall of seed from capsules in the canopy. This is why natural stands are typically even-aged. However, especially for Alpine Ash, stands may sometimes contain more than one age class where a fire has passed through the stand without killing the overstorey trees or has produced a mosaic of killed trees. The ash eucalypts do not produce lignotubers and will not coppice, and are thus regarded as obligate seeders.

There is a high risk that extensive areas of the forest will be 'reset' by catastrophic wildfires that kill standing trees and trigger the processes of regeneration. This was the case on several occasions between 1851 and 1939 and, more recently, on Ash Wednesday in 1983, when a wildfire burnt 44,000 ha of mountain forest in three to four days, including 13,800 ha of Mountain Ash.

The Ash forest type is comprised of the following sub-types and species groupings shown in Table 4.

Management History

Harvesting of the virgin stands close to population centres began late in the nineteenth century by splitters for the production of palings and shingles. Utilisation of forests for sawn timber was limited by the higher elevation and steeper terrain of the areas occupied by the better quality forests and the unstable nature of the timber when it was dried. It was not until the introduction of steam powered winches and reconditioning to stabilise sawntimber in the 1920s that the Ash forests were logged intensively (Griffiths, 1992). Extensive logging of the mature Ash forests continued until the catastrophic fires of 1939 when the majority of remaining stands available for wood production were killed. Large scale salvage operations were carried out over a period of several years before the dead trees became unsuitable for harvesting. Extensive areas of regrowth forests arose from these and earlier fires, including those of 1932 and 1926. Following completion of salvage logging, harvesting was reduced to a small scale. Harvesting understocked regrowth forests began on a small scale during the mid-1960s, and from about 1979, harvesting operations moved into the fully stocked stands of pre-1939 origin. Some 1939 regrowth stands were thinned in the late 1950s and 1960s (Squire *et. al.*, 1987). These operations were confined to fully stocked stands on relatively easy topography. Full scale harvesting of 1939 regrowth commenced in the late 1980s, and regrowth forests now supply about 80 per cent of the ash timber produced in Victoria.

According to Ferguson (1957), the harvesting and regeneration of virgin stands was once largely based on the clearfell system because of the difficult logging and extraction conditions in the often steep and rugged mountain terrain. Cunningham (1960) noted that the problem of regenerating cut-over mature *E. regnans* forest was not recognised until around 1950. By then it was evident that unless logging was followed by a severe fire, including wildfires, there was partial or complete failure of regeneration. Unlike most Mixed species forests, it was apparent that *E. regnans* forests do not regenerate easily after logging. This stimulated research into the issue. Since the 1980s, harvesting and regeneration of regrowth stands has involved clearfelling followed by regeneration burning and application of seed using hand or aerial techniques. In relation to the term 'regeneration burning', it is important to note that for the period between around 1950 and 1965, regeneration burning

Table 4. Sub-types, major and associated tree species for the Ash forests of Victoria.

Sub-type	Major tree species	Associated tree species
Mountain Ash	*E. regnans*	*E. obliqua, E. viminalis, E. nitens*
Alpine Ash	*E. delegatensis*	*E. chapmaniana, E. dalrympleana, E. pauciflora*

should be interpreted in the context of burning a variable proportion of the crowns of felled trees. The procedure was highly variable, depending on a number of factors, including aspect of individual coupes. Coupes on southerly aspects would have been burnt far less than those on exposed aspects.

Extensive harvesting of *E. delegatensis* began in the early 1950s, when supplies of *E. regnans* killed in the 1939 fires began to diminish and the post-war building boom generated a heavy demand for timber. With some notable exceptions, almost all mature stands were harvested by about 1990. The harvesting and regeneration systems followed a similar pathway to that described above for *E. regnans*.

Tabulated Information

Detailed information on biomass removals, residue management and growth rates of regrowth forests following harvesting for each five-year interval from 1945 to 2000 is available from the National Carbon Accounting System (NCAS). The information on volumes of wood harvested (removed from the forest) is summarised in Table 3.

Management Impacts on Carbon Stocks

The Ash forests have been a major source of sawlogs throughout the entire study period, supplying between 35 and 45 per cent of the annual average total sawlog cut for the eleven 5-year time intervals. Total sawlog production from this forest type between 1945 and 2000 was estimated to be 22.06 million m^3. The *E. regnans* forests have also been by far the major supplier of pulpwood to the Maryvale paper mill. Over 13.7 million m^3 of pulp were estimated to have been harvested from the Ash forests during the review period. On the other hand, negligible fuelwood, poles, posts and other so called minor forest products have been harvested from this forest type.

Harvesting of Ash forests consistently resulted in the removal of a high proportion of the canopy and standing basal area, and generated relatively large quantities of residue. As shown in Appendix 1, the Ash forests are highly productive, with a high total above-ground biomass compared with all other forest types in Victoria. Estimated residue levels therefore commonly exceeded 450 t ha^{-1}. Post-harvest growth rates were also high compared with the other three forest types studied in this review, though mean annual increments are still well below those achieved in short-rotation eucalypt plantations in Australia and elsewhere.

Consistent with the silvicultural system (i.e. clearfell) used to manage Ash forests in Victoria, since about 1965, a high proportion of the harvested area has consistently been burnt by relatively intense slash burns. Burning efficiency for coarse woody debris was estimated at 50 per cent, compared with 70 per cent for fine fuels.

Mixed Species

Floristics

This forest type covers extensive areas of Victoria in the north-east, south-west, central and eastern parts of the State. It occupies practically all the timbered country on the coastal plains and in the foothills north and south of the Great Dividing Range, and accounts for 70-80 per cent of the total public native forest estate. Campbell *et. al., (*1984) and Kellas and Hately (1987) provide detailed floristic descriptions of the forest type. The eucalypt component of these forests normally consists of a mixture of species, including Stringybarks, Gums and Peppermints. Though a very large number of species occur in these forests, the distribution of individual species is discontinuous and is restricted to certain combinations of soil, moisture, slope, aspect, etc. The forest therefore tends to be comprised of a mosaic of eucalypt species associations, which vary throughout the State. Kellas and Hately (1987) recognised two major species associations: Messmate-Stringybark-Peppermint-Gum which is widely distributed across the State, and Silvertop-Stringybark which is widespread south of the Great Dividing Range east of Melbourne.

The Mixed species forest type is comprised of the sub-types and species groupings shown in Table 5.

These species have adaptive characteristics that enable them to tolerate or survive even the most intense wildfires, including the production of epicormic shoots, lignotubers, and stimulated growth on the ashbeds produced by fire. These forest types will normally regenerate naturally after logging or wildfire through newly established seedlings, lignotubers and coppice. Stands are not usually even-aged because wildfires seldom kill whole stands, and timber harvesting has, until relatively recently, generally been selective.

Because this forest type is so extensive and complex, further detailed descriptions will be confined to the more intensively managed forests, corresponding to two geographic areas:

- Central Victoria; and
- East Gippsland Foothills and Coastal. These are the areas where management practices are likely to have had most impact on carbon stocks in soil and biomass.

Central Victoria Association

This association is found on and adjacent to the Dividing Range from Mt. Macedon in the east to Mt. Cole in the west. Elevations range from 300-650 m, and annual rainfall from 600-1000 mm.

The predominant tree species are Messmate (*E. obliqua*) and Narrow-leafed Peppermint (*E. radiata*). Other species include Red Stringybark (*E. macrorhyncha*), Brown Stringybark (*E. baxteri*), Broad-leafed Peppermint (*E. dives*), Blue Gum (*E. globulus*), Mountain Grey Gum (*E. cypellocarpa*), Manna Gum (*E. viminalis*) and Swamp Gum (*E. ovata*). Understorey vegetation is of a dry sclerophyllous nature, including many legumes and heath species. A more detailed description of the flora is given in the Land Conservation Council Report (1980) on the Ballarat area.

East Gippsland Foothills and Coastal Association

This association occupies extensive tracts of foothill and coastal land to the south of the Dividing Range. Elevations range from 100-800 m, and annual rainfall is 750-1000 mm.

The species may occur in pure stands or mixtures, with Silvertop (*E. sieberi*) and White Stringybark (*E. globoidea*) being the characteristic species. The forest also includes Messmate, Yellow Stringybark (*E. muelleriana*), Red Stringybark, Brown Stringybark, Mahogany (*E. botryoides*) and

Table 5. Sub-types, major and associated tree species for the Mixed species forests of Victoria.

Sub-Type	Major Tree Species	Associated Tree Species
Messmate/Gum	*E. obliqua, E. cypellocarpa, E. viminalis*	*E. ovata, E. radiata, E. globulus, E. muelleriana, E. globoidea*
Gum/Peppermint	*E. viminalis, E. rubida, E. radiata*	*E. cypellocarpa, E. dalrympleana, E. globulus*
Messmate/Stringybark	*E. obliqua, E. baxteri*	*E. radiata, E. viminalis, E. ovata*
Silvertop/Stringybark	*E. sieberi, E. globoidea*	*E. globulus, E. muelleriana, E. consideniana, E. cypellocarpa,*
		E. baxteri, E. obliqua
Mahogany/Stringybark	*E. botryoides, E. globoidea*	*E. sieberi, E. obliqua, E. cypellocarpa*
Stringybark/Box	*E. macrorhyncha, E. polyanthemos, E goniocalyx*	*E globoidea, E. melliodora, E. dives, E. sieberi*
Peppermint/Gum	*E. dives, E. rubida, E. mannifera*	*E. macrorhyncha, E. goniocalyx, E. polyanthemos*

a range of other associated species. Understorey vegetation is generally sclerophyllous and highly inflammable, but some moister types exist in far eastern Gippsland.

As noted in Appendix 1, Departmental Annual Reports have for many decades classified the Mixed species forests according to height. For the height class >40 m, Appendix 1 refers to the High Elevation Mixed species forests of East Gippsland which broadly equate to the Messmate/Gum sub-type in Table 5, but with the major tree species including *E. nitens*.

Management History

From European settlement until the formation of the Forests Commission in 1918, Victoria's Mixed species forests were harvested using the Sawmillers' Selection System: the sawmillers selected the best trees for their purpose and left the remainder standing. No deliberate effort was made to ensure adequate establishment and development of regeneration. The forest was exploited in an era of perceived resource abundance and limited public concern about the need to improve the limited resources available for rigorous forest management. However, vast tracts of forest, especially in north-east Victoria (e.g. the gum and Peppermint associations) and East Gippsland remained virtually undisturbed, except by fire.

The Forest Commission soon established some control over harvesting, by imposing a minimum diameter limit for harvested trees. A similar approach was introduced in NSW at about the same time – "trees of commercial quality above a specified diameter limit were harvested, irrespective of continuing growth potential, and all trees below that limit were retained, again, irrespective of growth potential" (Florence, 2007). The objective was to conserve or build up the merchantable growing stock. As a consequence, harvesting produced smaller openings in the canopy. This increased the risk that any seedlings that established on soil disturbed by tractors during harvesting, or developed from an existing pool of lignotubers, would be suppressed or killed by competition from the surrounding trees.

Diameter-limit harvesting, combined with the impact of periodic wildfires, often produced a complex forest structure consisting of two more or less distinct canopy strata: an upper stratum dominated by wide-crowned, overmature, unmerchantable trees (i.e. culls) and a lower stratum of smaller, suppressed trees of various sizes, ages and stem qualities. Today, as in the past, only a small proportion of the forest is harvested intensively for timber production. As shown by the two cases briefly described below, since World War II there has been considerable variation in the type and intensity of management used, even within the main production zone.

Central Victoria Association (High Intensity)

This association was extensively cleared during the mining boom of the middle of the nineteenth century. The regrowth from these activities and the remaining virgin stands have been extensively harvested for firewood, sawlog and pulpwood production from the early part of the twentieth century up until the present time.

The Wombat Forest, near Daylesford and Trentham, is part of this association. Early harvesting was largely uncontrolled, but by 1884 diameter-limit cutting was introduced to prevent the removal of trees less than 60 cm in diameter, 90 cm above ground level (Kellas and Hately 1987). In 1901, a Royal Commission into the management of the forest led to the progressive introduction of tighter controls and regulations on harvesting, which by the 1950s had evolved into a formal selection system. This system involved periodic selection fellings that removed the poorer quality trees and mature high quality trees, either singly or in small groups. However, stand basal areas were maintained at between 21 and 26 m^2 ha^{-1} and, because of the competition imposed, little seedling regeneration was achieved and the development of regrowth was severely restricted (Weir, 1969). For these reasons, and because the expected increase in overwood quality was not being achieved rapidly enough, a shelterwood system was introduced in 1973. This is a two cut system. The first cut is a regeneration felling that reduces the overwood basal area to about 9-14 m^2 ha^{-1}. The retained trees are removed in a second cut (final) about 20 years later. This system is still in use.

East Gippsland Foothills and Coastal Association (Low Intensity)

The objective of harvesting controls progressively introduced by the Forest Commission after 1918 was to conserve and build up the merchantable growing stock. In effect, these controls merely eked out the useful timber supply (sawlogs, sleepers, poles, piles and posts) and allowed culls to accumulate and increasingly restrict the establishment and growth of regeneration. The Depression in the late 1920s and early 1930s provided an opportunity to address this problem in some of the more accessible areas where workmen, employed by the State, used axes to ringbark and kill the culls. This practice was a form of Timber Stand Improvement (TSI).

TSI was used again, most notably, in the 1960s and 1970s when cull trees, which remained following earlier logging and regeneration operations in some 6,500 ha of highly productive forest, were poisoned to reduce competition with the emerging post-logging regrowth. Notwithstanding these efforts, much of the forest was still in poor condition, the legacy of fire damage and selective utilisation. For decades, landholders had used fire extensively for clearing and grazing purposes, and many of the fires had escaped into the surrounding so called degraded stands (i.e. high basal area of culls). These fires often triggered the establishment of seedling regeneration but failed to kill the culls. Where practicable, soon after the fire, the stands were logged to remove/salvage the few remaining merchantable trees, and TSI was used for up to 10 years later to release the sapling stage regeneration.

By the 1960s, the timber demand triggered by the post-war housing and construction boom finally reached East Gippsland. At about this time, a seedtree harvesting regeneration system was introduced on the better quality sites, involving payment to the sawmiller for felling some culls, retention of 5-15 trees ha^{-1} (usually including some culls), a slash burn in the autumn following logging and liberation (usually ringbarking or poisoning culls) when the regeneration was well established. This system consistently resulted in successful regeneration following harvesting. This is still the favoured system for this forest association.

Tabulated Data

Detailed information on biomass removals, residue management and growth rates of Mixed species forests following harvesting for each five-year interval from 1945 to 2000 is provided in an external (to this report) database. The information for harvested volumes is summarised in Table 3.

Management Impacts on Carbon Stocks

The Mixed species forest type occupies a very large part of Victoria's native forest estate (Figure 2) and, although highly variable in both timber quality and productivity, has made a major contribution to the supply of a wide range of forest products. Indeed, total production from the Mixed species forest is estimated to be almost double that from the Ash forests, although the latter have a much higher mean annual increment (MAI) and total biomass.

Table 3 shows that the annual average production of sawlogs ranged from an estimated 52-64 per cent of total sawlog production from State forests between 1945 and 2000. The Mixed species forests contributed an impressive 37.09 million m^3 of sawlogs during this period.

Pulpwood production has also been significant from these forests, but in total, was only about half of the pulp harvested from the Ash forests. Ash pulp is preferred on quality criteria. Table 3, however, shows that pulpwood production from

Mixed species forests has steadily increased over the 55-year review period, from a meagre 11,000 $m^3 yr^{-1}$ during 1945/46-1949/50 to an estimated 520,000 $m^3 yr^{-1}$ during the last five years. This reflects a number of factors, including the introduction of residual log catergories, and incremented global demand for export woodchips.

The Mixed species forests, by their very nature, have also been a continuing source of all other forest products recorded in Annual Reports. Many of the individual eucalypt species of this forest type produce highly durable timbers and timbers suited to heavy construction uses. Some sub-types within the Mixed species forest type also have been a prime source of electricity and telephone poles. Pole production was significant in the 1960s, whilst sleeper output from these forests was important from around 1900 through to 1970. Nearly 1 million $m^3 yr^{-1}$ of firewood was cut from these forests between 1945/46 and 1949/50, but this has decreased to 50,000-100,000 $m^3 yr^{-1}$ in recent years

The level of retained basal area and the per cent crown removed varied markedly over the study period for this forest type (refer to data tables). In the first 5 time intervals, thinning and partial cut harvesting predominated in these forests. Residue levels were generally around 100 t ha^{-1} in total. This changed when the seedtree silvicultural system was introduced, with total slash levels increasing to about 150-200 t ha^{-1} and basal area removal increasing to around 90 per cent.

Box-Ironbark

Floristics

The Box-Ironbark forest type is highly fragmented (ECC, 2001). It occurs mainly on the poor soils of the inland plains in north-central Victoria, but small pockets, sometimes associated with rain shadows, also occur within the Mixed species forest range, such as near Airey's Inlet, south of Geelong, near Heyfield in East Gippland and in north-east Victoria between Wangaratta and Wodonga.

The principal area of pure Box-Ironbark forest is found between the Wimmera and Goulburn Rivers, extending as 'open forest' from the northern slopes of the Great Dividing Range onto the northern plains (Kellas, 1987). Annual rainfall in this area is 380-510 mm.

The dominant tree species commonly found in the principal area (Goldfields) of Box-Ironbark forest are *E. tricarpa* (Red Ironbark), *E. microcarpa* (Grey Box), *E. goniocalyx* (Long-leaved Box), *E. polyanthemos* (Red Box), *E. macrorhyncha* (Red Stringybark), *E. melliodora* (Yellow Box) and *E. leucoxylon* (Yellow Gum/White Ironbark). Three major species associations occur in this area: *E. tricarpa*, *E. macrorhyncha* and *E. polyanthemos* on the steeper slopes and ridges; *E. tricarpa*, *E. leucoxylon* and *E. microcarpa* on the lower slopes where the soils are better drained, and *E. microcarpa* and *E. leucoxylon* on the alluvial plains (Kellas, 1987). Generally, there is sparse undergrowth of drought resistant plants forming a low ground cover, a tall shrub layer and sometimes a small tree layer commonly dominated by wattles (e.g. *Acacia pycnantha* (Golden Wattle)).

The Box-Ironbark forest in northeast Victoria differs from that in the Goldfields in that it supports a much denser cover of grass species (commonly 30 per cent) and there are differences in species composition, such as the replacement of *E. tricarpa* with *E. sideroxylon* (Mugga/Red Ironbark).

Detailed descriptions of the floristics can be found in Environment Conservation Council (2001) which lists 73 ecological vegetation classes, i.e. groups of species with similar environmental requirements.

The Box-Ironbark forest type corresponds to the sub-type and species grouping shown in Table 6.

Management History

At the time of European settlement, the Box-Ironbark forests evidently had a very simple structure, an upper tree stratum and a lower stratum that was essentially a ground layer of grasses. There were only about 30 trees ha^{-1}, and some of these had attained diameters in the 120-150 cm range (Newman, 1961). However, the forest was extensively harvested during the mining boom of the middle of the nineteenth century, and stands near the mines were completely removed leaving bare ground. Much of the forest however did regenerate, evidently mainly from regrowth of lignotubers (Kellas, 1987).

The regrowth forest soon came under pressure from an expanding economy demanding land for agriculture and timber for mining props, firewood and charcoal, and sleepers for the rapidly developing rail system. Some control over harvesting was achieved in the 1880s to 1890s through the introduction of diameter-limit cutting. At about the same time, supervised thinning of regrowth stands commenced, and has continued ever since.

In the 1920s, the Forests Commission introduced a management system that involved retention of about 50 good quality large trees per ha (standards) and, beneath these, about 370 smaller trees (coppice from previous thinning operations) to be managed on a 40 year rotation for poles, piles, heavy construction timbers, posts, and firewood, with intermediate thinning treatments being used to remove poor quality trees. This management technique was regarded as a coppice with standards system. Some of the standards may have been remnants of the original forest (Kellas, 1987). Essentially, this system is still in use.

Today, about 150 years after extensive areas were cleared during the mining boom, the forest is highly modified from its original structure (e.g. fewer large, old trees). It is also very fragmented and much reduced in extent (ECC, 2001). The forest has a simple, relatively open structure, usually involving three strata: an open, uniform upper stratum of relatively large trees (i.e. standards), a middle stratum of clumps of smaller trees (coppice) and a sparse understorey containing heath and other drought-resistant plants. The total basal area of trees is generally about 13 m^2 ha^{-1} with a total number of trees around 500 stems ha^{-1}. On better sites, the fully stocked basal area is considered to be about 20 m^2 ha^{-1}. An important aim of future management will be to improve the abundance of large, old trees.

Tabulated Data

Detailed information on biomass removals, residue management and growth rates of the Box-Ironbark forests following harvesting for each five-year interval from 1945 to 2000 are provided in an external (to this report) database. The information for harvested Box-Ironbark products is summarised in Table 3.

Management Impacts on Carbon Stocks

The Box-Ironbark forests have produced few sawlogs during the review period. Sawlogs harvested from these forests tend to be used for speciality timbers. Average annual sawlog production has been less than an estimated 8,000 m^3 yr^{-1}. There has been no pulpwood harvested from the Box-Ironbark forests, but firewood production has been an extremely important output from the forests. Total firewood production for the review period is estimated at over 4 million m^3. In the immediate post-war period, these forests were supplying fuelwood at an average annual rate of around 200,000 m^3 yr^{-1}. This was a strategically important energy source for Victoria.

Table 6. Sub-types, major and associated tree species for the Box-Ironbark forests of Victoria.

Sub-Type	Major Tree Species	Associated Tree Species
Box/Ironbark	*E. tricarpa* (sideroxylon), *E. microcarpa*	*E. leucoxylon, E. polyanthemos, E. melliodora, E. albens, E. macrorhyncha*

Consistent with the durable nature of the main species that comprise the Box-Ironbark forests, sleeper production has also been an important timber product, though total volumes (around 100,000 m^3 over 55 years) are low compared with firewood. Sleeper numbers, however, are very significant as detailed in the Annual Reports.

The Box-Ironbark forests have also been a steady source of poles, posts and piles, with annual production peaking at over 20,000 $m^3 yr^{-1}$ in the 1950s.

Until the late 1960s, a form of the coppice with standards silvicultural system was widely used to provide the large volumes of fuelwood and other products requiring durable timbers from these forests. This commonly removed around 60 per cent of the basal area and 60 per cent of the canopy. Fire was only scantly used, and residue levels were estimated to be less than 20 t ha^{-1}.

In the 1970s, thinning of the coppice component became the dominant silvicultural practice. It is estimated that thinning removed around 40 per cent of the basal area and generated residue levels in the vicinity of 15 t ha^{-1}. Fire was not used in these thinning operations, which were aimed at releasing retained stems rather than encouraging regeneration.

River Red Gum

Floristics

The River Red Gum forest type takes its name from the species *E. camaldulensis* (River Red Gum). The species is the most widely distributed tree in Victoria. The forest form (i.e. pure stands of River Red Gum) mainly occurs in proximity to major watercourses or in areas prone to regular flooding. Elsewhere, it is widely associated with rivers, seasonal watercourses and drainage depressions, usually as scattered trees but sometimes as woodlands (e.g. parts of the western plains).

In the context of this review, the large areas of pure stands on the flood plains of the Murray, Goulburn and Ovens Rivers are of most interest. Of the 158,000 ha of River Red Gum forest found on public land in Victoria, 43 per cent occurs in this area (DNRE, 2001). These stands occur in a sub-humid to semi-arid environment with an annual rainfall of about 400 mm, and require flooding for adequate growth and regeneration.

The Barmah-Millewa Forest (the contiguous area of forest in Victoria's Mid-Murray FMA and NSW), covers about 60,000 ha, and is the most extensive and consolidated occurrence of River Red Gum forest in Australia. The Barmah Forest vegetation was described by Chesterfield (1986), and provided the basis for the following account given by Bren (1988): "The most common association is Red Gum with grasses or sedges. Low lying sites directly connected to the river carry either Giant Rush (*Juncus ingens*) or Moira Grass (*Pseudoraphis spinescens*) only. The Moira Grass occurs as extensive plains fringed with regenerating Red Gum clumps. At the outer limits of the forest or on 'high ground' various box-eucalypts (mainly *E. largiflorens* and *E. microcarpa*) occur. The forest carries a diverse fauna, but is deficient in ground-based animals because of flooding (Chesterfield *et. al.*, 1984). Because of the absence of woody species other than Red Gum, the forest has an unusually open appearance compared to most eucalypt forests."

The River Red Gum forest type corresponds to the sub-types and species groupings shown in Table 7.

Management History

During pioneer settlement in the nineteenth century (about 1840), the forest was heavily logged to provide wood (Fahey, 1987). Substantial regeneration followed a moderately large flood in 1870 (Jacobs, 1955). Since settlement, the forest has been extensively grazed and harvested to produce sawn timbers, railway sleepers, fencing timbers and fuelwood (DNRE 2001).

The presence of European man and introduced animals has had a major impact on some areas of the forest. Introduced animals have grazed on the vegetation, disturbed and compacted the soil, and have been associated with altered fire regimes (Campbell *et. al.*,1984). Other agents of change include altered river and ground water regimes due to upstream clearing and, recently, irrigated farming and river regulation. If the river is not flooded for some years, extensive defoliation by the moth *Uraba lugens* can occur (Harris, 1974).

The management of the forest has followed the path of exploitation (i.e. Sawmillers' Selection System), control (i.e. diameter-limit cutting) and active management (some attention to regeneration and size class distributions) already described for the Mixed species forest type. Ferguson (1957) noted that the River Red Gum forests had been "worked over for production of mill logs and railway sleepers continuously on a rough selection cutting basis for the best part of 70-80 years". Present management involves the use of group and single tree selection systems involving scattered successive fellings of either individual trees or small groups (generally less than 1 ha, but sometimes up to 3 ha) to produce openings in the forest. Openings produced by the removal of single trees are often too small to be regenerated. In this case, harvesting is, essentially, a thinning. Regeneration of the larger openings usually requires some management inputs (e.g. slash burning to produce a seedbed and induce seedfall from the edge trees), even on sites that are subject to regular flooding. The aim is to coordinate harvesting and water management operations to foster eucalypt germination and growth.

Large areas of the forest still contain regrowth dating from the late nineteenth century. Although analyses of stand structure show that the numbers of trees and their average size are still increasing, in some areas the proportion of large old trees is still lower than it was before settlement. A major goal of management is to ensure that there are sufficient large old trees in the forest to contribute to the maintenance of biodiversity.

Tabulated Data

Detailed information on biomass removals, residue management and growth rates of the River Red Gum forests following harvesting for each five-year interval from 1945 to 2000 are provided in an external (to this report) database. The information on harvested volume is summarised in Table 3.

Management Impacts on Carbon Stocks

River Red Gum forests occupy only a small portion of Victoria (Figure 2), yet total production from this forest type over the 55 years was over 6.6 million m^3. Firewood production peaked in the late 1940s when output was around 200,000 $m^3 yr^{-1}$. Sleeper production was a constant 2,500 to 3,000 $m^3 yr^{-1}$ for the first 40 years of the study period. Pulpwood has not been harvested from the Red Gum forests.

2.5 GENERAL DISCUSSION AND CONCLUSIONS

Only one third of Victoria is forested. Far less than this area of forest has the potential for the sustainable harvest of significant volumes of forest products. Many forests currently used for timber production (and for that matter conservation reserves as well) were decimated in

Table 7. Sub-type, major and associated species for the River Red Gum forests of Victoria.

Sub-type	Major tree species	Associated tree species
River Red Gum	*E. camaldulensis*	*E. largiflorens, E. microcarpa, E. melliodora*

the gold rush era, while other forests have been affected to a greater or lesser degree by one or more wildfires over the past century. Furthermore, a large proportion of the native forest estate is excluded from hardwood production through either successive land use decisions (e.g. creation of new parks and reserves) or harvesting prescriptions (e.g. logging is not permitted adjacent to major streams). Effectively therefore, only a relatively small area of native forest is suitable and available for wood production.

Despite these limitations, Victoria's forests have produced a combined harvested volume of sawlogs, fuelwood, pulpwood, sleepers, poles, piles and posts of nearly 110 million m^3 between 1945 and 2000. Annual production has been relatively constant over this lengthy period at about 2 million $m^3\ yr^{-1}$. Importantly, this review indicates in a qualitative manner that the condition of the growing stock in forests, now available for wood production has not been compromised in any significant way by past timber harvesting. Furthermore, the future capability of selected forests to produce sawlogs for value added products may be enhanced through increased attention to regeneration, fire protection and forest health.

Most of the forest products have come from the widespread Mixed species forest and the Ash forests. The Box-Ironbark and River Red Gum forests have been more important in relation to speciality products like sleepers and poles. Firewood has been a common forest product from all forests except the Ash forests.

There have been major shifts in the output of specific forest products over the 55-year review period. As examples, pulpwood production has steadily increased from less than 100,000 $m^3\ yr^{-1}$ to over 1,100,000 $m^3\ yr^{-1}$ while firewood production declined from over 1,300,000 $m^3\ yr^{-1}$ to around 150,000 $m^3\ yr^{-1}$ over the study period. Annual sawlog production has varied between 800,000 and 1,340,000 $m^3\ yr^{-1}$ over the 55 years.

Given the underlying reason for this review, we have given emphasis to two key issues: standing biomass in forests at the time of harvest, and estimates of harvested products from each forest type. Victoria was fortunate in having reliable information on total volumes harvested from its native forests on an annual basis, but corporate knowledge was required to allocate these volumes between the four forest types adopted in the review (Ash, Mixed species, Box-Ironbark and River Red Gum). The biomass estimates were used to approximate the quantity of slash remaining in the forest (see Appendix 1) after taking account of the harvested volumes and the silvicultural system used for each 5-year time interval.

Other important factors from a carbon accounting perspective included annual areas harvested, regeneration success, shifts in silvicultural practices and whether or not logging residues were burnt to facilitate the regeneration process. There was assumed reliable information on the annual areas regenerated, and this review assumed that areas regenerated for each 5-year interval equated to the areas harvested.

Carbon sequestration rates in biomass of post-harvest forests is a critical component of the carbon balance. In this review, MAI, periodic annual increment (PAI) for uneven-aged forests, and gross bole volume supplied by the Department of Sustainability and Environment were used along with specified nominal rotation lengths to estimate post-harvest growth for the four forest types. This information was as follows:

Ash	an MAI of 5.50 $m^3\ ha^{-1}\ yr^{-1}$ over 80 years
Mixed species	an MAI of 3.85 $m^3\ ha^{-1}\ yr^{-1}$ over 100 years
Box-Ironbark	a PAI of 0.22 $m^3\ ha^{-1}\ yr^{-1}$ over 120 years
River Red Gum	a PAI of 0.55 $m^3\ ha^{-1}\ yr^{-1}$ over 120 years

The above-ground biomass estimates (expressed in dry t ha^{-1}) for the four forest types adopted in this review were Ash 540 t ha^{-1}, Mixed species 340 t ha^{-1}, Box-Ironbark 85 t ha^{-1} and River Red Gum 135 t ha^{-1} (see Appendix 1). It is recognised that these estimates are subject to substantial variance due to a number of factors, not the least being the highly variable productivity within a forest type, as influenced by edaphic and climatic factors.

Of the 107 million m^3 of products harvested over the 55-year review period, it is estimated that sawlogs accounted for around half this volume. The Ash forests have consistently supplied between 35 and 45 per cent of the average annual sawlog cut and they have become an increasingly important source of pulpwood both in Victoria or overseas. The more extensive but less productive Mixed species forests by their very nature have supplied the full range of timber products covered by this review (i.e. sawlogs, pulpwood, sleepers, firewood, fencing timbers, poles). On the other hand, the Box-Ironbark and River Red Gum forests have been major sources of durable timber for sleepers, fencing and poles/piles, and firewood. Production levels of these products have been strongly influenced by historical events such as the closure of country rail lines and post-war energy needs.

For a significant portion of the review period, clearfell and seedtree silvicultural systems have been widely used in the Ash and Mixed species forests in particular. Typical residue (slash) levels for each forest type were estimated to range from 85 to 205 t ha^{-1} for Ash forests, 120 to 160 t ha^{-1} for Mixed species forests (but higher for seed tree systems in East Gippsland), 46 to 57.5 t ha^{-1} for River Red Gum forests and 37 to 47 t ha^{-1} for Box-Ironbark forests. Apart from forest type and silvicultural system, the main factor that influenced residue levels was the type of product harvested (e.g. sawlog-only or an integrated sawlog and pulp log operation).

Victoria has traditionally paid a great deal of attention to achieving effective regeneration across all harvested areas since at least the 1960s. Where regeneration failure has been detected from routine (and now mandatory) regeneration surveys, remedial action has invariably been undertaken. Accordingly, the post-harvest growth estimates assume 100 per cent regeneration success across all logged coupes.

Slash burning has been used extensively to assist in the regeneration process since the 1960s in the Ash and Mixed species forests, and to a lesser extent in River Red Gum forests. Good information was available to provide estimates of burn efficiencies for typical Mixed species forests. These estimates, however, needed to be applied to the other forest types in the absence of specific data.

It is concluded that forest management practices in Victoria since World War II have had significant impacts on carbon flux in the forests. Each year over the past 55 years has seen large removals of carbon in forest products, large volumes of logging residues left on the forest floor, and variable amounts of carbon have been lost to the atmosphere through slash burning. There have also been new forests created following timber harvesting. These relatively well managed regrowth forests continue to sequester significant amounts of carbon.

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5. APPENDICES

5.1 APPENDIX 1

ASSUMPTIONS USED IN DERIVING DATA TABLES

General Assumptions

The following general assumptions were made in deriving the individual data tables.

Areas and Volumes Harvested

Except for the last three years, the Department of Natural Resources and Environment and previous agencies responsible for the management of State forest have published Annual Reports, which provide detailed information on total volumes harvested by broad product class (e.g. sawlogs, sleepers) and areas regenerated. This information has been reported in a consistent framework for almost all of the entire review period. In deriving the tables, it was assumed that the average area regenerated for each 5-year time interval equated to the average area harvested. This is a reasonable assumption given Victoria's tradition of according high priority to regeneration.

There is no readily available information on volumes harvested by forest type, except for the period 1989-2000, when Victoria operated a Logsales system for Ash, Mixed species and durable timbers. In order to apportion the total annual harvest to the four forest types, a number of assumptions were used, together with expert judgement, supported by the Annual Reports which often contain useful comments on forest activities across the State. In particular, it was necessary to assume some average yields for each forest type in determining the portion of the total cut attributable to that forest type. For the last two time intervals, Logsales data were used to determine the ratio of Ash, to other forest types for the total sawlog and pulpwood harvest.

Tenure

About two thirds of Victoria is freehold land which is mostly cleared and used for a range of agricultural, residential and industrial uses. Only about 4 per cent of this freehold land is native forest.

The remaining one third of Victoria is public land, and is mostly native forest, woodland or shrubland. Given this strong bias towards public ownership, combined with local knowledge, it is reasonable to assume that over 90 per cent of the total harvested volume of native hardwood timber has been sourced from State forest for at least the last three decades. In the absence of reliable records on the volume of timber harvested from native forest on freehold land, data from Departmental Annual Reports for State forest have been largely used to compile the tables.

Salvage Logging

For the period 1945-1950, salvage logging of mature *E. regnans* killed by the 1939 wildfires was a major source of timber. This logging was focused on the most accessible stands, but was highly variable in terms of volumes harvested, harvesting methods (clearfelling or selection depending on suitability of stand for sawlog production, and extent of post-fire degrade such as longitudinal or barrel checking) and product mix (sawlog–only or sawlog plus pulpwood). Areas close to the Maryvale paper mill would have been favoured for integrated operations. However, the tables assume an average pulpwood harvest over the entire salvaged area. The pulp yields are therefore low, reflecting this assumption and the fact that Maryvale was still in a build-up phase. This also accounts for the high residue levels associated with the salvage logging.

Ratios of Sawlog and Pulpwood

Pulpwood for the Maryvale paper mill is sourced from both Ash and Mixed species forest types, whereas pulpwood for the former Bacchus Marsh hardboard mill was sourced solely from Mixed species forest in the Wombat Forest. Excellent information exists on annual harvested volumes, from this area. In the former instance, however, it was necessary to use non-quantified explanatory information in Annual Reports to guide the derivation of an estimate of the proportion of Mixed species to Ash pulpwood on an annual basis.

Growth Rates of New Forest

Broad estimates of average growth rates that take account of variations in site quality, stocking, fire and utilisation history, etc, for each of the four forest types were provided by DNRE. These estimates are summarised in Table 8.

Specific Assumptions

Regeneration success

Victoria has traditionally placed strong emphasis on regeneration success following timber harvesting across all of its forest types. Research on the subject commenced in earnest in the 1950s and has continued to the present day, leading to a progressive improvement in the cost-effectiveness of operational regeneration works. In recent times, there has been public reporting of regeneration results in public forests against widely accepted stocking standards. Murphy and Fagg (1996) reported regeneration results for the 1989/90 to 1992/93 logging seasons 91 per cent of the total harvested area surveyed in this 4-year period had what is termed ‘acceptable stocking’, which corresponds to an average density of 2000-2500 eucalypt seedlings per hectare at age four years.

Table 8. Broad estimates of forest growth over nominal sawlog rotations for major commerical forest types.

Forest Type	Mean or periodic annual increment (m^3 ha^{-1} yr^{-1}) Sawlog volume	Total merch. volume	Gross bole volume	Nominal sawlog rotation (years)
Ash (MAI)	2.75	5.00	5.50	80
Mixed species (MAI)	1.80	3.50	3.85	100
River Red Gum (PAI)	0.25	0.50	0.55	120
Box–Ironbark (PAI)	0.10	0.20	0.22	120

The authors have accepted these estimates. However they believe that the growth rates for the Ash and River Red Gum forest types are likely to exceed those in the above table, whereas the estimates for the Mixed species forest may not be realised unless more attention is given in the future to thinning, fire protection and forest health surveillance.

If a coupe is found to be ineffectively regenerated following mandatory surveys soon after timber harvesting, the Victorian Code of Forest Practices for Timber Production and previous Departmental Standing Instructions require remedial action to be taken. This can take many forms from enrichment planting to mechanical disturbance of the entire coupe followed by sowing or planting. Thus, although initial or first attempt regeneration success may be in the range 85-95 per cent depending on the forest type and seasonal conditions, the ultimate goal is to achieve 100 per cent regeneration success within a few years of harvesting. In terms of carbon stocks however, it is important to appreciate that there is usually a significant density of eucalypts (e.g. 500-1,000 stems ha^{-1}) on coupes classed as 'unstocked' in standard regeneration surveys. Such coupes simply do not have the number and distribution of eucalypt seedlings prescribed to optimise future production of quality sawlogs. Furthermore, the coupes will invariably have a significant presence of wattle and other tree species whose biomass is significant for at least part of the next rotation. Also, it has been commonly reported from various Forest Districts throughout the State over the past few decades that many coupes initially classified as un-regenerated have subsequently been found to be adequately stocked. This is largely attributed to the small seedlings being 'missed' or overlooked in regeneration surveys. Accordingly, from a carbon perspective, the tables assume 100 per cent regeneration success across all forest types.

Biomass Estimates

Victoria has reasonably reliable biomass data for the major forest types used for commercial timber production. This is supported by comprehensive inventory data and, for the past decade, accurate information on log sales for Ash, Mixed species and durable timbers. Sources of information used to arrive at estimates of biomass components given in the tables are summarised below for each forest type.

All biomass data for each of the four forest types are expressed as dry weight. Likewise, all data in the individual AGO tables are expressed as dry weight, except for post-harvest growth.

Ash

The Table 9 provides a general biomass distribution for the above-ground components of a 50 year-old stand of regrowth *E. regnans*. Table 9 draws heavily on Feller (1980) who worked in the Maroondah catchment north east of Melbourne and Cumming (1992) who intensively sampled 61 coupes in the Central Gippsland region west of Melbourne. In the absence of supporting published data for similar aged or older natural stands, it has been assumed that *E. delegatensis* and mature *E. regnans* have a similar aboveground biomass to that of regrowth *E. regnans*. The values will be underestimates for the older stands.

In the absence of published data for 30 year old *E. regnans* stands, a figure of 290 t ha^{-1}, was used to derive biomass estimates for thinning. This figure, which is about 55 per cent of the estimated biomass for mature stands, was based on the average of figures for 16 and 27 year old *E. grandis* reported in Keith *et. al.*, (2000).

The above data have been used to estimate the quantities of bark and slash left on site following logging and thinning operations. These estimates are given in the data tables. It should be noted, however, that for partial cuts and thinning, the figures for slash and bark refer to logging debris only and exclude any biomass in living trees.

Mixed Species

The Mixed species forests available for timber harvesting in Victoria are highly variable in terms of species composition and productivity. The Departmental Annual Reports consistently refer to three classes of Mixed species forest based on height (low productivity or <27 m, medium productivity or 27-40 m, and high productivity or >40 m). Representative examples of these three classes are the High Elevation Mixed species forests of East Gippsland (high productivity), the Wombat Forest in central Victoria (medium productivity) and the Heywood Forest in south-western Victoria (low productivity). Detailed biomass data exist

Table 9. Aboveground biomass distribution in a 50 year old Ash forest.

Component	Biomass		Data source
	t ha^{-1}	%	
Harvested logs*	285	53	Cumming (1992)
Stembark	65	12	Feller (1980)
Residue to >10 cm SED	30	6	D. Thomson, *pers. comm.*
Standing dead trees	20	4	Feller (1980)
Understorey	55	10	Feller (1980)
Litter	45	8	Feller (1980)
Branches and leaves	40	7	Feller (1980)
Total	**540**	**100**	

* Actual total volume harvested, comprising about 35% sawlog and 65% pulpwood.

for the medium class, whilst high quality resource assessment information is available for all forests. Given that the highest proportion of harvested wood has consistently been derived from the more productive forests in the medium class, no attempt has been made to distinguish between the classes from a biomass component perspective. However, a bias was given to data sources derived from the most commonly harvested class of Mixed species forests, which are in the 27-40 m height class.

Biomass distribution for a typical mature Mixed species forest of medium to high productivity in Victoria following clearfell or seed tree harvesting for sawlog and pulpwood is provided in Table 10.

Note: The estimate of branch and leaf biomass by Stewart *et. al.,* (1979) for an East Gippsland Mixed species forest is considerably higher than that estimated by Baker and Attiwill (1985) for an *E. obliqua* forest in the Central Highlands of Victoria. The Stewart *et. al.,* (1979) value has been used because of similarity in forest type for the other biomass components.

In the absence of published data for 40 year old Mixed species stands, a figure of 190 t ha^{-1} was used to derive biomass estimates for thinning. This figure, which is about 55 per cent of the estimated biomass for mature stands, is comparable with the estimate used to derive biomass estimates for thinning in *E. regnans* stands. Note that the actual amount of biomass removed during thinning depends on the thinning intensity applied.

The above models have been used to estimate the quantities of bark and slash left on site following logging and thinning operations. These estimates are given in the data tables. It should be noted however that for partial cuts, shelterwood and thinning, the figures for slash and bark refer to logging debris only and exclude any biomass in living trees.

Box-Ironbark

Based on Keith *et. al.,* (2000), there appears to be no published biomass data for Box-Ironbark forests or similar forest types. Similarly, there seems to be no unpublished information on the subject. However, there are detailed floristic and structural descriptions of Victoria's Box-Ironbark

Table 10. Aboveground biomass distribution in a mature Mixed species forest.

Component	Biomass t ha^{-1}	Biomass %	Data source
Harvested logs*	155	45	Stewart *et. al.,* (1979), Brennan *et. al.,* (2000),
			Cumming & Black (1993)
Bark	50	15	Stewart *et. al.,* (1979), Baker & Attiwill (1985)
Residue including stumps	25	7	Brennan *et. al.,* (2000)
Litter and understorey	19	6	Stewart *et. al.,* (1979)
Branches and leaves	78	23	Stewart *et. al.,* (1979)
Retained live trees (culls, habitat, seed)	13	4	Brennan *et. al.,* (2000)
Total	**340**	**100**	

*Mean of stemwood estimates by Stewart et. al., (1979) of 195.6 t ha^{-1} and two independent assessments, one by Brennan et. al., (2000) of actual volumes harvested (99.4 m^3 ha^{-1} or 49.7 t ha^{-1} sawlog and148.4 m^3 ha^{-1} or 74.2 t ha^{-1} pulpwood and the other by Cumming and Black (1993) for a seedtree treatment in East Gippsland (276 m^3 ha^{-1} or 138 t ha^{-1} of sawlogs and pulpwood).

Table 11. Aboveground biomass distribution in a Box-Ironbark forest.

Component	Biomass $t\ ha^{-1}$	%	Data source
Harvested products:			
Fuelwood	10	12	Anon. (1998)
Sawlog/sleepers	2	2.5	Anon. (1998)
Fencing materials	6	7	Anon, (1998)
Stembark	2	2.5	Authors' Estimate
Retained Components			
Understorey/litter/slash	20	23	Stewart *et. al., (*1979)
Overwood	45	53	Authors' Estimate
Total	**85**	**100**	

Note: The estimates assume a thinning from below supplemented by removal of some defective trees, with basal area being reduced from about 20 $m^2\ ha^{-1}$ to between 8 and 10 $m^2\ ha^{-1}$.

forests which enable reasonable estimates to be made of some biomass components by adjusting data for low quality Mixed species forests in far east Gippsland, Victoria (Stewart *et. al.*, 1979). Detailed timber assessments have also recently been conducted, which have also incorporated supplementary ecological information (DNRE, 1998). This information has been used to construct a biomass distribution for the Box-Ironbark forests, that is summarised in Table 11.

Estimates of harvested biomass and retained overwood draw heavily on information on timber harvesting levels across the Bendigo Forest Management Area (FMA) which has a total area of 148,000 ha. Over a 10-year period commencing in 1986, the products and average volumes harvested were sawlogs (700 $m^3\ yr^{-1}$), sleepers (600 $m^3\ yr^{-1}$), fencing timbers (5,700 $m^3\ yr^{-1}$) and fuelwood (36,700 $m^3\ yr^{-1}$). Silvicultural practices over the same period retained about 50 per cent of the basal area including some of the larger trees.

The above model has been used to estimate the quantities of bark and slash shown in the data tables. It should be noted however that all the figures for slash and bark in the tables refer to both biomass in logging debris and in retained trees.

River Red Gum

The authors are not aware of any published or unpublished studies on the biomass of well stocked, natural stands of *E. camaldulensis*. However, the silviculture of River Red Gum forests has been systematically and comprehensively studied by B. D. Dexter (e.g. Dexter, 1967). His pioneering work provided the knowledge for modern day management of these forests. He has maintained a professional interest in the management of River Red Gum forests to the present day.

The quality and hence productivity of River Red Gum forests varies according to a range of factors, with flood events being particularly important. According to B. D. Dexter, (*pers. comm.*), the forests in the middle reaches of the Murray River have suffered serious reductions in winter-spring flood events and unseasonal flooding of lower lying areas in summer and autumn. This changed flood regime is due to water diversions. Since the 1950s the frequency, duration and extent of forest flooding have been significantly reduced, this has not only compromised future productivity (i.e. lower MAIs) but also threatens the long-term integrity of the forests (Dexter, *pers. comm.*).

Jacobs (1955) claims that the basal area of River Red Gum can range from around 35 m^2 ha^{-1} for veteran stands to around 69 m^2 ha^{-1} for dense clumps of sapling regeneration. In terms of merchantable yield, Jacobs (1955) suggests that sites of high quality should produce around 7 m^3 ha^{-1} yr^{-1} of logs, fuelwood, posts, poles, sleepers, etc. He further suggests that yields would be about half this on areas of medium site quality. These estimates of course relate to pre-river regulation flooding regimes.

Dexter (1998) reports results from extensive operational-scale field trials undertaken between 1962 and 1966 to investigate regeneration techniques in the Barmah State forest. The precise volumes of produce harvested as part of these trials were recorded. In one such trial (Black Swamp) covering 102 ha of a stand originating in 1870-1880 (except for some scattered veterans) on a mixed site quality, the total cut of sawlogs, sleepers and fencing material was 3,220 m^3 or 31.6 m^3 ha^{-1}. The breakdown was sawlogs 2.4 m^3 ha^{-1}, sleepers 20.3 m^3 ha^{-1} and fencing materials 8-9 m^3 ha^{-1}. Dexter (1998) concluded that with improved flooding and some silvicultural treatment, merchantable, growth rates of at least 1 m^3 ha^{-1} yr^{-1} should be readily achievable over 100 years. Expert judgement suggests that a nominal rotation age should lie between 110 and 150 years. Consistent with growth estimates tabulated in the general assumptions, 120 years is assumed for biomass computations in the present review.

An unpublished draft report by the Forestry Commission of NSW in September 1983 provides a provisional yield table for even-aged stands of River Red Gum (sourced from a 1954 Management Plan). Total volume at age 108 years for Site Quality I stand was estimated to be 520 m^3 ha^{-1} compared with 310 m^3 $ha^{-1,}$ for Site Quality II stands. Stocking levels were 90 and 70 stems ha^{-1} respectively. The report also noted that logging in the Murrumbidgee River Red Gum forests resulted in yields of up to 220 m^3 ha^{-1} of all products (sawlogs, sleepers and other material). These are useful data for estimating biomass.

On the basis of the above information combined with a recent analysis by Dexter (*pers. comm.*), the biomass distribution in a mature River Red Gum forest was estimated and is summarised in Table 12. The main assumption used in the model is that an 'average' River Red Gum forest harvested over the past 55 years (i.e. stands that had grown under

Table 12. Aboveground biomass distribution in a mature River Red Gum forest.

Component	Biomass t ha^{-1}	Biomass %	Data source
Total (potential*) merchantable volume	80	59	Jacobs (1955), Dexter (*pers. comm.*), For. Comm. NSW (1983)
Non–merchantable volume	25	19	Estimate
Bark	10	7	Estimate (about 5% of total bole biomass)
Understorey/litter/slash	20	15	Estimate (about 10% of total bole biomass)
Total	**135**	**100**	

* includes retained growing stock

The above model has been used to estimate the quantities of bark and slash shown in the data tables. It should be noted however that all the figures for slash and bark in the tables refer to both biomass in logging debris and in retained trees.

pre-river regulation flooding regimes for most of their rotation) had a total potential merchantable MAI of 1.3 $m^3 ha^{-1} yr^{-1}$ over a nominal rotation age of 120 years, or a standing total basal area of up to 40 $m^2 ha^{-1}$. This average MAI assumes that the forests harvested between 1945 and 2000 grew under pre-river regulation conditions for the greater part of their rotation. The MAI also reflects the logging history of the River Red Gum forests in the late 19th and early 20th centuries.

Comments on Biomass Estimates

The above biomass estimates are broadly in line with those of Grierson *et. al., (*1992) except for the River Red Gum forests. They are also reasonably consistent with the estimates of the growth rates detailed in the General Assumptions.

The biomass models presented here, together with the harvested volumes, were the main sources of information used to generate the individual data tables in the entered spread sheets. In particular, the biomass models were used to estimate residue levels after determining the volumes of harvested product and the silvicultural system used in the harvesting operations. For example, in the Ash forest type the residue levels would vary significantly according to whether the operation was a thinning or a clearfell for sawlogs only or for sawlogs and pulpwood.

Burning Efficiency

Only a limited number of studies have been undertaken of the loss of carbon following slash burning in harvested eucalypt forests in Victoria. Also, whilst a high intensity slash burn is generally the preferred method to prepare a receptive seedbed following timber harvesting, seasonal conditions often prevent all planned burns in any one year being conducted. It is beyond the scope of this project to identify, on an annual basis, the number of burns successfully completed and the number of coupes carried over to the next season. Some carried over coupes would be burnt if adequate fine fuels were still available – otherwise they would remain unburnt and be subject to an extended soil disturbance treatment (e.g. heaping) prior to sowing or planting. It is estimated that, on average, 90 per cent of coupes would be burnt, with 10 per cent remaining unburnt with no loss of fine fuels or coarse woody debris (CWD) from burning.

For those coupes that are burnt, the data of Stewart and Flinn (1985), where there were high levels of coarse woody debris, provide a reliable indication of burning efficiency. For 12 burnt plots out of a total of 14 plots systematically located across a Mixed species forest in north east Victoria which had been cleared in preparation for pine planting, they found that 82 per cent of debris <70 mm diameter (i.e. mostly fine fuels) was lost, with only 18 per cent remaining as ash, charcoal and unburnt debris. It is reasonable to assume that 100 per cent of the fine fuel component in that debris was lost. However, this did not occur over the entire cleared area where two plots remained unburnt and where 95 per cent of the northerly aspect was burnt but only 40 per cent of the southerly aspect. Again, burning coverage is highly variable due to weather conditions, logging method and aspect.

Based on the above information, the following assumptions on burning efficiencies are made for all forest types in the tables.

Fine fuels (<100 mm):
100 per cent loss over 80% of coupe area for 90% of coupes = 70% burn efficiency

CWD (>100mm):
80 per cent loss over 70% of coupe area for 90% of coupes = 50% burn efficiency

It is important to note that burning efficiency is not relevant to the salvage of fire-killed *E. regnans* during the period 1945-1950. The intense wildfires of 1939 consumed all fine fuels and most crowns. Dense regeneration occurred soon after the fires. It was therefore not necessary, nor desirable, to undertake slash burning following salvage logging.

Thinning Yields

Flinn and Mamers (1991) provide data on preliminary thinning trials in young fire and logging regrowth in East Gippsland Mixed species forests. From a total of eight coupes, the mean yield of pulpwood was 76 green t ha^{-1}. However, the better quality stands were yielding around 100 green t ha^{-1} which is likely to be the typical yield from past thinning operations in Mixed species forests throughout the State (e.g. fuelwood thinning programs). This figure has therefore been adopted for thinning yields in Mixed species forests.

For *E. regnans*, thinning yields were estimated from the work of Webb (1966). The residue quantities associated with this mechanical thinning operation assumed that 30 per cent of the branches and leaves and 50 per cent of the understorey estimated from the *E. regnans* biomass model given earlier ended up as slash. This was equivalent to 40 t ha^{-1} on a dry weight basis. Of this 40 t ha^{-1}, 30 t ha^{-1} was assumed to be in the <100mm category.

Yields from Shelterwood Silvicultural System

In the past 25 years, a significant volume of sawlogs and pulpwood has been harvested from the Wombat Forest in central Victoria using primarily the Shelterwood Silvicultural System. This system replaced the Selection System in the 1973/74 harvesting season at a time when the sawlog harvest was around 50,000 m^3 yr^{-1} and the pulpwood harvest 70,000 green t yr^{-1} (Kellas *et. al.*, 1994). Introduction of this new system was expected to increase sawlog yields from 15 m^3 ha^{-1} to 40 m^3 ha^{-1} for the initial shelterwood harvest. In the first ten years, around 10,000 ha were subject to an initial cut. From a timber production viewpoint however, the Wombat Forest is highly variable in terms of productivity and the level of defective (non-merchantable) trees. Sawlog yields from both the initial and final shelterwood cuts vary substantially over the past 25 years. Based on a range of data sources, it has been assumed that the average yield of sawlogs from the initial harvest following the introduction of the Shelterwood System was 45 m^3 ha^{-1} for the first decade then declining to 40 m^3 ha^{-1} in more recent times. The yield for the final cut is about 30 m^3 ha^{-1}.

SECTION 4

Tasmania

Bernard Walker

Ken Felton

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TASMANIA

SUMMARY

Changes in forest management practices in Tasmania since 1945 are documented. The most important processes identified affecting carbon stocks over time were harvest removals, slash/fire management, regeneration and growth, and changes in forest areas contributing to wood production.

Extensive selection harvesting of predominantly sawlogs took place on private and State land from settlement to the start of the woodchip export industry in the early 1970s. Selection was of variable intensity depending on forest type and market factors. Following the commencement of the woodchip export industry, the quantity of commercial biomass removed during harvest dramatically increased. For example, the annual pulpwood harvest from State forest increased from approximately 400,000 green t yr^{-1} to 1,600,000 green t yr^{-1}.

Over the period 1945 to 2000, approximately 72 million m^3 of sawlogs were harvested from Tasmania's private and State forests. Over the same period approximately 55 million green t of pulpwood were harvested from State forests, but the quantity removed from private forests is unknown.

Large areas of new forests have been established following regeneration of harvested areas. The rate of biomass accumulation in these is faster than the relatively mature forests they have replaced.

Regeneration burning has been used consistently to reduce logging slash following harvesting in all forest types. This also ensures regeneration in both wet and dry forests, and provides strategic protection from wildfires in dry eucalypt forest types.

Extensive areas of both hardwood and softwood plantations have been established, particularly since the 1960s. As at September 2005, Tasmania had approximately 155,500 ha of hardwood plantations and 71,600 ha of softwood plantations. Plantations have been established on both cleared land and ex-forest (cleared) sites.

Tasmania is prone to wildfires and there has been a history of natural and human-induced fires that have resulted in substantial biomass removal and the establishment of extensive areas of single or multi-aged regrowth forest or Buttongrass plains.

Significant areas of forest previously available for wood production have been transferred into conservation reserves, mainly since the 1980s.

1. OBJECTIVE

The purpose of this review was to identify and describe changes in forest management practices during the period 1945-2000 that have had a significant impact on carbon stocks in the Tasmanian forest estate. The report describes what has happened in the forests using a stratification involving important forest management areas, forest types, management practices, and time periods. The time period was variable, aiming to capture change in practices that significantly altered C stocks.

The text is supported by a number of data tables and figures. In conjunction with the report, the purpose of the tables is to describe the management actions and silvicultural regimes that, when combined with ancillary information (e.g. spatial data on multi-temporal canopy disturbance, vegetation maps, climate data etc.), can be used to calculate carbon accounts annually since 1972. The data tables cover the period 1945 to 2000. Assumptions made when compiling the tables are documented in Appendix 1.

2. REPORT STRUCTURE AND SCOPE

The report is structured as follows:

1. A broad description of the Tasmanian forest estate and forest management history from European settlement to the present.
2. An account of the basis for stratification into Management Areas, generic forest types, and management practices described later in the report.
3. A description of changes in each Management Area concentrating on forest management practices affecting carbon stocks.

The scope of the study includes only public and private forests utilised for wood production and as such does not include woodlands or most conservation forests. It does discuss conservation forests that have been used for wood production after 1945 but that have since been transferred into the reserve system.

Access to spatial and non-spatial data used to compile this review and associated data tables are discussed in Appendix 3.

A system to document data and the reliability of both data and statements made in the text was developed (Raison and Squire, 2007).

The report covers a long period of time during which the names of many important forest management entities have changed. In the text the most relevant names have been used.

3. BROAD DESCRIPTION OF FOREST ESTATE

3.1 GENERAL DESCRIPTION OF TASMANIAN FORESTS

Forested land in Tasmania as at June 1996 comprised some 3.2 million hectares (Table 1) or 49 per cent of the total State land mass (Forestry Tasmania, 1998). For the purposes of this review, six broad forest types were identified as follows:

- Wet eucalypt forest
- Dry eucalypt forest
- Rainforest
- Other native forest
- Hardwood plantations
- Softwood plantations

Table 1. Tasmanian forest by type and tenures as at 30 June 1996.

Forest Type	Public Land '000 ha	Public Land % of Total Forest	Private Land '000 ha	Private Land % of Total Forest	Total Forest '000 ha
Rainforest	570	95%	28	5%	598
Dry eucalypt forest	1,040	63%	601	37%	1,641
Wet eucalypt forest	415	60%	281	40%	696
Other native forest	68	69%	31	31%	99
Plantation	64	46%	75	54%	139
Total forest	2,157	68%	1,016	32%	3,173

The detailed Regional Forest Agreement (RFA) vegetation types were amalgamated to fit the above categories (Appendix 2).

This review is primarily concerned with forests available for commercial forest management. Figure 1 shows the distribution of forest types on tenures where commercial forestry is allowed

3.2 BRIEF FORESTRY HISTORY FROM SETTLEMENT TO THE PRESENT

Europeans first settled Tasmania in 1803 and its abundant timber resources were almost instantly recognised (Carron, 1985). The first sawpit, located on the eastern slopes of Mt Wellington, was in operation by 1804 (Tasmanian Woodchip Export Study Group, 1985). By the 1830s, harvesting mainly centered on the Port Arthur penal settlement with harvesting also occurring around Launceston. As well, native pines were being harvested on the West Coast at Macquarie Harbour (Carron, 1985).

The Victorian gold rush of the 1850s sparked a building boom in Victoria and the Tasmanian timber export industry grew rapidly. Security of tenure arising from legislative changes allowed the sawmilling industry to expand between the 1860s and 1920s due to an influx of venture capital. An oversupply situation, and hence fierce competition, existed. Thus only premium grade material was readily saleable and the level of utilisation in the forest was limited to the best quality sawlog material. (Tasmanian Woodchip Export Study Group, 1985)

The Forestry Department was formed in 1920, resulting in higher regulation of the timber industry on State land and initiatives, such as the start of a softwood-planting program. Very high sawlog production levels existed until the Depression of 1931/32 lowered production levels significantly.

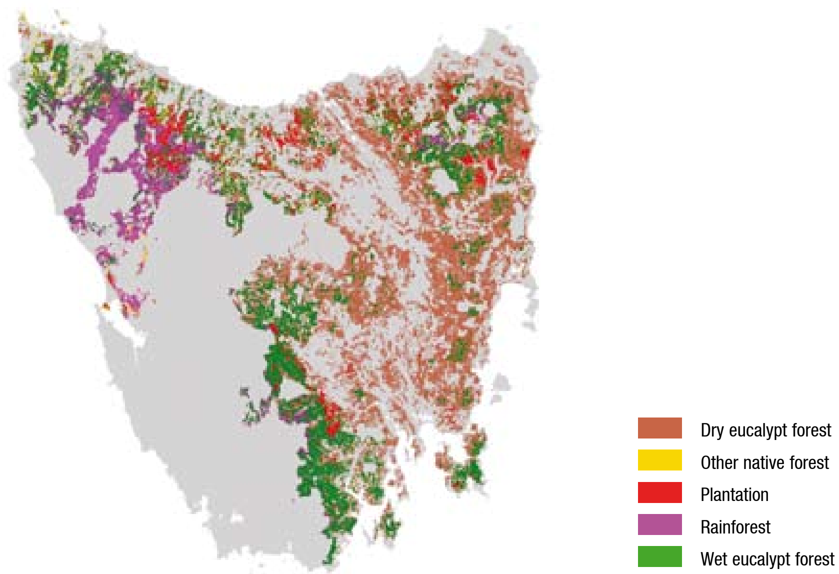

Figure 1. Distribution of forest types on areas available for commercial forestry in Tasmania.

In 1934, production returned to the highs of the 1920s, and concerns about diminishing supplies of accessible timber were raised in the late 1930s.

A pulpwood industry commenced in 1938 when Australian Pulp and Paper Manufacturers (APPM) began harvesting eucalypt pulpwood in the Burnie Concession to supply the new Burnie Pulp and Paper Mill. Australian Newsprint Mills (ANM) commenced pulp and newsprint production from eucalypt wood from their Boyer mill in 1941.

Sawlog production rose to new levels during the war years but declined immediately thereafter and remained depressed until 1947/48 when it increased. Figure 2 shows the total hardwood sawlog cut in Tasmania from State and private land between 1947/48 and 1995/96.

The Forestry Commission[1] was established in 1947. The cut from State land grew during the 1950s as the Forestry Commission opened up virgin areas with new road networks. Its 1950/51 Annual Report states that up to 20 per cent of mature forest was estimated to be accessible to forest roads. About 40 per cent was within reach if secondary roads were constructed and the remainder would only be accessible upon construction of new major primary and secondary roads.

In the early 1950s, the challenge of systematically regenerating the wet eucalypt forest types was recognised. Regeneration methods were refined in the late 1950s based on the research work completed by Gilbert and Cunningham (Gilbert, (1958) and Cunningham, (1960)), that recognised the role of fire in the regeneration of wet forests following harvesting. Regeneration burning commenced in those parts of Tasmania where pulpwood markets existed, with small scale programmes elsewhere.

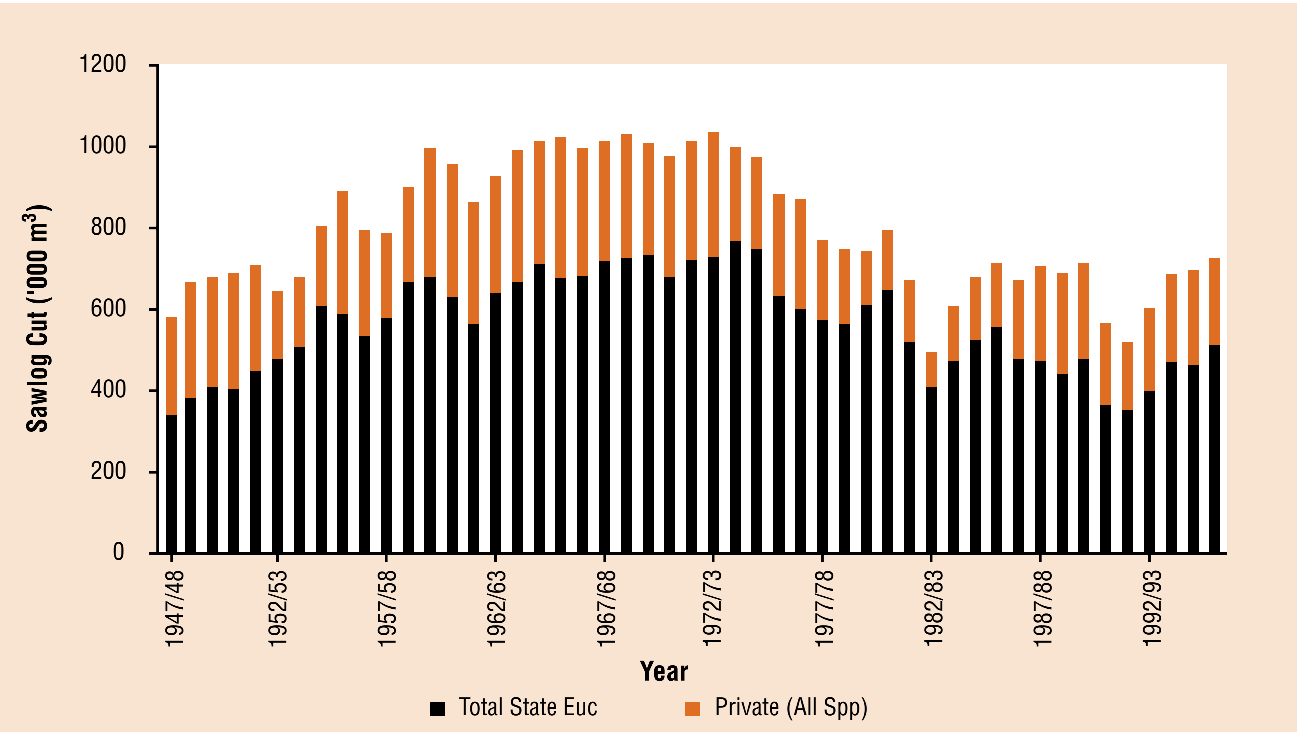

Figure 2. Harvest of hardwood sawlogs between 1947/48 and 1995/96.

[1] Forestry Tasmania superseded the Forestry Commission in 1994

In 1962/63, the Forestry Commission started a small, short-lived timber stand improvement programme in Brown-top Stringybark (*Eucalyptus obliqua*) and White-top Stringybark (*Eucalyptus delegatensis*) forests to remove low quality mature trees to promote regrowth. In regenerated areas, salvage logging commenced to remove cull trees remaining after previous selection operations. The rationale was to recover sawlogs and stimulate growth of the regenerating forest. Also, around this time, the Forestry Commission started a formal protective burning program (Forestry Commission Annual Report, 1962/63).

The rate of pine planting increased on State land from the 1960s, to complement dwindling hardwood supplies. In 1967/68, the first loans were obtained for this purpose under the Commonwealth-State Softwood Forestry Agreement (Forestry Commission Annual Report, 1967/68).

The eucalypt sawlog cut from State forests exceeded the Forestry Commission's estimated sustainable levels during the 1960s and into the 1970s, until an industry restructure took place. A forest management focus of improving forest utilisation was one of the initiatives put in place.

In 1971, the woodchip export industry commenced with mills being established at Triabunna and Long Reach (near Launceston). Another mill was opened at Long Reach in 1972. The export woodchip industry dramatically increased the quantity of pulpwood harvested from State and private land and allowed pulpwood already on the ground following earlier sawlog harvests[2] and in dead standing trees to be harvested.

Figure 3 shows State native pulpwood production in Tasmania over the period 1964/65[3] to 1999/00. The large increase in the mid-1970s followed the advent of increased pulpwood harvests for export as woodchips.

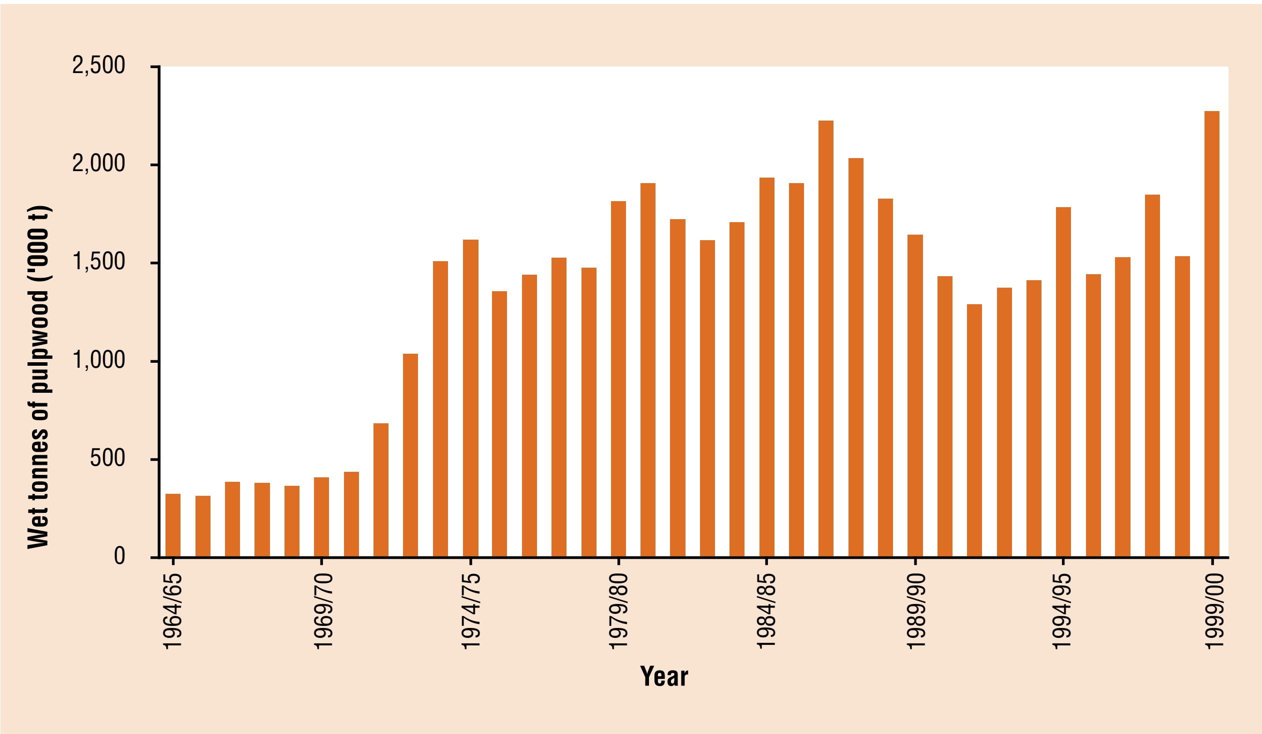

Figure 3. Pulpwood production from native forests between 1964/65 and 1999/00.

[2] Mainly from the tops and branches of felled sawlog trees

[3] The annual cut between 1945 and 1964 was around 350,000 tonnes

The first large scale harvesting of State softwood plantations commenced in 1973/74 (Forestry Commission Annual Report, 1973/74).

The Private Forestry Division of the Forestry Commission was created in 1977/78. Incentive schemes were introduced, including pine establishment assistance and a native forest regeneration grant, which provided eucalypt seed and a sowing service free of charge for private land clearfelled for woodchips prior to 1978.

Sawlog quotas to sawmillers from State land were reduced by 20 per cent in 1977 with further cuts in 1981 and 1983 to bring harvests into balance with sustainable yield estimates. The reduced sawlog quotas and growth of the export woodchip industry combined to have a significant effect on forest utilisation, with moves to integrate sawlog/pulpwood harvesting and higher sawlog utilisation. Smallwood[4] harvesting was conducted by some contractors in the 1970s and 1980s, predominantly in North East Tasmania.

Refinements of selection cut silvicultural regimes such as thinning, advanced growth retention and shelterwood systems and multi-aged systems generally, were introduced in the 1980s.

In 1982, a moratorium on harvesting rainforest was imposed for State land following the deliberations of the Rainforest Conservation Working Group.

In the 1980s and 90s, the Federal Government exerted strong controls over the export woodchip industry via the use of export license conditions. These impacted on forest utilisation by dictating factors such as the volume that could be sold from Management Areas, places where harvesting could not occur, the types of wood that could be harvested (e.g. small wood, lakeside salvage) and requirements for regeneration and plantation establishment on private property.

In 1985/86, smallwood logging was started by APPM in addition to that carried out by Forest Resources. Export licences dictated that companies harvesting on private land establish four hectares of eucalypt regeneration plus one hectare of plantation for every 1,000 t of wood harvested.

In the 1980s and 90s, several substantial reviews were undertaken into aspects of the forest industry. In the context of this report, a major consequence of these was the transfer of commercial forests into conservation reserves.

Table 2. Land Areas in Reserves ('000 ha) for Tasmania.

Decade	10 Year Increase	Cumulative Land Area in Reserves
1920		23
1930	85	108
1940	81	189
1950	53	242
1960	48	290
1970	628	918
1980	303	1,221
1990	660	1,881
2000	511	2,392

[4] Pulpwood below normal specifications for production of export woodchips. Often areas already harvested were logged for a second time using specialist harvesting equipment. "Yields of pulpwood from private forest areas where these operations have been implemented, have been increased by 20-30%" (Tasmanian Woodchip Export Study Group, 1985)

Both the 1987 Helsham Inquiry and the 1997 Regional Forest Agreement (RFA) had a significant impact as indicated by Table 2, which shows changes in land area in reserves by decades from 1920 to 2001 (FFIC, Hobart, 2001, *pers comm.*).

During the 80 years, since the establishment of the Forestry Department, there have been numerous changes in the categories of tenure of public land. The figures are for reserves of similar status being national parks, forest reserves and other 'formal' reserves. Significant additional forest is reserved in informal[5] reserves such as streamside reserves and wildlife corridors established under the Forest Practices Code and, on State forest, under Forestry Tasmania's Management Decision Classification system.

Figure 4 shows areas of forest that have been previously harvested that are no longer on tenures available for harvesting. Note that this does not provide a full picture of the effects of reservation on the commercial forest estate, as it does not include reserved, unlogged forest.

In 1990, as a consequence of the development of a Forests and Forest Industry Strategy for Tasmania (Forest & Forest Industry Council of Tasmania, 1990), harvesting of regrowth eucalypt forest became more common, especially in Southern Tasmania.

There was a move away from clearfell harvesting operations and greater use of selection systems during the 1990s. The 1990/91 Forestry Tasmania (FT) Annual Report stated that some 50 per cent of operations in native forest on State land and 43 per cent of operations on private land did not employ clearfelling. Table 3 shows the same statistic for six years between 1992/93 and 1997/98 for State land.

3.3 FIRES

Details concerning wildfire and fire management are the subject of a separate report (Gould and Cheney, 2007). As general background for this report, Figure 5 collates records of the area burnt and the number of wildfires in Tasmania on all tenures between 1945 and 2000.

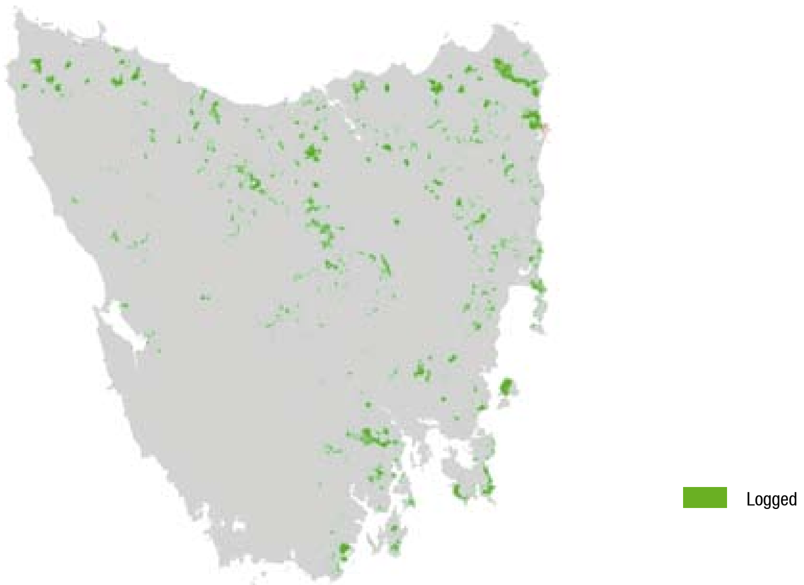

Figure 4. Areas of previously harvested native forest that are no longer available for harvesting.

[5] The test of whether a reserve on State land has formal or informal status is whether or not Parliament has to be involved in its revocation. For private land, State legislation allows an owner to formally set aside land for conservation purposes.

Table 3. Area (ha) and percentage of State forest land clearfelled and selectively harvested, for periods 1992-1998.

	Clearfell %	Selection %	Clearfell ha	Selection ha	Total ha
92/93	47%	53%	2,726	3,081	5,807
93/94	58%	42%	3,300	2,346	5,646
94/95	30%	70%	844	1,974	2,818
95/96	60%	40%	2,364	1,586	3,950
96/97	32%	68%	2,684	5,670	8,354
97/98	63%	37%	4,974	2,882	7,856

Lightning, the only natural cause of wildfire, is relatively infrequent, especially in southeastern Tasmania. Nevertheless, wildfires started by lightning have been recorded in western parts in the past two decades. The relative importance of lightning as a fire cause since 1803 and before European settlement is obscure. There is little doubt however, that fires lit by aborigines and resulting from lightning strikes led to a "...complex mosaic of disclimax communities… with considerable areas… occupied by sedgeland, scrub and sclerophyll forest, or mixed forest" rather than climax temperate rainforests (Jackson, 1999).

The majority of wildfires resulted from human activity, being either escapes from farmers' clearing fires, or regeneration and fuel reduction burns, or deliberately lit. In the decades from settlement to the 1980s, farmers frequently used fire to reduce hazards, improve access and produce 'green pick'

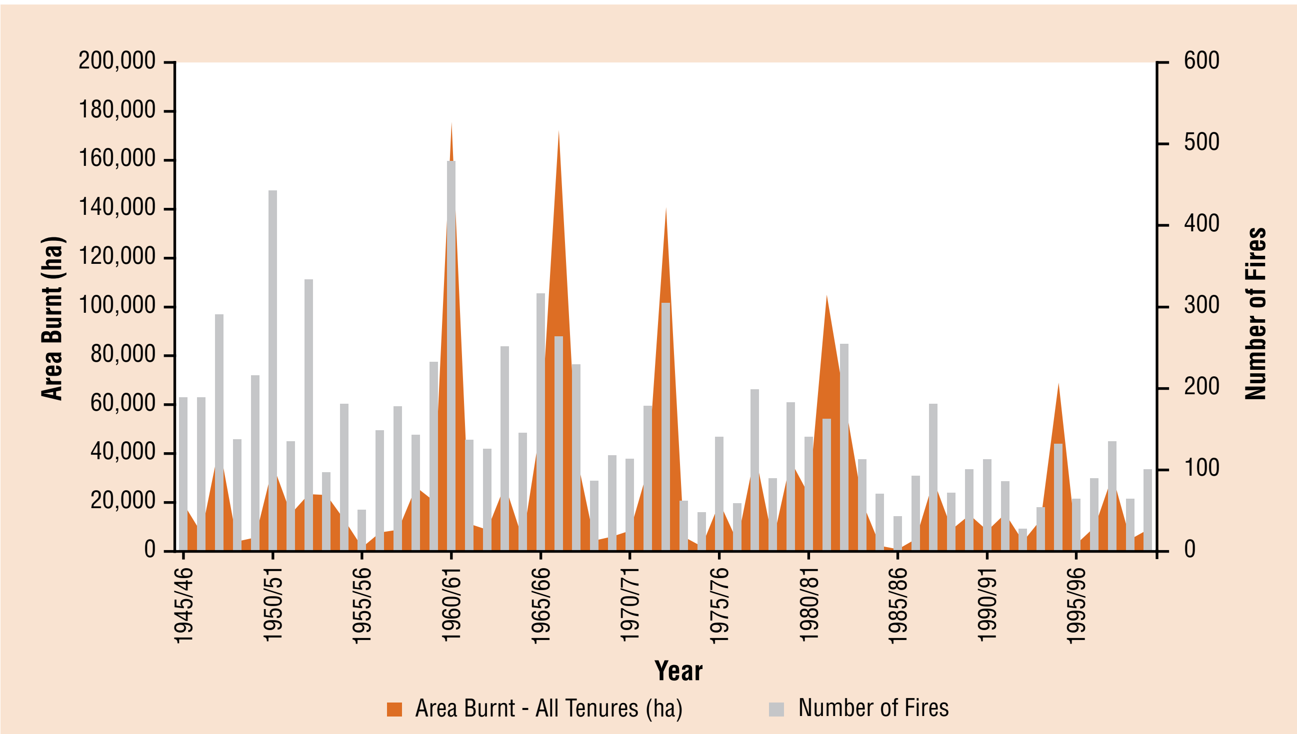

Figure 5. Areas burnt and numbers of wildfires on all tenures between 1945/46 and 1999/2000.

on grasslands. A 'burn everything' culture was evident in rural areas, and was of great concern to many foresters because of the damage caused to forests by wildfire (Cubit, 1996). On areas where high fuel loads existed, such as harvested areas, the problem was compounded. The Tasmanian Woodchip Expert Study Group (1985) concluded that "For the 12 years to 1982/83, 10 per cent of the 5,300 ha of State dry eucalypt forest regenerated without a post-logging burn was invaded by wildfire, compared with 2.2 per cent of the other 26,100 ha".

A fire regime of relatively frequent low-intensity fires has been the norm in dry eucalypt forests, with planned fuel reduction burns a part of the regime. In the wet forests before the 1960s, harvesting slash had mostly been burnt by wildfires. Planned fires were rarely used. Slash was often burnt by fires invading from adjacent land. Some 'wildfires' were in fact deliberately lit to encourage the establishment of eucalypt regeneration before it became official practice to conduct regeneration establishment burns.

Burning of logging slash following harvesting of eucalypt forests became established as a *formal* silvicultural technique in the early 1960s. Potential pulpwood and fuel wood is burnt to waste, if necessary, as experience demonstrates that unburnt slash is generally burnt in a wildfire (K Felton, Hobart, 2001, *pers. comm.*).

Figure 6 shows the area of State forest burnt in regeneration establishment burns between 1960 and 1998. The big increase in the mid-1970s followed the advent of increased pulpwood harvests for export as woodchips. The small areas burnt in some individual years are mainly a consequence of unfavorable burning conditions.

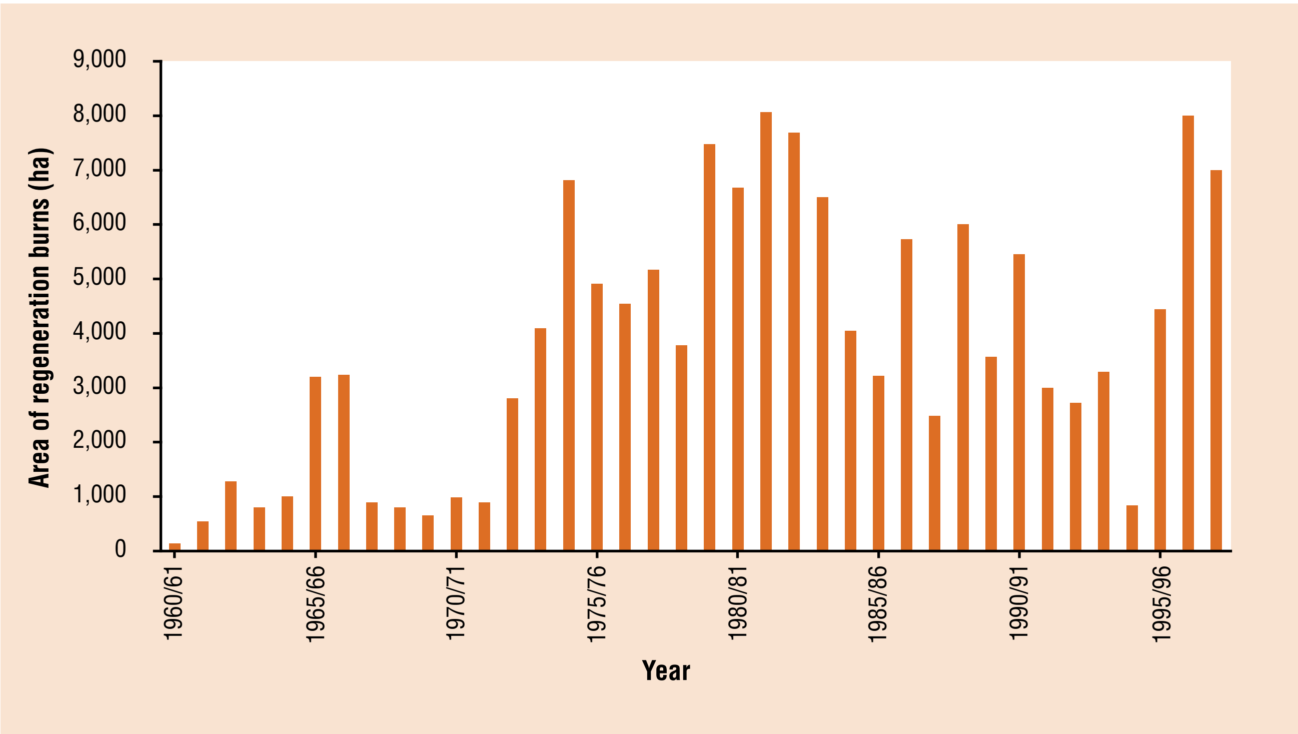

Figure 6. Areas of State forest subjected to regeneration establishment burns between 1960/61 and 1997/98.

The use of planned fuel reduction burning in dry eucalypt forests and moorlands increased in the 1970s to reduce fuel levels and thus the risk of severe damage from wildfires. After peaking in the 1980s, fuel reduction burning declined in the 1990s due to a combination of factors. Importantly, fuel reduction burning became operationally difficult as a consequence of the increased areas of adjacent young native forest regeneration plantations. Figure 7 indicates the area of State Forest where fuel reduction burning took place between 1965 and 1998 in Tasmania.

3.4 PLANTATION ESTABLISHMENT

Details concerning plantation establishment and management are the subject of a separate report (Snowdon and James, 2007). As an overview, Tasmania as at September 2005 had approximately 155,500 ha of hardwood plantations and 71,600 ha of softwood plantations (Parsons *et. al.*, 2006). Table 4 shows the distribution of the plantation on State and private land in Tasmania in 1999 (National Forest Inventory, 2000).

The majority of hardwood has been planted since 1985, whereas peak planting of softwoods occurred between 1965 and 1985. Figure 8 shows annual plantation establishment levels on State land. Increased hardwood areas resulting from prospectus plantings by Forestry Tasmania are evident from the mid-1990s. Prospectus plantings on private land by other private forestry companies also increased over the same period.

4. STRATIFICATION TO GUIDE THE COLLECTION AND ANALYSIS OF DATA

Historical data were analysed over relevant time periods in terms of the following themes or strata:

1. Management Area
2. Tenure
3. Forest Type
4. Management Practice

4.1 HISTORICAL 'MANAGEMENT AREAS'

Many of the early trends in forest management in Tasmania are best explained in terms of the management priorities and practices of the individual land managers, be they government, or private. The Management Areas selected are based on historical Concession[6] area boundaries, and are:

- North West
- Burnie
- Wesley Vale
- Triabunna
- Australian Newsprint Mills (ANM) Concession
- Southern Forests
- West Coast

The Management Areas include both private property and State lands. This review has not considered forestry activity on King Island or the Furneaux group of islands. Figure 9 shows the zones used.

Table 4. Areas (ha) of plantation in Tasmania in September 1999 (source: National Forest Inventory, 2000).

Public Hardwood	Public Softwood	Private Hardwood	Private Softwood	Joint Venture Hardwood	Joint Venture Softwood	Total Hardwood	Total Softwood
15,800	3,500	83,900	30,700	2,100	41,200	101,800	75,400

[6] Acts of Parliament granting Companies rights of access to forest resources on State land for exploitation under conditions agreed between the Government and those Companies. The last of these was cancelled in 1992.

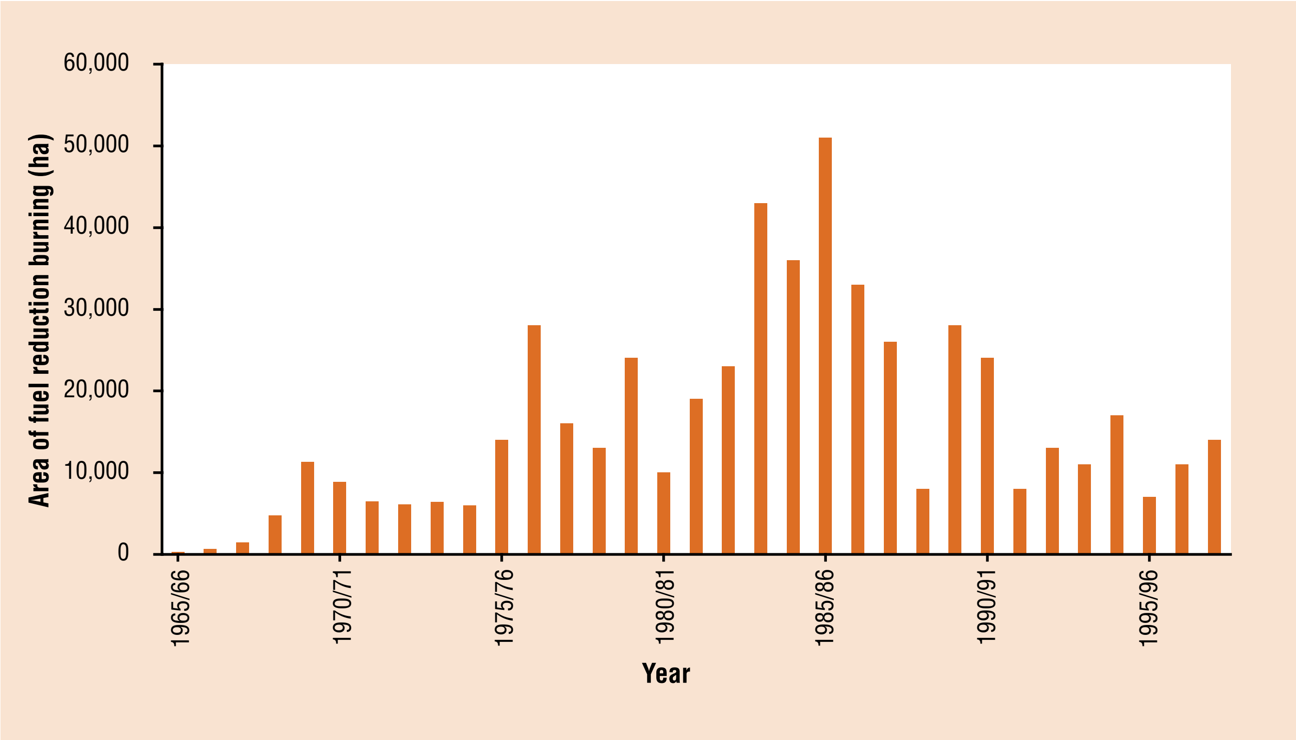

Figure 7. Areas of State forest subjected to fuel reduction burning between 1965/66 and 1997/98.

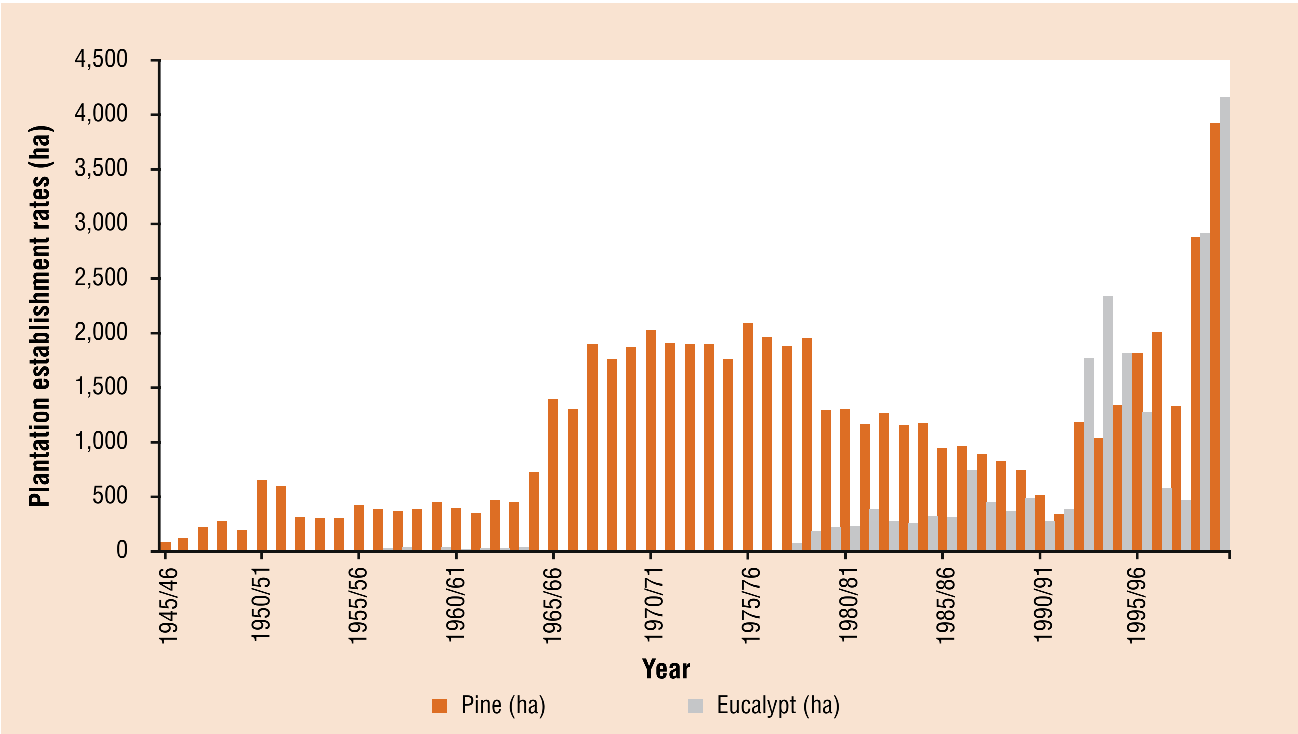

Figure 8. Annual rates (ha) of new plantation establishment on State land between 1945/46 and 1999/2000.

4.2 TENURE

The location of tenures available for commercial forestry is illustrated in Figure 9.

Private

This category includes land and forests under freehold title, including land owned by industrial forestry companies.

In the earliest years of exploitation of Tasmania's forest estate, harvesting focused on the most accessible high quality forests. These were generally privately owned or became privately owned. As well, private forested land was targeted for agricultural clearing and other infrastructure development. In later years the proportion of harvesting on private land reduced as forests were cut-out. Until recently, there has been little restriction on the clearing of private land.

Figure 10 shows sawlog cuts from private land in Tasmania between 1947 and 1987 as percentages of the State's total cut. Though the proportion of sawlogs harvested from private property has declined, it is still quite high.

State forests

This class predominantly consists of forest managed by Forestry Tasmania.

4.3 FOREST TYPES

Six forest types have been chosen that are consistent with available RFA datasets and generally reflect the different management regimes utilised. The six classes are amalgamations of the 52 communities recognised in the RFA vegetation community mapping project. Appendix 2 shows how the RFA communities were amalgamated.

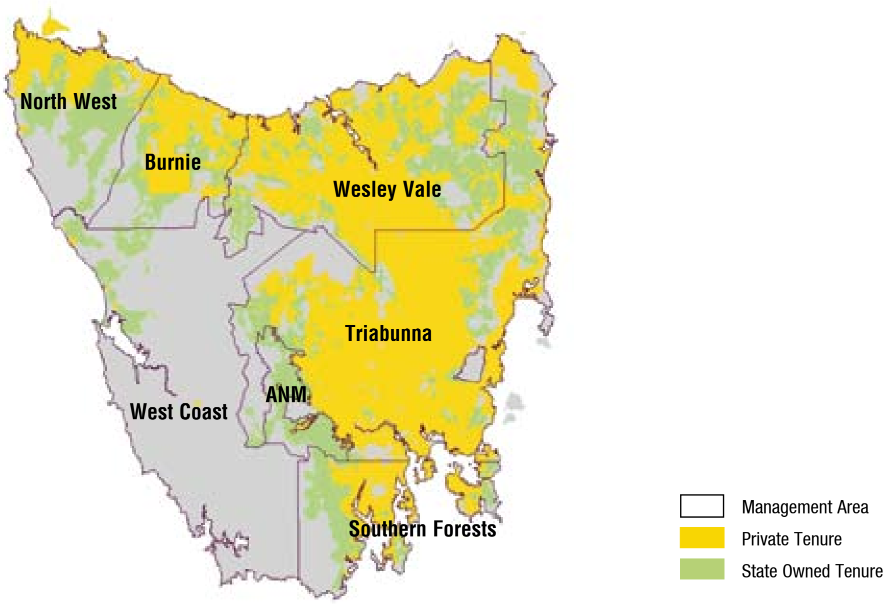

Figure 9. Distribution of commercial forest by tenure and management area.

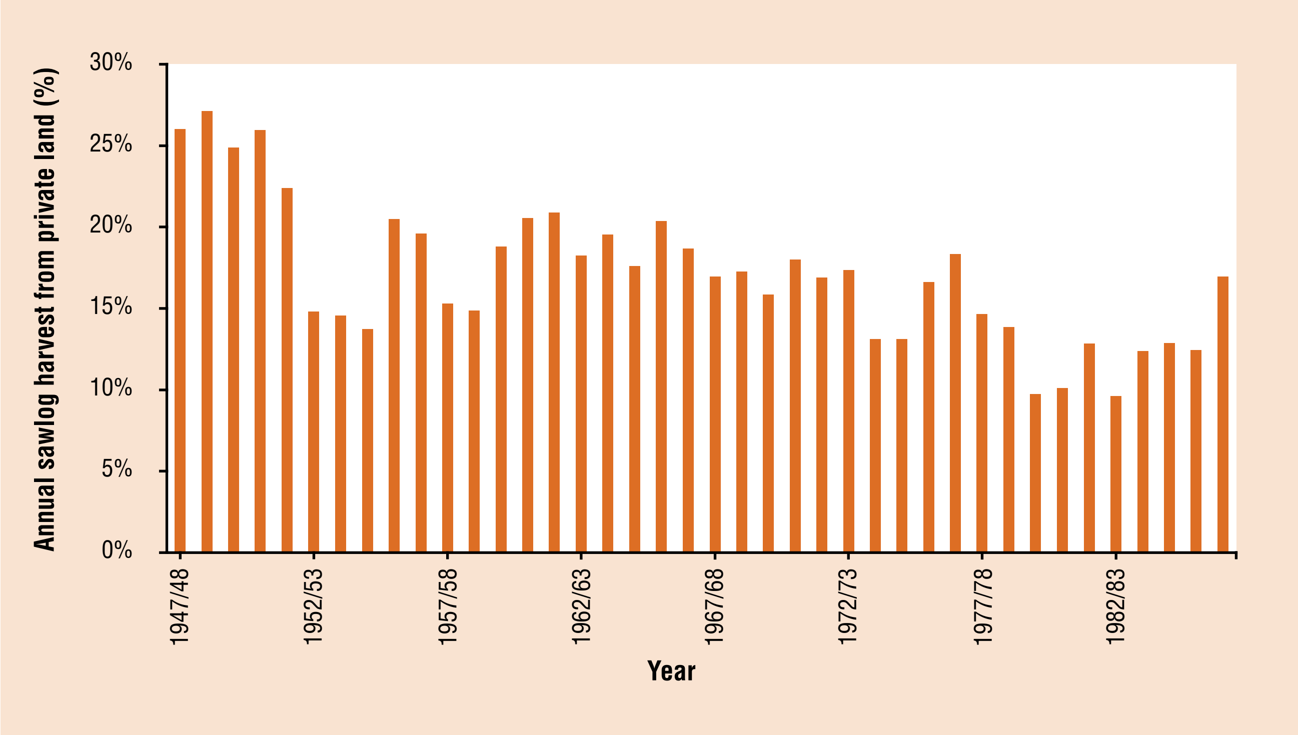

Figure 10. The percentage of annual State hardwood sawlog harvest derived from private land for the period 1947/48 to 1987/88.

Rainforest

These are defined as closed forests in areas of high rainfall dominated by tree species such as Myrtle (*Nothofagus cunninghamii*), Sassafras (*Atherosperma moschatum*), Celery Top Pine (*Phyllocladus aspleniifolius*) and Leatherwood (*Eucryphia lucida*) that can regenerate in the absence of a major disturbance. They do not contain any significant sclerophyll (e.g. eucalypt or acacia) elements.

Rainforests which occur on productive soils are relatively tall (to 40 m), have a very open understorey, and are termed callidendrous rainforests. At the other end of the height and understorey density spectrum are implicate rainforests, with a very dense understorey and short dominants. The thamnic type is intermediate between the two.

Note that in situations where Myrtle is disturbed by human-induced (e.g. road construction, harvesting etc.) or natural disturbance, it becomes susceptible to myrtle wilt fungus. When infection occurs in the callindendrous rainforests, death of large areas can result, to an extent that may be detected via remote sensing.

Wet Eucalypt Forests

These include eucalypt forests with a closed understorey, which consists predominantly of wet sclerophyll forests and mixed forests (eucalypt forest with a rainforest understorey). These occur on areas with high annual rainfall, generally over 750 mm yr^{-1}. Predominant eucalypt species include *Eucalyptus obliqua*, *E. delegatensis*, Swamp Gum (*Eucalyptus regnans*) and White Gum (*Eucalypts viminalis*).

In some parts of the State, large areas of even-aged regrowth occur as a result of fire or past harvesting. Particularly in the south, large areas of regrowth have been affected by dieback resulting in death of individual trees or crown damage. Again, this is detectable by remote sensing.

Dry Eucalypt Forests

These forests are mostly of low to medium height with an understorey characterised by drought-tolerant shrub species and a ground layer commonly composed of bracken, sedges and grasses (Duncan, 1999). This is the dominant natural vegetation of the drier lowlands and uplands of eastern and northern Tasmania, but is also found in moist and wet environments of the centre and west depending on geology, landform, landuse and fire history. Predominant eucalypt species include Black Peppermint (*Eucalyptus amygdalina*), *E. viminalis*, *E. delegatensis*, Mountain White Gum (*Eucalyptus dalrympleana*) and Cabbage Gum (*Eucalyptus pauciflora*). These forests are typically uneven-aged.

Other Native Forests

This forest type consists of *Acacia* and other native secondary species forests, which contain no significant eucalypts or rainforest species. Predominant species include Silver Wattle (*Acacia dealbata*) and Blackwood (*Acacia melanoxylon*).

Hardwood Plantations

Intensively managed hardwood plantations, primarily Blue Gum (*Eucalyptus globlulus*) and Shining Gum (*Eucalyptus nitens*).

Softwood Plantations

Intensively managed softwood plantations, practically all Radiata Pine (*Pinus radiata*).

4.4 FOREST MANAGEMENT PRACTICES

The term 'Management Practices' encompass the techniques used for harvesting, slash management and forest regeneration. There has been a broad range of harvesting and silvicultural techniques applied over the last 50 years. The account below relates to eucalypt forests except where noted.

Selection – Sawlogs Only

The harvesting of selected trees to produce only sawlogs was standard practice from European settlement in 1803 until the 1940s, when pulpwood could be sold. Quantities of firewood, sometimes harvested with the sawlogs, were so small as to be incidental.

Since the early 1970s, when the woodchip export industry resulted in a rapid increase in the harvest of pulpwood, selection harvesting has decreased in importance. Currently, in eucalypt forests, harvesting is for sawlogs and pulpwood together, except in exceptional circumstances. For non-eucalypt forests, selection harvesting is used for very small areas of rainforest and blackwood swamp forests.

The proportion of stand biomass removed in a sawlog selection operation varied greatly, depending on stand and market conditions, but was generally small.

Selection cuts to produce only sawlogs were often followed by a wildfire (or wildfires). Some fires were deliberately lit to facilitate clearing, to aid access to other areas of forest, or to assist eucalypt regeneration in wet forests. The major use of planned fire following selection cuts for sawlogs in eucalypt forests was fuel reduction burning which had, as an objective, the removal of the fire hazard in the slash, often coupled with a desire to facilitate the establishment of eucalypt regeneration. In this case, the harvesting practice crossed a boundary and became a silvicultural system. The absence of eucalypt regeneration after a fire is very unusual in a selectively harvested eucalypt forest, as retained trees supply seed for the establishment of seedlings. These seedlings are supplemented by advance growth and coppice shoots in dry eucalypt forests.

Selection – Sawlogs and Pulplogs

This harvesting technique began once a pulpwood market was available. As the markets allowed, it replaced selection harvesting for sawlogs only, evolving over time into several silvicultural systems. Silvicultural systems that are currently used in eucalypt forests and involve a selection cut can be identified as:

- Seed tree retention
- Shelterwood
- Overstorey removal
- Advanced growth retention
- Potential sawlog selection
- Selective logging
- Thinning

(Private Forestry Council, 1991).

Most of the systems were developed in dry eucalypt forests that had been cut in the past to supply sawlogs only. As pulpwood markets developed, such cutover forest was re-logged.

Since the 1980s, provisions have been made for the establishment of regeneration when using a silvicultural system (with the exception of thinning). Eucalypt seed may be sown if seed on retained stems (as supplemented by advance growth and coppice shoots) is expected to be insufficient. Mechanical soil disturbance, additional to that produced by harvesting operations, may be carried out. Fuel reduction burning[7] is common, providing an improved seed bed and reducing fire hazard. Managers avoid creating large, continuous areas, which have not been given a fuel reduction burn because of the undue fire risk.

The proportion of the eucalypt biomass removed in logs depends on the stand. For example, the harvest of large trees from a well stocked forest dominated by mature eucalypts, to leave groups of advance growth (advance growth retention) will remove most of the biomass, whereas the removal of a small number of overstorey trees will give a much lower figure, perhaps down to one tenth of the biomass (K. Felton, 2001, *pers. comm.*).

Thinning of native eucalypt forests has been practiced in State forest for some years. Thinning continues to be almost universal in pine plantations and is beginning to be used in eucalypt plantations.

Small areas of rainforest are logged using a selection system. The remaining shelterwood supplies seed, which is supplemented by advance growth and coppice shoots.

Clearfell – Regeneration by Seeding

As an initial step it is necessary to define the term ‘clearfell’. In its literal sense it means all the trees in a stand, large or small are cut at the one time and, in the silvicultural system, replaced by an even-aged crop of regeneration. Troup (1955) applies the term in this way.

The wet eucalypt forests of Tasmania have an even-aged character, (even though they usually have two or more age classes of eucalypt present), and are managed by a clearfelling system in all but a few particular cases. The dry eucalypt forests, with their characteristic uneven-aged structure, are rarely clearfelled, though some in the Eastern Tiers were treated this way in the first decade of the export woodchip industry (1970s).

In areas where markets cannot be found for all available pulpwood, the harvesting operation is still usually categorised as clearfelling, (and appears as such in statistical data), partly at least because it has almost universally been followed by a burn. After the fire almost all trees are dead, though the presence of some live eucalypts means that the new stand is not strictly even-aged.

[7] In selection operations, the focus of the fuel reduction burn is to remove unmerchantable material from the tops and branches of felled trees. This is commonly referred to as a top disposal burn.

Planned post-logging burns were not applied in the wet eucalypt forests types before the 1960s. Before that time, slash was often burned in a wildfire, which was also true of slash not treated with a regeneration establishment burn after the 1960s. A long time interval between harvest and wildfire of up to 15 years was common (and perhaps longer in some cases). In the interval, fine fuels resulting from harvesting decayed, larger fuels dried out and regeneration, especially of understorey trees and shrubs, became important.

After a wildfire, seed in the crowns of remaining eucalypt trees is usually sufficient to give an adequate stocking of eucalypt regeneration. Stocking percentages after a wildfire tend to be high (K. Felton 2001, *pers. comm.*). In the case of the managed system, seed is normally applied artificially (from the air since the mid-1960s), though operational trials using seed trees have been conducted.

In the 1960s and early 1970s, in coupes that had many standing trees (eucalypt or understorey) left after the harvest, some or all of these trees were cut (or pushed over) to create more fuel and increase the rate of drying of the fuel[8]. Some, however, remained standing. As pulpwood utilisation increased, a higher proportion of biomass ended up on the forest floor after the harvest and the need to create extra fuel disappeared. In a contrary way, in the last decade, islands of unlogged forest are left in clearfelled coupes for environmental reasons.

In summary, clearfelling is the usual silvicultural system applied in wet eucalypt forests. After the post-harvest burn the ground is fully open to the sun. Before a burn there can be a significant cover of trees in logged forest and, in the past, this cover could be large. Well stocked vigorous eucalypt regeneration is the norm after a burn. In the absence of a fire, eucalypt regeneration is much less abundant though, in both cases, regeneration of other species rapidly occupies the site (K. Felton 2001, *pers. comm.*). Some coupes where slash had been retained unburnt have been re-logged because their eucalypt growing stock has been poor (K. Felton 2001, *pers. comm.*).

Conversion to Plantation or Agriculture

The arable land and land under the towns of Tasmania was once forested, the forests having been deliberately removed. Techniques not involving a managed commercial timber harvest were used in the first years after settlement but the harvesting of at least sawlogs from cleared areas has since become standard practice. Since the woodchip export industry began, the proportion of the available pulpwood utilised has increased, but some is still burnt to waste. In addition, large quantities of wood not suited for sawing, pulping or fuelwood are burnt. A normal sequence is harvest, broadcast burn, push into heaps, and burn the heaps. The heaps may be retained for many years before they are burnt and some, in plantations, may be retained until the plantation is regenerated. If the quantity of debris after harvest is low, then the broadcast burn may be omitted, in which case burning of the heaps is very likely.

As well as deliberate clearing to produce arable land for farming, grazing of dry eucalypt forests has resulted in their gradual loss through a combination of poor regeneration, aging of trees, and the effects of drought.

Fuelwood Harvest

Wood is the traditional source of energy for domestic heating, and is still very important. As the government does not regulate fuelwood harvests, statistics are few, and non-existent until recent years. Forestry Tasmania records indicate that an average of 37,000 t of firewood are harvested annually from State forest (Tasmanian Woodchip Export Study Group, 1985). It has been shown (Davies, 1982) that most of the firewood supplied for domestic

[8] The term cull falling is applied to this operation.

use in Hobart came from private land and that this is probably also true for Launceston (Tasmanian Woodchip Export Study Group, 1985) and Burnie.

Domestic firewood traditionally came from dead trees in pastoral areas (some of which had been ring barked) of the Midlands, Derwent Valley and East Coast, the cutters being quite selective. In recent years, domestic firewood has been more commonly taken from forests, either at the time of a harvest for other products, or as a follow-up operation.

Small amounts of wood have been used industrially from time to time in recent decades. Currently, there is some interest in using logging residues for wood-fired electricity generation.

5. DETAILED DESCRIPTIONS OF CHANGES WITHIN MANAGEMENT AREAS

This section provides detailed descriptions of the management practices applied within each Management Area. Data tables have also been prepared (Appendix 1).

5.1 NORTH WEST

The North West has never been a Concession area, so the forest management on State land in this region has always been carried out by Forestry Tasmania. The area continues to service a large sawmilling industry. Pulpwood has been harvested since the 1970s.

Freehold land in this zone is of high value for agricultural enterprises and much of the suitable forest was cleared for this purpose.

General Description

This zone consists largely of wet eucalypt forests, rainforest and other native forest including swamp forests on gently undulating terrain. The forests are interspersed with patches of Buttongrass moorland. The majority of Tasmania's rainforest is in this Management Area.

The Arthur River divides the area into northern and southern portions. These two subdivisions reflect differences in forest type, levels of historical exploitation, access and land use patterns (Forestry Commission, 1989).

Approximately half of the State forests are wet forests dominated by *E. obliqua*, Brooker's Gum (*Eucalyptus brookeriana*) and Smithton Peppermint (*Eucalyptus nitida*) as mature forest and regrowth. Understorey occurs as wet sclerophyll or rainforest types (Forestry Commission, 1989).

With the exception of the Woolnorth block owned by Gunns Forest Products, very few large, contiguous areas of private forest remain.

The *Acacia melanoxylon* swamps in this Area have been the State's primary source of blackwood timber for almost a century (Forestry Commission, 1982). Much of the original area of the *A. melanoxylon* swamps has been drained, sold to private owners and converted to agriculture. Most of the approximately 8,000 ha of current swamp forests on State land have been harvested since before the turn of the 20th century.

History of Forestry Development

The North Arthur eucalypt forests of all tenures were heavily cutover by selective logging for sawlogs prior to the 1970s. Regrowth stands, found near the north coast, arose from logging and fires dating back to the 1800s. On State land, over three quarters of the even-aged regrowth is in the North Arthur forests while the remaining quarter is in the South Arthur (Forestry Commission, 1989).

Table 5 lists events that have impacted on carbon stocks in the North West Management Area or that could assist the interpretation of remotely sensed data.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

In an historical context, only a small proportion of the pulpwood potentially available in this Management Area has been utilised. Demand for export woodchips has been less than the total amount of pulpwood available in Tasmania. In this Management Area, cartage costs to market are high, resulting in the accumulation of surplus pulpwood. On State land, planning has tried to ensure that coupes selected for logging provided the correct sawlog to pulpwood ratio, given fairly consistent demand for sawlog but variable demand for pulpwood from year to year. In general, this led to specific targeting of forests with a higher proportion of sawlogs.

Artificial regeneration treatments following harvesting of mature eucalypt forests, commenced in the 1960s. Wildfires in 1961 and 1967 also created areas of eucalypt regeneration, predominantly burning cutover forest in the North Arthur. Due to lack of consistent pulpwood markets and silviculture, an overstorey of predominantly dead trees still exists in most regenerated areas.

Also, because of limited pulpwood markets, multi-stage harvesting continued to be used on some coupes after the introduction of integrated harvesting in 1973. This involved a first stage where understorey species sawlog were removed, a second stage where eucalypt sawlog and associated pulpwood was removed, followed by a final removal of predominantly pulplogs. The latter stage could only occur if a market for pulpwood existed. If it didn't, a decision was made to either hold over the coupe for a delayed final cut or burn the remaining pulpwood in a regeneration establishment burn. A 'snapshot' of this Management Area at any point in time would show a patchwork of harvesting coupes in various stages of completion.

Regeneration

"Before integrated logging commenced in 1973, … 10,000 ha of forest (State) had been systematically regenerated to eucalypt mainly from re-stocking of the 1961 wildfire area. From 1972 to 1982, a further 9,200 ha were sown following clearfell operation." (Forestry Commission, 1989). Regeneration surveys show that over 90 per cent of these areas were fully stocked (Forestry Commission, 1989).

Plantation Development

Some private plantations have been established on predominantly ex-forest sites. These are mainly

Table 5. Key events in the North West Management Area.

Time	Activity
1826	First settlement established in this area.
1969	Harvesting commenced in the South Arthur forests (Annual Report Forestry Tasmania, 1997).
1973	APPM (Burnie) commenced harvest of pulpwood from cut–over forests south of the Arthur forests.
1982	Myrtle pulpwood arising from harvest of eucalypt mixed forests taken by both APPM and Forest Resources.
To present	Sawlog cuts have remained fairly consistent. A market for all pulpwood produced has not been consistently available. Thus, wastage of some pulpwood in regeneration establishment burns continues.

eucalypt plantations (*E. globulus* or *E. nitens*) on freehold land owned by forestry companies. Some plantation development has occurred in recent years on State land as part of Forestry Tasmania's Intensification of Forest Management (IFM) project, and as areas within its prospectus plantation scheme. Plantations established on private land are mainly being managed on short (15 to 20 year) rotation pulpwood regimes. On State land, hardwood sawlog regimes are anticipated, with selected stems having been pruned.

Wildfires and Fuel Reduction Burns

Fuel reduction burns are carried out on moorlands adjacent to production forests, especially south of the Arthur River, where aerially ignited burns became an established practice in the early 1970s.

Change in Forest Areas Contributing to Wood Production

Significant areas of predominantly rainforest on State land were formally reserved from timber production during the RFA process. Prior to the RFA, accessible rainforests were exploited until the imposition of a moratorium on rainforest harvesting in 1982. Following the RFA, several hundred hectares of *E. brookeriana* wet eucalypt forest owned by North Forest Products were placed in a private CAR[9] reserve.

Summary of Management Factors Affecting C Stocks

Table 6 summarises changes in the most important processes affecting C stocks over time (harvest removals, slash/fire management and regeneration techniques).

Table 6. Silvicultural practices in the North West Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature wet eucalypt between 1945 and 1959.	Selective harvests prior to pulpwood markets and regeneration establishment burns.
	State mature rainforest between 1945 and 1982.	Harvesting for sawlogs till 1982 rainforest moratorium.
	State mature other forest between 1945 and 2000.	Harvest of sawlogs from blackwood swamps.
Selection – sawlogs and pulplogs	Private mature wet eucalypt between 1945 and 1972.	Minor pulpwood markets prior to export woodchipping.
	State mature rainforest between 1997 and 2000.	Harvest of rainforest in selected areas post RFA.
Clearfell – regeneration by seeding	State mature wet eucalypt between 1960 and 1972.	Systematic regeneration operations began – pulpwood wasted.
	State mature wet eucalypt between 1973 and 2000.	Pulpwood markets arising from export woodchipping.
Conversion to plantation or agriculture	State mature wet eucalypt between 1994 and 2000.	Plantation establishment.
	Private mature wet eucalypt between 1973 and 2000.	Plantation establishment.
	Private mature dry eucalypt between 1945 and 2000.	Agriculture.
	Private mature rainforest between 1945 and 2000.	Agriculture.
	State mature other native between 1945 and 1980.	Agriculture after change to private tenure.
	Private mature other native between 1945 and 1980.	Agriculture.

[9] Comprehensive and Adequate Reserve system (JANIS, 1997).

5.2 BURNIE

The Burnie Management Area's boundaries are those of the 1926 Burnie Concession, which was held by APPM. As well as State Forest, the Area contains substantial holdings of private land, large areas of which have been managed as a forestry enterprise by APPM since the 1930s.

General Description

The Management Area is dominated by a rolling, hilly plateau composed of Tertiary basalt rising from the coast and extending some 70 km to the south. The Area's forests consist mainly of wet eucalypt forests, rainforest and other native forest. The major eucalypt species are *E. obliqua* at lower elevations and *E. delegatensis* at higher elevations. Areas of temperate rainforest dominated by *Nothofagus cunninghamii* are found on both State and private land.

As in the North West Management Area, freehold land in this zone is of high value for agriculture and most suitable land has been cleared.

There have also been substantial areas of plantation established on private land owned by APPM and other landowners.

History of Forestry Development

Table 7 lists events that have impacted on carbon stocks in the Burnie Management Area or that could assist the interpretation of remotely sensed data.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

The harvesting methods employed in the Management Area reflected the variable requirement for sawlogs and pulpwood over time. Many areas were harvested up to three times (Walker, 1985):

- Sawlogs, and pulpwood in heads removed
- All merchantable trees cut except eucalypt seedtrees
- All remaining commercial wood removed

Table 7. Key events in the Burnie Management Area.

Period or Date	Activity
1820s	Selective harvest of accessible forests commenced often followed by clearing for agriculture. Tracts of regrowth forests were created along the north coast following harvest and wildfire.
1937	The Burnie Pulp and Paper Mill commenced operation utilising eucalypt species and *Nothofagus cunninghamii* (approx 25%). Boilers were fired with fuelwood up to 1959.
From 1953	Increased pulpwood was harvested to supply three extra paper machines.
1954	An integrated sawmill and chipping facility to cut timber and pulpwood billets for chipping was constructed. An Agreement between the Forestry Commission and APPM stated that pulpwood should be obtained from fully integrated sawlog and pulpwood operations on State land rather than from selective logging or smaller trees or regrowth forests.
From 1972	The total quantity of pulpwood harvested increased when export pulpwood was sent by train to APPM's export woodchip mill at Long Reach.
1992	The Burnie Mill stopped using *P. radiata* and *Nothofagus cunninghamii.*
1996	The Hampshire export hardwood woodchip mill was constructed. Export of eucalypt woodchips commenced with *Nothofagus cunninghamii* from private land also being utilised.
1998	Burnie Mill stopped making pulp in 1998 instead using 100% imported pulp.

[10] APPM became North Forest Products and subsequently Gunns Forest Products

Between 1936 and 1954, sawlog and pulpwood were cut on separate areas and pulpwood in the heads of sawlog trees was wasted (Walker, 1985). Most timber was cut on private land, much of which was being cleared for agriculture. In 1945, a major roading program commenced on APPM's Surrey Hills and Woolnorth blocks. In 1946, logging of rainforest commenced on Surrey Hills to supply *Nothofagus cuninghamii* (Myrtle) and *Atherosperma moschatum* (Sassafras) logs to veneer and sawmills.

The first fully integrated operation in mature forest commenced on State land in 1958. Because of APPM's policy of not using fire for regeneration, Forestry Tasmania accepted responsibility for regeneration establishment burns and subsequent sowing on State land for several years until APPM accepted this technique on both State and private land in the 1960s. Previously APPM relied on mechanical scarification to create a seedbed for eucalypt regeneration.

Between 1954 and 1956, most of APPM's log requirements were obtained from its freehold land. Between 1956 and 1984, roughly half of APPM's requirements was sourced from freehold land and the remaining half from State land (Walker, 1985).

From the late 1980s, by agreement with Forestry Tasmania, the rainforest harvest on State land was limited to operations on previously cut-over areas.

Regeneration

Some eucalypt regeneration failures were experienced on areas of State land managed by APPM. The majority of the area is now fully stocked. On higher elevation land owned by APPM, problems were experienced with the regeneration of *E. delegatensis* forests on Whitegrass. In the 1980s, shelterwood or other selection systems were adopted to counter this problem. Most previously harvested areas with understocked eucalypt regeneration were converted to plantation.

On APPM's freehold land most suitable native forest has been cleared and established to plantation. Areas not suitable for plantation have been regenerated to native forest.

Plantation Development

Large areas of private land, mainly owned by APPM, have been planted with hardwood (mostly *E. nitens*) and softwood (mostly *P. radiata*), and significant areas of State land have been planted with *P. radiata*. Planting of *P. radiata* on both tenures substantially accelerated in the 1960s. Planting of eucalypt species on freehold commenced in the 1970s. Much of the earlier planting occurred on previously cleared land.

APPM initially planted *P. radiata* for pulpwood, therefore, pruning and non-commercial thinning were not conducted. During the late 1980s, APPM commenced third or fifth row thinning in *P. radiata*. APPM's hardwood plantations are being managed on a short (15 to 20 year) pulpwood regime and limited thinning or pruning has been carried out.

State *P. radiata* plantations are managed on sawlog regimes and most stands have been pruned and commercially and/or non-commercially thinned. Eucalypt plantations on State land are also managed on sawlog regimes.

Summary of Management Factors Affecting C Stocks

Table 8 summarises changes in the most important silvicultural practises affecting C stocks over time.

5.3 WESLEY VALE

The Wesley Vale Management Area includes much of North East Tasmania and takes its boundaries from the Concession on State land provided to APPM in the *Wesley Vale Pulp and Paper Industry Act 1961*.

The Area's private land has been extensively cleared for agriculture. Substantial areas of private forests are also under long-term management for forest production.

Table 8. Silvicultural Practices in the Burnie Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature wet eucalypt between 1945 and 1954.	Pulpwood wasted on State forest.
Selection – sawlogs and pulplogs	Private mature wet eucalypt between 1945 and 1957.	Private forests targeted for pulpwood but sawlogs also taken. No seedbed preparation.
	Private mature dry eucalypt between 1945 and 2000.	Private forests targeted for pulpwood but sawlogs also taken.
	State mature rainforest between 1945 and 1982.	Harvesting till 1982 rainforest moratorium.
	State mature rainforest between 1997 and 2000.	Harvest of selected areas of rainforest post RFA.
	Private mature rainforest between 1945 and 1960.	After 1960 majority of logged rainforest converted to plantation.
Clearfell – regeneration by seeding	State mature wet eucalypt between 1955 and 2000.	First burn in 1958.
	Private mature wet eucalypt between 1958 and 2000.	Commenced seedbed preparation, first by scarification and later by burning.
Conversion to plantation or agriculture	State mature wet eucalypt between 1945 and 2000.	Predominantly conversion to *P. radiata.*
	Private mature wet eucalypt between 1945 and 2000.	Predominantly conversion to *P. radiata* with eucalypts established from 1980s.
	Private regrowth wet eucalypt between 1980 and 2000.	Re–cut of earlier harvested areas to establish eucalypt plantations.
	Private mature dry eucalypt between 1945 and 2000.	Predominantly conversion to eucalypts.
	Private mature rainforest between 1945 and 2000.	Predominantly conversion to *P. radiata* until eucalypts established from 1980s.

General Description

The lower elevation areas consist predominantly of dry eucalypt forest with wet eucalypt forest and rainforest occurring at higher elevations.

The least productive forests are located on the dry coastal hills and plains. In these areas the predominant overstorey species are *E. obliqua*, *E. amygdalina* and *E. viminalis*. The most productive forests are of *E. regnans*, *E. obliqua*, *E. viminalis* and *E. delegatensis* on the moderate to steep slopes of the catchments of the major rivers. At higher altitudes, 500 to 800 m above sea level, there are large plateau areas carrying slow growing *E. delegatensis* forests. Some areas of temperate rainforests occur in wet gullies and on other fire-protected sites (Forestry Commission, 1983a).

History of Forestry Development

Table 9 lists events that have impacted on carbon stocks in the Wesley Vale Management Area or that could assist the interpretation of remotely sensed data.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

Historically, there has been heavy demand for wood from both private and State land in this Management Area. Before woodchip exports commenced in 1971 all harvesting involved selective cuts for sawlogs and veneer logs though, in high yielding stands, the operation was effectively a clearfell. Many forests were re-cut once integrated harvesting started and accessible stands close to mills were re-cut a second or even a third time.

Table 9. Key events in the Wesley Vale Management Area.

Period	Activity
Settlement – 1940s	Selective cutting for sawlogs commenced in accessible forests after settlement. Very active clearance for agriculture.
1963	Particle board plant at Wesley Vale commenced operation using *P. radiata* and young *Nothofagus cunninghamii*.
1971	Refiner groundwood pulpmill at Wesley Vale commenced operation utilising *P. radiata*.
1971/1972	APPM and Forest Resources[11] commenced integrated sawlog/pulpwood harvesting on private and State land. Forest Resources harvested many areas to smallwood standards.
1985	Smallwood harvesting started by APPM.
1986	Cable harvesting introduced to allow steeper sites to be harvested.

After 1971, APPM predominantly obtained its export pulpwood from State forest whereas Forest Resources[11] sourced its pulpwood from private land, and under the conditions of its export licences was responsible for substantial levels of regeneration and plantation establishment.

Clearfelling, with regeneration establishment burning, was used in the wet eucalypt forests. A wide range of selection harvesting systems evolved in the dry eucalypt forests.

Forest Resources introduced smallwood harvesting on private land in the early 1970s and APPM introduced smallwood harvesting on certain areas in 1985.

Regeneration

Records of regeneration mostly post-date the introduction of integrated logging. "Before fully integrated logging commenced in 1972 a total of 759 hectares of (State) forest was regenerated with eucalypt seeding. Since then, 8,234 hectares have been sown. The standard of regeneration has been high, with over 82 per cent of total area regenerated adequately" (Forestry Commission, 1983a). Records for private land are incomplete.

Plantation Development

Substantial areas of plantation have been established throughout the area. Large areas of both private and State land have been planted with hardwoods or softwood (mostly *P. radiata*). The first softwoods on State land were planted in the 1920s (Forestry Commission, 1983a) and planting on both tenures accelerated substantially in the 1960s.

Summary of Management Factors Affecting C Stocks

Table 10 summarises changes in the most important silvicultural practices affecting C stocks over time.

5.4 TRIABUNNA

The Triabunna Management Area includes much of eastern Tasmania. The majority of low elevation private land suitable for grazing has been cleared, especially on the East Coast and in the Midlands. However extensive tracts of private forest remain, particularly in the Central Highlands and the Eastern Tiers.

Tasmanian Pulp and Forest Holdings (TPFH)[12] gained Concession rights to pulpwood from State land in 1968. The objective was to harvest pulpwood from sawlog operations and poorer forests where sawlog selection operations were not economically viable (Forestry Commission, 1987c). The Company was responsible for road construction and harvesting. Forestry Tasmania was responsible for regeneration and fire management.

[11] Became Boral and subsequently Gunns Forest Products

[12] Became North Forest Products – Triabunna and subsequently Gunns Forest Products

Table 10. Silvicultural Practices in the Welsey Vale Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature wet eucalypt between 1945 and 1970.	No pulpwood markets.
	State mature dry eucalypt between 1945 and 1970.	No pulpwood markets.
	Private mature dry eucalypt between 1945 and 1970.	No pulpwood markets.
	State mature rainforest between 1945 and 1982.	Harvesting till 1982 rainforest moratorium.
Selection – sawlogs and pulplogs	State mature dry eucalypt between 1971 and 2000.	Pulpwood markets available. Selection silviculture appropriate.
	Private mature dry eucalypt between 1971 and 2000.	Pulpwood markets available. Selection silviculture appropriate.
Clearfell – regeneration by seeding	State mature wet eucalypt between 1971 and 2000.	Woodchip exports began.
	State mature dry eucalypt between 1971 and 2000.	Woodchip exports began.
Conversion to plantation or agriculture	State mature wet eucalypt between 1960 and 2000.	Predominantly conversion to *P. radiata* until eucalypts established from 1980.
	State regrowth wet eucalypt between 1980 and 2000.	Conversion to *P. radiata* and eucalypts.
	Private regrowth wet eucalypt between 1980 and 2000.	Conversion to *P. radiata* and eucalypts or agriculture.
	State mature dry eucalypt between 1960 and 2000.	Predominantly conversion to *P. radiata* until eucalypts established from 1980s.
	Private mature dry eucalypt between 1971 and 2000.	Conversion to agriculture and some plantation establishment.

General Description

The Management Area contains mostly dry eucalypt forest types but some wet eucalypt types also occur, mainly at higher elevations. The eucalypt forests vary considerably depending on rainfall, altitude and fire history. The coastal lowlands are characterised by poor soils, low rainfall and a history of frequent fires, resulting in open dry sclerophyll forest. The main species are *E. amygdalina*, White Peppermint (*Eucalyptus pulchella*), *E. globulus*, *E. viminalis* and *E. obliqua*.

Intermediate altitudes on the East Coast hills carry better quality forest with mixes of *E. obliqua*, *E. viminalis* and *E. globulus* being common. *E. regnans* is found in sheltered locations south of Triabunna. On the upper reaches of the Eastern Tiers, *E. delegatensis* forests, mostly with several age classes are dominant (Forestry Commission, 1987c).

The Central Plateau contains large areas of *E. delegatensis* forest. River valleys and the lower slopes of the Great Western Tiers contain stands of *E. viminalis*, *E. dalrympleana* and *E. obliqua* (Forestry Commission, 1987c).

Forests are mainly a mix of mature and regrowth trees of a range of ages, known as irregular forest. Large areas of more homogeneous forest arising from silvicultural regeneration now exist.

History of Forestry Development

Table 11 lists events that have impacted on carbon stocks in the Triabunna Management Area or that could assist the interpretation of remotely sensed data.

11. Key events in the Triabunna Management Area.

Period	Activity
Settlement onwards	Selective cutting for sawlogs commenced in the Derwent Valley after settlement. *E. obliqua, E. regnans* and *E. globulus* were mainly harvested, as timber cut from *E. delegatensis* was found to be unstable. Logging was later extended to the Sorell area and the East Coast (Forestry Commission, 1987c).
After 1945	Reconditioning and kiln seasoning were developed, which allowed the utilisation of *E. delegatensis.* Thus, harvesting extended into higher elevation areas of the Central Plateau and the Eastern and Western Tiers (Forestry Commission, 1987c).
1950s, 60s	High levels of sawlogs were cut to satisfy high market demand.
1970	Fully integrated pulpwood and sawlog harvesting operations commenced.
Mid-1980s	Harvesting commenced in the far north of the Management Area.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

Before 1970, selective harvests were practiced, with fuel reduction burning or wildfires encouraging the establishment of eucalypt regeneration. After harvesting of pulpwood began, forests were generally clearfelled, with regeneration by seeding. This was widely practiced up to the early 1980s, when selection harvesting systems were more commonly implemented. Regrowth retention or shelterwoods are now widely used. Until a complete primary road network had been built, closer forests were cut before more distant forests. Hence, initial integrated harvesting tended to be close to primary extraction roads built by TPFH radiating out from Triabunna.

TPFH operated in private forests in addition to State forest, especially forest close to Triabunna. The approximate proportion was two thirds cut from State forests and one third from private forests (Forestry Commission, 1987c).

Forest Resources commenced operations on private land in the Central Highlands in 1972, actively developing selection harvesting techniques in the *E. delegatensis* forests of this region.

A Forestry Commission Working Plan (Forestry Commission, 1987c) for the Area's State forests set standards for 'conventional' and 'non-conventional' pulpwood. Non-conventional wood consisted of small logs, short logs, hollow logs and downers or dead standing trees, provided they produced chipable logs. Material was harvested down to 2.4 m with a minimum small end diameter of 10 cm (overbark). As in the Wesley Vale Management Area, non-conventional pulpwood was taken from selected areas in times of high pulpwood demand.

Little information is available on levels of slash remaining after logging operations. In one study in the east coast, dry eucalypt forests, an average of 13 t ha^{-1} of fuel in the 0 to 20 mm diameter class and 127 t ha^{-1} in the larger sizes was present (Tasmanian Woodchip Export Study Group, 1985).

Plantation Development

Very few plantations have been established in this Management Area because natural factors, such as soils and rainfall, do not favour intensive management. From 1962, *P. radiata* plantations were established in the Fingal area[13] to provide employment to displaced coal miners. After 1990, some eucalypt plantations were established on private and State forests.

[13] Most of the plantations are in the Wesley Vale Management Area, but some are within the Triabunna Area.

Change in Forest Areas Contributing to Wood Production

The RFA process drew attention to the fact that the existing reserves in the State over-represented (by CAR criteria) rainforest and wet eucalypt forest types, with dry eucalypt forest types being under-represented. Hence, one outcome of the RFA was that significant parts of the State forests of the Eastern Tiers and other parts of the Triabunna Management Area were transferred to secure reserve tenures.

Summary of Management Factors Affecting C Stocks

Table 12 summarises changes in the most important silvicultural practises affecting C stocks over time.

5.5 AUSTRALIAN NEWSPRINT MILLS (ANM) CONCESSION

The ANM Concession is predominantly State land over which ANM held virtually exclusive rights of management from 1935. From the late 1980s, ANM's management responsibilities began to change. Input by Forestry Tasmania staff increased until, in 1992, negotiations for a Wood Supply Agreement to replace the Concession Act lead to a transfer of ANM's forest management responsibilities to Forestry Tasmania.

General Description

The Management Area mainly consists of wet eucalypt forests with some patches of rainforest, particularly in the west. Most of the forests are highly productive and are dominated by the ash eucalypts *E. regnans*, *E. obliqua* and *E. delegatensis*. The forests are characterised by a wet sclerophyll or rainforest understorey.

History of Forestry Development

Table 13 lists events that have impacted on carbon stocks in the ANM Management Area or that could assist the interpretation of remotely sensed data.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

Before ANM began operations, sawlogs were selectively harvested but, given the Management Area's relative remoteness this was limited to its eastern margins. Sawmills of the region mainly utilised eucalypt species. An ANM-owned peg factory at New Norfolk utilised White Sassafras (*Atherosperma moschatum*).

Table 12. Silvicultural Practices in the Triabunna Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature dry eucalypt between 1945 and 1970.	No pulpwood markets.
	Private mature dry eucalypt between 1945 and 1970.	No pulpwood markets.
Selection – sawlogs and pulplogs	State mature dry eucalypt between 1971 and 2000.	Pulpwood markets available. Selection silviculture appropriate.
	Private mature dry eucalypt between 1971 and 2000.	Pulpwood markets available. Selection silviculture appropriate.
Clearfell – regeneration by seeding	State mature wet eucalypt between 1971 and 2000.	Woodchip exports began.
	State mature dry eucalypt between 1971 and 2000.	Woodchip exports began.
Conversion to plantation or agriculture	State mature wet eucalypt between 1971 and 2000.	Predominantly conversion to eucalypts.
	State mature dry eucalypt between 1964 and 1972.	*P. radiata* establishment close to Fingal.
	Private mature dry eucalypt between 1971 and 2000.	Predominantly conversion to agriculture.

Table 13. Key events in the ANM Management Area.

Period	Activity
1820s onwards	Sawmilling commenced. Most easily accessible forests cut by the 1920s (Forestry Commission, 1987a). Regrowth eucalypt established in areas not cleared for agriculture.
1941 (22 February)	ANM commenced newsprint production at Boyer based on eucalypt groundwood from mature *E. regnans* forests. Sawlog and pulplog operations were integrated (ANM, 1979).
1958, 64, 68, 71	Increased mill production levels and thus required harvest levels (ANM, 1979).
1950s	Steam powered ground hauling gave way to high lead logging with spar trees, which gave increased access to difficult terrain. Early cartage of logs was by train, but road trucks became important in the 1940s, which gave expanded access to new areas (Burns, 1988).
1957	Cold Caustic Soda pulping process was introduced, which reduced reliance on *E. regnans* from 90% of mix to 75%. Ash forests of other species were targeted for harvesting (ANM, 1979).
1971	Regrowth of *E. regnans, E. delegatensis, E. obliqua* and *Acacia dealbata* began to be used in the Groundwood Impregnation Billet process. Large areas of regrowth arising from 1904, 1914, 1934 wildfires were eventually utilised by this and successive processes (ANM, 1979).
1978	Commenced use of *P. radiata* Thermo Mechanical Pulp from State and ANM plantations.
1983	Forest Resources began to harvest 50,000 t yr^{-1} of pulpwood for export woodchips.
1990	The Boyer mill stopped utilising mature eucalypt. Derwent Forestry Company was formed to utilise the mature eucalypt resource to ensure a supply of sawlogs to sawmills and pulpwood to the export woodchip industry. Pulpwood was utilised down to a standard similar to export pulpwood operations elsewhere in Tasmania.

When ANM commenced operating, generally forest closest to the ANM log yard at Maydena was harvested first and once an area (usually a valley) was opened up it was heavily utilised. That is, there was limited dispersal of logging coupes.

The majority of harvesting was clearfell (without a planned burn) until the 1960s when clearfell, regeneration establishment burning and seeding was introduced. Following burning, seed trees and hand broadcast seeding was used until 1966 when ANM started using aerial seeding.

The ANM Management Area contains some of the most productive forests in Tasmania. In the first cut, it was not uncommon for assessed volumes on coupes in mature forests to exceed 1,000 green t ha^{-1} (K. Felton, 2001, *pers. comm.*). Strict standards existed for pulpwood used in the groundwood process[14] and much pulpwood of export standard was wasted, as under the Concession legislation, ANM was not required to supply pulpwood to others.

Evidence to the Helsham Inquiry suggested that about 24 per cent of the total commercial volume of wood available from the ANM Concession was of export pulpwood standard (Frankcombe, 1987). However, until the 1980s, a high proportion of this potential pulpwood volume was not utilised. Utilisation of pulpwood improved from the early 1980s when increasing quantities of export pulpwood were harvested.

Extremely high levels of slash often remained after harvesting. "In wet eucalypt forests, approximately 78 t ha^{-1} of small-sized fuel (0 to 50 mm diameter) and 900 t ha^{-1} of larger fuels and peat can be present on some areas after integrated logging in the ANM Concession" (Frankcombe, 1966).

[14] Eucalypt or wattle and predominantly *E. regnans,* light coloured wood, containing no rot and no charcoal

Regeneration

Regeneration was patchy and uneven until the late 1950s, when systematic post-harvest burning was introduced (ANM, 1979). From the 1960s, some previously logged areas with understocked regeneration were treated. As well, some areas where eucalypt regeneration had failed were planted with eucalypts.

Plantation Development

Trial plantings of *P. radiata* started in 1963. Significant plantings on the Concession commenced in the 1970s, with the aim of growing pulpwood for the Boyer mill (ANM, 1979).

Wildfires and Fuel Reduction Burns

Significant wildfires in 1904, 1914 and 1934 and escaped regeneration establishment burns in 1966 led to the development of even-aged forests.

Change in Forest Areas Contributing To Wood Production

Significant areas of State forest were removed from production forestry after the Helsham Inquiry and the RFA, particularly along the Area's western boundary.

Summary of Management Factors Affecting C Stocks

Table 14 summarises changes in the most important silvicultural practises affecting C stocks over time.

5.6 SOUTHERN FORESTS

Rights to the pulpwood from State forests were allocated to Australian Paper Manufacturers (APM) in 1954 and revoked in 1993 when the pulp mill closed. Since then forest management has been carried out by Forestry Tasmania.

General Description

The Southern Forests are predominantly State land in the west and east, with private land in the central part. Private land in this zone is a mixture of small-scale farming and urban development in the western part with some larger farming enterprises in the cental and eastern parts.

The Southern Forests are mainly high quality wet eucalypt forests occurring as both mature and regrowth stands. 75 per cent of the productive wet forests are dominated by *E. obliqua*, with the remainder being *E. regnans*, *E. globulus* and *E. delegatensis* (Forestry Commission, 1974). Poorer quality dry eucalypt forests are found near the coast and are dominated by Peppermints (*E. amygdalina* and others). Regrowth has arisen from extensive wildfires and regeneration of previously logged areas.

Table 14. Silvicultural Practices in the ANM Management Area.

Operation	Forest Type and Period	Management Practices
Clearfell – regeneration by seeding	State mature wet eucalypt between 1945 and 1957.	Harvesting for sawlogs and 'Boyer' pulpwood from *E. regnans.*
	State mature wet eucalypt between 1958 and 1982.	Harvesting for sawlogs and 'Boyer' pulpwood from. predominantly *E. regnans* but also other Ash species.
	State mature wet eucalypt between 1983 and 2000.	Export pulpwood harvested.
	State regrowth wet eucalypt between 1971 and 2000.	Boyer mill began to utilise regrowth.
Conversion to plantation or agriculture	State regrowth wet eucalypt between 1971 and 2000.	Predominantly *P. radiata* plantations.
	Private regrowth wet eucalypt between 1971 and 1989.	Predominantly *P. radiata* plantations.
	State mature dry eucalypt between 1970 and 1989.	Predominantly *P. radiata* plantations.

Table 15. Key events in the Southern Forests Management Area.

Period	Activity
1800s onwards	Sawmilling commenced. Most easily accessible forests cut by the 1920s (Forestry Commission, 1986).
1920 - 1960s	Accessible regrowth forests cut for timber for apple cases. Some sawmillers cut regrowth sawlogs for general purpose timber (Forestry Commission, 1983b).
1945 on	Virtually no private wet eucalypt forest or dry eucalypt State forest harvested after this time (K. Felton 2001, *pers. comm.*).
1948	Forestry Tasmania commenced roading into regrowth forests to supply logs for apple cases and later into mature forests for sawlogs (Forestry Commission, 1983b).
1962	Pulp mill established by APM using regrowth and mature wood in separate streams. Harvest of sawlogs increasingly integrated with pulpwood harvest after this time (Forestry Commission, 1986).
1966,1967	Major bushfires occurred. Salvage logging of burnt areas commenced.
1970's	Cardboard replaced wood in apple cases in the 1970s, thus harvesting reduced in regrowth forests.
1975	APM commenced harvesting in its Reserve Area, which was located in the Tasman and Forestier Peninsulas in the eastern part, and the western margin of the Concession Area.
1980/81	APM harvested wood fuel for its mill's boiler. Wood was generally collected from mature forest operations.
(Dec) 1982	APM mill closed. Woodchip sales of approximately 65,000 t yr^{-1} commenced to APPM and Forest Resources. The area of fully integrated logging increased.
1988	Transfer of land from the Western part of the Management Area to the World Heritage Area occurred after the Helsham Inquiry (Helsham, 1988).

Early logging was on flatter areas in the east, which led to modern day regrowth on these rolling foothills. Subsequent fires damaged more than one third of regrowth stands; two or more age classes are often present in the stands (Forestry Commission, 1974).

History of Forestry Development

Table 15 lists events that have impacted on carbon stocks in the Southern Forests Management Area or that could assist the interpretation of remote-sensed data.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

Sawmills of the region mainly utilised eucalypt species. Early harvesting for sawlogs was selective, and subsequent wildfires and seeding from remaining trees often resulted in stands of even-aged regrowth. The wildfires, which regenerated large areas of forest, were intense. There were no recorded fires between 1946 and 1960, but large wildfires in 1961, 1966 and 1967 mostly burnt logged forest that had not had a post logging regeneration establishment burn (K. Felton, 2001, *pers. comm.*).

APM's Port Huon mill, which opened in 1962, required mainly eucalypt regrowth and took only small quantities of mature eucalypt wood. After it opened, the majority of the harvesting was clearfell followed by a regeneration establishment burn. Cull felling was practiced to create more fuel, and wood that could have been used for pulpwood was burnt to waste because experience had clearly shown that it was too risky to leave slash unburnt. Fire salvage was a priority operation after the 1966 and 1967 wildfires (Forestry Commission, 1974).

APM's reliance on eucalypt regrowth resulted in huge waste of potential pulpwood in the mature forests, which had been targeted to supply the area's substantial sawmilling industry. This waste gradually decreased when the forests began to be utilised for export pulpwood in the 1980s.

Regeneration

From the mid-1960s, large areas of dieback were observed in older regrowth eucalypt forest, mainly between the Huon and D'Entrecasteaux Rivers (Forestry Commission, 1974). The 1983 Working Plan recorded that approximately 33 per cent of the regrowth was dieback affected and that merchantable yields and growth were reduced (Forestry Commission, 1983b). Investigations into the cause of dieback showed relationships with long-term drought (K. Felton, 2001, *pers. comm.*). In recent decades, regrowth forest has not been affected by dieback.

Plantation Development

Very little plantation development occurred on private land until recently. Plantings of eucalypts have been carried out since the 1990s on State land with the objective of growing solid wood, sawlogs or peeler billets.

Change in Forest Areas Contributing To Wood Production

Significant areas were removed from production forestry after the Helsham Inquiry and the RFA process, particularly along the western boundary of this area.

Summary of Management Factors Affecting C Stocks

Table 16 summarises changes in the most important silvicultural practices affecting C stocks over time.

5.7 WEST COAST

General Description

Very little of this zone, which is virtually all State land, is now available for commercial forestry as most is in the World Heritage Area. Forests mainly consist of wet eucalypt forests and rainforest, but there are very significant areas of Buttongrass moorland, sub-alpine and alpine vegetation.

History of Forestry Development

Commercial forestry has never been important in the Area, though selective harvesting of Huon Pine (*Lagarostrobos franklinii*) began along the Gordon, Franklin and Pieman rivers soon after 1803 and gradually spread to other rivers. Selective harvesting of other native conifers, and of Blackwood (*Acacia melanoxylon)*, followed.

Table 16. Silvicultural Practices in the Southern Forests Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature wet eucalypt between 1945 and 1961.	No pulpwood markets.
Clearfell – regeneration by seeding	State mature wet eucalypt between 1962 and 1982.	Most potential product from mature forest wasted (burnt) because Huon mill utilised predominantly regrowth eucalypts.
	State mature wet eucalypt between 1983 and 2000.	Export woodchips commenced.
	State regrowth wet eucalypt between 1962 and 2000.	Huon mill commenced utilising regrowth.
Conversion to plantation or agriculture	State regrowth wet eucalypt between 1990 and 2000.	Establishment of eucalypt plantations.

Note that very little private forest has been harvested for forest products since 1945. Some cleared agricultural land has been converted to plantations.

Areas of forest close to the many mines were cut to supply timber and firewood for domestic and industrial purposes. Since 1945, only small areas have been harvested.

Harvesting of Huon Pine (*Lagarostrobos franklinii):* and King Billy Pine (*Athrotaxis selaginoides*) ceased with the imposition of the rainforest moratorium in 1982, with the exception of salvage logging.

Eucalypts in the northern part of the Management Area were cut to supply sawmills and APPM's mill at Burnie.

Management Activities Affecting Carbon Stocks

Harvesting, Silviculture and Slash Management

The Area's forests have been successively selectively harvested to obtain sawlogs and craftwood meeting ever more stringent utilisation standards. Very little pulpwood has been harvested from this Area. Regeneration of harvested mature eucalypt forests in the Area's northern part generally relied on natural seeding.

Wildfire has almost universally followed harvesting, except in the riverine forests harvested for Huon Pine. Severe damage in cutover rainforest followed the first fire and led to eucalypt regeneration where there was a seed source. Subsequent fires resulted in some deforestation.

Plantation Development

P. radiata plantings began at Strahan in the mid-1970s to employ dock labour made redundant when ore from the Queenstown copper mine began to be transported by road rather than sea. Other plantings are minor.

Wildfires and Fuel Reduction Burns

Since European settlement, deliberately lit wildfires have been a feature of most summers on the West Coast. Explorers used fires to remove scrub to facilitate passage and prospecting for minerals. Most of the scrub was pyrogenic vegetation resulting from fires that burnt before European settlement, and the fires invaded rainforest and sub-alpine and alpine vegetation, causing significant damage. Since 1945, there has been a gradual reduction in the area burnt by wildfires, which have tended to be clustered along points of easy access. However, the more remote Zeehan fire in 1980/81 burnt 14,000 ha and the Savage River fire of 1983 burnt 45,000 ha, the latter burning significant areas of rainforest.

Change in Forest Areas Contributing To Wood Production

Very large areas of land have been transferred into conservation reserves but only minor areas of wood production forest were affected.

Summary of Management Factors Affecting C Stocks

Table 17 summarises changes in the most important processes affecting C stocks over time (harvest removals, slash/fire management and regeneration techniques).

Table 17. Silvicultural Practices in the West Coast Management Area.

Operation	Forest Type and Period	Management Practices
Selection – sawlogs only	State mature rainforest between 1945 and 2000.	Consistent supplies from normal forestry operations and/or salvage operations.
Conversion to plantation or agriculture	State mature dry eucalypt between 1973 and 1980.	Strahan plantations (*P. radiata*), managed using sawlog regimes.

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8. APPENDICES

8.1 APPENDIX 1

ASSUMPTIONS/RATIONALE USED IN DERIVING DATA TABLES

The purpose of this Appendix is to document the assumptions made when completing the data tables (see Raison and Squire, 2007; Appendix 2).

Time Periods

These were of variable length and selected to reflect significant changes in activities affecting carbon stocks.

Forest Type

Broad types were derived from amalgamation of RFA forest communities. Forest community groupings are listed in Appendix 2.

Tenure

State or Private.

Status

Regrowth status was confined to even-aged forest in the wet eucalypt forest type. Uneven-aged dry forest was classified as 'mature' despite containing regrowth stems.

Felling Type

- Selection – Sawlogs Only
- Selection – Sawlogs and Pulplogs
- Clearfell – Regeneration by aerial seeding
- Conversion to plantation or agriculture
- Fuelwood harvest

See the main report for detailed descriptions. The term 'clearfell' was only used when a high proportion of the canopy was removed and the majority of the area was regenerated with a post-harvest fire (wildfire or planned) or scarification and seeding. Fuelwood harvest was defined for completeness but was not used in the data tables, as the volumes harvested were relatively insignificant.

Felling Purpose

Felling purpose was described as product removal, regeneration or clearing.

Percentage Total Basal Area Removed

In the absence of measurements, a clearfelling and subsequent post-harvest burn was assumed to remove almost 100 per cent of the total basal area including non-merchantable stems. Values for selection harvesting were estimated by working backwards from this based on the authors' estimate of the likely selection intensity. For clearfell, it was assumed that non-merchantable material was knocked over. For selection harvests, it was assumed that this material remained standing.

The authors believe that the estimates provided meet Data Quality Standard (DQ) level 3.

Percentage of Canopy removed

In the absence of measurements, clearfell and subsequent post-harvest burn was assumed to remove almost 100 per cent of the canopy including non-merchantable stems. The authors estimated values for selection felling types by working backwards from 100 per cent accounting for the selection system used and the likely selection intensity.

The authors believe that estimates provided meet DQ level 3.

Fire Type

Possible fire types included:

- Fuel reduction burn
- Regeneration
- Site preparation
- Wildfire

It is possible that over a period, two or more fire types could occur. For example, a wildfire could burn an area previously subjected to a fuel reduction burn. In this case, only the likely predominant type was allocated. It was assumed that a wildfire could occur some time (commonly >15 years) after harvesting.

The authors believe that estimates provided meet DQ level 3.

Percentage of Harvested Area Burnt

The percentage applies to the area within logged boundaries (harvested area). For wildfires it was assumed that 100 per cent of the area was burnt. The percentage burnt for prescribed fires (regeneration establishment or fuel reduction) was estimated based on the authors' informed opinion and was generally less than 100 per cent.

The authors believe that estimates provided meet DQ level 3.

Percentage of Burn Efficiency For Fines

This was defined as fuel less than 100 mm in diameter. No data could be found to allow a quantitative estimate, so a qualitative grading system (Low, Moderate, High) was used based on an estate level view. Wildfires were allocated a grade of High, regeneration burns Moderate, and fuel reduction burns a grade of Low.

Very rough estimates of values for the grading system could be High 80 per cent, Moderate 70 per cent and Low 50 per cent.

The authors believe that estimates provided meet DQ level 2.

Percentage Burn Efficiency for Coarse Woody Debris (CWD)

This was defined as fuel greater than 100mm in diameter. Once again, a grading system was used, with wildfires being allocated a grade of High, regeneration burns Moderate, and fuel reduction burns a grade of Low. Evidence suggests that the percentage of CWD burnt will be lower than that for fines (Flinn, *et. al.*, 2007). Very rough estimates of per cent burn efficiency for the grading system could be High 60 per cent, Moderate 50 per cent and Low 40 per cent.

The authors believe that estimates provided meet DQ level 2.

Product removals

For mature forest, total estimated harvestable[15] volumes from Working Plan reviews were combined to provide a Management Area average for a clearfell operation. Separate estimates were prepared for State and private land (See Table 18). Taking into account the estimated basal area removed from the forest, this volume was then reduced for selection harvesting operations. Note that the estimated volumes used have generally been adjusted to account for actual yields achieved in harvesting. Thus, they do not always represent total measured (in plots) merchantable volume. This would particularly be the case in the North West and Southern Forest Management Areas where, for example, clearfell operations are used, but pulpwood is sometimes not collected due to limited pulpwood markets.

[15] Tasmanian forest planners generally derive expected yields per hectare (total estimated harvestable product volumes) for individual forest classes by adjusting merchantable volume, estimated from inventory plots, using yields per hectare actually achieved in harvesting operations.

Table 18. Estimated Clearfell Harvest Quantities by Management Area for Tasmania.

	Management Area	Sawlog (m^3 ha^{-1})	Pulpwood (green t ha^{-1})
State Forest	North West	42	283
	Burnie	40	257
	Wesley Vale	28	216
	Triabunna	18	148
	ANM	75	408
	Southern Forests	89	560
Private	North West	23	135
	Burnie	Use State Value (40)	Use State Value (257)
	Wesley Vale	28	138
	Triabunna – Coast	12	91
	Triabunna – Highlands	9	100
	ANM	Use State Value (75)	Use State Value (408)
	Southern Forests	8	120

The quantities in Table 18 are estate averages and were applied to both mature and regrowth forest types. The authors believe that estimates provided meet DQ level 3.

Estimated Gross Bole Volume (GBV) is not readily available at the estate level. If access to measurement plot data were provided by Forestry Tasmania, GBV would be available for a large number of reference sites and relationships between estimated merchantable volume and GBV could be established for these sites. An attempt to analyse inventory plot data was beyond the scope of this review. Private Forestry Tasmania's Farm Forestry Toolbox (Version 3.5) was used to calculate GBV and merchantable volume for a representative tree, being a 35 metre tall *E. obliqua* with a DBHOB of 100 cm. For this tree, merchantable volume was approximately 75 per cent of GBV.

Poles/posts, firewood and bark volumes were ignored because information was scarce and quantities relatively insignificant. For example, for State land, the harvest of craftwood, posts, poles and fuelwood was approximately four per cent of the total cut of wood products over the period 1988/89 to 1992/93 (Forestry Commission, 1994). Few data are available for private land.

Estimated harvestable volumes from rainforest are variable. For the purposes of this review, 20 m^3 ha^{-1} sawlogs and 160 green t ha^{-1} pulpwood were assumed as an estate average for all Management Areas. It was assumed that Blackwood swamps suitable for harvesting would yield 60 m^3 ha^{-1}sawlogs.

The authors believe that estimates provided meet DQ level 2.

Slash <100mm

Slash quantities were only roughly approximated.

Table 19 records total dry biomass for six sites (A to F) in Australia (Tasmanian Woodchip Export Study Group 1985 pp 218-219). Estimates of the quantity of slash less than 100 mm were based on these estimates, being calculated, for the closest matching forest type, as:

- 50 per cent of leaves and branches plus
- 50 per cent of understorey plus
- 100 per cent of litter

An extra regrowth site (G) was added based on information in Flinn, *et. al., (*2007).

Adjustments were made for selection harvesting systems based on the authors informed opinion.

The authors believe that estimates provided meet DQ level 2.

Slash >100 mm

The quantity of slash greater than 100 mm diameter, resulting from a clearfell operation, was obtained by:

subtracting estimated product removals from total estimated harvestable volumes[16] (Table 18).

adding for the closest matching forest type, the following quantities from Table 19:

- 50 per cent of leaves and branches plus
- 50 per cent of understorey plus
- 100 per cent of dead wood

For selection harvesting systems, estimates were based on the authors informed judgement.

The authors believe that estimates provided meet DQ level 2.

Table 19. Biomass (dry t ha^{-1}) recorded in Australian eucalypt forests.

Biomass Component	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Stem	272.0	203.8	243.6	222.9	367.0	328.2	380
Leaves and branches	29.0	21.2	40.4	38.8	27.0	42.5	40
Total tree	301.0	225.0	284.0	261.7	394.0	370.7	420
Understorey	4.0	10.3	1.2	4.5	42.1	3.7	55
Dead wood	11.0	–	–	130.0	–	–	20
Litter	18.0	27.3	19.5	11.1	28.1	18.2	45
Total	334.0	262.6	304.7	407.3	464.2	392.6	540

Site A	*E. obliqua* on granite in Victoria.
Site B	*E. diversicolor* on a red earth in Western Australia.
Site C	*E. diversicolor* and *E. calophylla* on a yellow podsolic in Western Australia.
Site D	*E. marginata* and *E. calophylla* on a lateritic podsolic in Western Australia .
Site E	Mixed species forest at Eden, NSW.
Site F	*E. obliqua* forest in Victoria.
Site G	50 year old *E. regnans* regrowth in Victoria (Flinn, *et. al.*, 2006).

[16] These two values are equivalent unless pulpwood was wasted in a clearfell operation or a selection operation was used.

Table 20. Merchantable MAI estimates for Tasmanian eucalypts.

Management Area	Estimated Site Index[17]	Merchantable volume at age 80 years ($m^3\ ha^{-1}$)	Average Merchantable MAI ($m^3\ ha^{-1}\ yr^{-1}$)
North West	35	600	8
Burnie	35	600	8
Wesley Vale	30	450	6
West Coast	30	450	6
Triabunna	30	450	6
ANM	35	600	8
Southern Forests	35	600	8

Merchantable Mean Annual Increment (MAI)

Merchantable MAI estimates (Table 20) for eucalypts were based on local regrowth yield tables (Forestry Commission, 1981) taking into account the authors' estimate of average site index for each Management Area. The same estimates of site index were used for State and private land.

MAI was only estimated for a 'new', fully stocked stand of eucalypt regrowth established following a clearfell harvest. Data estimating growth on residual eucalypt stems following a selection harvest were not readily available. Similarly data on the post-harvest growth of understorey species were not available.

The authors believe that estimates provided meet DQ level 3.

Total MAI

This was assumed to mean the MAI of gross bole volume including non-merchantable stems. No information was readily available to estimate this, so no estimates have been provided.

Notional years to next cut

This was based on information supplied in Working Plans. Generally for regrowth forest established after a clearfell operation this is assumed to be 80 years. The period is significantly less for a selection cut.

Adequacy of regeneration

A rating was given for estimated adequacy of regeneration (Poor, Acceptable, Good). Table 21 shows the results of regeneration surveys on State land for the period 1972 to 1982 throughout Tasmania (Tasmanian Woodchip Export Study Group, 1985).

Given the results presented in Table 21, it was generally assumed that regeneration arising from a clearfell harvesting operation followed by a regeneration establishment burn was Good. That is, over 85 per cent of the area was stocked. Acceptable would generally indicate that there was sufficient regeneration not to justify a remedial treatment. Poor indicated that remedial operation would be carried out if feasible.

The authors believe that estimates provided meet DQ level 3.

[17] Expressed as Mean Dominant Height (MDH) in metres at age 50 years

Table 21. Effectiveness of regeneration on public land in Tasmania.

Year of treatment	Percentage of area Stocked [18]
1972	91
1973	89
1974	87
1975	78
1976	83
1977	90
1978	86
1979	84
1980	89
1981	88
1982	78
Average[19]	**85**

8.2 APPENDIX 2

AMALGAMATION OF RFA VEGETATION COMMUNITIES INTO SIMPLIFIED FOREST TYPES

Table 22 shows how vegetation communities mapped for the Tasmanian RFA were amalgamated into broad forest types for the purposes of this review. A full description of each community is available in the Tasmanian RFA Environment and Heritage Report - Appendix C (Public Land Use Commission, 1997).

The forest community mapping is available to the Commonwealth as a GIS coverage and should link to the national vegetation layer (from NVIS) being used by the AGO.

[18] Stocked according to standards contained within Regeneration Surveys and Stocking Standards. Native Forest Silvicultural Technical Bulletin No. 6. Forestry Tasmania 1991 (latest revision)

[19] Weighted by area regenerated

Table 22. Relationship between Tasmanian Vegetation communities and forest classes used in this report.

Vegetation community code	Vegetation community description	Forest Class
AC	Coastal *E. amygdalina* dry sclerophyll forest	Dry eucalypt forest
AD	*E. amydalina* forest on dolerite	Dry eucalypt forest
AG	*E. amydalina* forest on granite gravel	Dry eucalypt forest
AI	Inland *E. amydalina* forest	Dry eucalypt forest
AS	*E. amydalina* forest on sandstone	Dry eucalypt forest
C	*E. coccifera* dry forest	Dry eucalypt forest
D	Dry *E. delegatensis* forest	Dry eucalypt forest
DSC	*E. viminalis*/*E. ovata/E. amygdalina*/*E. obliqua* damp sclerophyll forest	Dry eucalypt forest
G	*E. viminalis* and/or *E. globulus* coastal shrubby forest on Holocene sand	Dry eucalypt forest
GG	Grassy *E. globulus* forest	Dry eucalypt forest
MO	*E. morrisbyi* forest	Dry eucalypt forest
N	Dry *E. nitida* forest	Dry eucalypt forest
NF	Furneaux *E. nitida* forest	Dry eucalypt forest
O	Dry *E. obliqua* forest	Dry eucalypt forest
OV	*E. ovata*/*E. viminalis* forest	Dry eucalypt forest
P	*E. pulchella – E. globulus – E. viminalis* grassy shrubby dry sclerophyll forest	Dry eucalypt forest
PJ	*E. pauciflora* on Jurassic dolerite	Dry eucalypt forest
PS	*E. pauciflora* on sediments	Dry eucalypt forest
RI	*E. risdonii* forest	Dry eucalypt forest
RO	*E. rodwayi* forest	Dry eucalypt forest
SG	*E. sieberi* on granite	Dry eucalypt forest
SO	*E. sieberi* on other substances	Dry eucalypt forest
SU	*E. subcrenulata* forest	Dry eucalypt forest
T	*E. tenuiramis* on granite	Dry eucalypt forest
TD	*E. tenuiramis* on dolerite	Dry eucalypt forest
TI	Inland *E. tenuiramis* forest	Dry eucalypt forest
V	*E. viminalis* grassy forest	Dry eucalypt forest
VF	Furneaux *E. viminalis* forest	Dry eucalypt forest
AV	*Allocasuarina verticillata*	Other native forest
BF	*Acacia melanoxylon* forest on flats	Other native forest
BR	*Acacia melanoxylon* forest on rises	Other native forest
BS	*Banksia serrata* woodland	Other native forest
CR	*Callitris rhomboidea* forests	Other native forest
F	King Billy Pine with deciduous beech	Other native forest
H	Huon Pine	Other native forest

Table 22. Relationship between Tasmanian Vegetation communities and forest classes used in this report.

Vegetation community code	Vegetation community description	Forest Class
L	*Leptospermum spp./Melaleuca squarrosa* swamp forest	Other native forest
ME	*Melaleuca ericifolica* forest	Other native forest
NP	*Notelaea ligustrina* and/or *Pomaderris apetala* forest	Other native forest
PD	Pencil Pine with deciduous beech	Other native forest
PP	Pencil Pine	Other native forest
SI	Silver wattle (*Acacia dealbata*) forest	Other native forest
X	King Billy Pine	Other native forest
PL	Plantation	Plantation
M–	Thamnic rainforest on less fertile sites	Rainforest
M+	Callidendrous and thamnic rainforest on fertile sites	Rainforest
BA	*E. brookeriana* wet forest	Wet eucalypt forest
DT	Tall *E. delegatensis* forest	Wet eucalypt forest
KG	King Island *E. globulus*/*E. brookeriana*/*E. viminalis* forest	Wet eucalypt forest
NT	Tall *E. nitida* forest	Wet eucalypt forest
OT	Tall *E. obliqua* forest	Wet eucalypt forest
R	*E. regnans* forest	Wet eucalypt forest
VW	Wet *E. viminalis* forest on basalt	Wet eucalypt forest

8.3 APPENDIX 3

ACCESS TO SPATIAL AND NON SPATIAL DATA USED TO COMPILE REPORT AND DATA TABLES

The main report contains data summarised as graphs or tables, for example, total sawlog and pulpwood harvests since 1945 or areas burnt in wildfires, fuel reduction burns or regeneration burns. An Excel spreadsheet summarising the tabular data behind these summaries is also provided.

GIS data was obtained from Forestry Tasmania to support the review. This included spatial data describing:

1. Management Area boundaries.
2. Regional Forest Agreement (RFA) forest classes and the amalgamation of these into simplified forest types for this review.
3. Tenure boundaries.
4. Timber harvesting history[20], showing forest that has been clearfelled and regenerated or planted, selectively logged or not logged. Where available, an estimate is provided of the start and finish, by decade, of harvesting activity.

The AGO should be able to access most of these data through data sharing processes put in place following the RFA. The possible exceptions to this are timber harvesting history and Concession boundaries, which are owned by Forestry Tasmania.

[20] Not available for all Management Areas

SECTION 5

Western Australia

Jack Bradshaw

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

Page No.

LIST OF TABLES

WESTERN AUSTRALIA

SUMMARY

Changes to forest management in the south west of Western Australia (WA) since the beginning of European settlement are described. Emphasis is given to the changes that have taken place since 1945 in terms of quantities of wood products that have been removed, the intensity of harvesting and silvicultural treatment, and the use of fire as a management tool. Changes in the factors that influence carbon balance in the forest are discussed.

The publicly owned forest in this area is less than two million hectares in extent and has been actively managed since 1918. About 14 per cent of the existing forest area is privately owned. Wood production from private land, principally sourced from land clearing in the past, has virtually ceased. There is little active management of private forest for wood production and there are few data available on its present condition.

During the period 1945-2000, the proportion of forest that is dominated by regrowth and therefore accumulating biomass of a significant rate has increased from an estimated 24 per cent to 37 per cent. In recent years there has been a major shift in the management intent of publicly owned forest towards a greater proportion being devoted to conservation purposes – rising from 2 per cent in 1970 to 53 per cent in 2001. As a consequence of this change, wood production from publicly owned forest in the near future is expected to reduce to about 35 per cent of the levels of the previous decade.

1. INTRODUCTION

This review is part of an Australia-wide analysis of changes to forest management practices since 1945 in the context of their potential impact on forest carbon stocks. The information is aimed at informing the modelling process being undertaken by the Australian Greenhouse Office to predict historical changes and those that may occur in the future.

The review of management practice covers the *Eucalyptus marginata* (Jarrah), *E. diversicolor* (Karri), *E. wandoo* (Wandoo) and *E. gomphocephala* (Tuart) forests of WA. Most of this forest is contained within the area defined for the Regional Forest Agreement (RFA, 1998a, b, 1999). Area statistics used here refer to the RFA region as well as to the Tuart forest on the coastal plain and the Karri forest of the south coast that occur outside the RFA area. Data for private forest (other than Karri) and for other vegetation types are confined to the RFA area.

Disturbance to these forests, other than by fire, began with European settlement in 1826. Since that time, some 80 per cent of the forested private land has been cleared and 85 per cent of the crown land has undergone some form of disturbance by logging (RFA, 1998a, b). One third of the original forest has been cleared. About 90 per cent of that which remains is on crown land under secure tenure.

Appendices 1 and 2 describe the basics for forests stratification, sources of data, and assumptions made in deriving the information presented in this report and the accompanying data tables. Tables are contained in the appendicies and refered to throughout the text.

Throughout this review, all volumes and weights have been converted to ‘air dry tonnes’ (12 per cent moisture content) unless otherwise indicated.

2. FOREST TYPES

The tall forests of WA are confined to the south west of the state from Perth in the north to Albany in the south. The climate is Mediterranean, with an annual rainfall that varies from 650 to 1400 mm yr^{-1}. The forests occur within the Swan Coastal Plain, the Warren and the Jarrah Forest biogeographic regions. Since 1882 there have been numerous approaches to the mapping of forest and vegetation, varying according to the purpose, the resolution and the information available (Bradshaw *et. al.*, 1997). The forest types discussed are those used at the broadest management scale and are principally based on the amalgamation of the forest ecosystems; used in the RFA (RFA, 1998a, b). The 'Jarrah forest' is made up of twelve Jarrah ecosystems, the 'Karri forest' of six ecosystems and the 'Wandoo' of two ecosystems. The 'forest ecosystems' were derived from a combination of:

- 'Forest associations', an overstorey species and density classification (Bradshaw *et. al.*, 1997);
- Groupings of 'vegetation complexes', a classification based on attribution of vegetation to landform and climate (Mattiske and Havel, 1999); and
- Geographic zones (Bradshaw and Mattiske, 1997).

The forest outside the RFA area (Tuart and south coast Karri) is based on the 'forest associations'.

There are no reliable maps of forest type covering all of the private land, though reasonable estimates of their areas have been derived by analysis of related forest ecosystem, vegetation complex and remnant vegetation (RFA, 1998a).

The existing forest on private property and crown land, and the estimated area of forest that has been cleared, are shown in Figure 1. Details of the source data of forest type maps are given in Appendix 1.

2.1 JARRAH

The Jarrah forest occurs throughout the entire south west forest region within a wide range of climate and soil type. It occurs in mixture with *Corymbia calophylla* (Marri) throughout its range and with Wandoo on the drier eastern edge; with *E. patens* (Blackbutt) in moister sites; and to a lesser extent with Karri and *E. guilfoyle*i (Yellow Tingle) in the cooler southern forests. It reaches its best development in the northwest of its range, on the deep lateritic soils of the Darling Plateau with an annual rainfall exceeding 1,000 mm yr^{-1}, where much of it occurs in pure stands. There is a strong west to east rainfall gradient that is reflected in the reduced height and productivity from about the 900 mm rainfall isohyet. In the southern end of the range a higher proportion of the forest is underlain by podsolic soils and these forests are characterised by a much higher proportion of Marri in mixture with Jarrah. In the south, the Jarrah forest occurs as a mosaic with Karri types. In the lower south and south east of its range it occurs as a mosaic with shrubby flats and sedgelands. A further major difference occurs in the Blackwood Plateau (also called the Donnybrook Sunklands) where the landform is a mosaic of laterite ridges and seasonally moist sandy flats (RFA, 1998b Map 12). This is also reflected in lower site quality (Bradshaw *et. al.*, 1997- height class map).

Despite the relative uniformity of the overstorey composition there is wide variation in understorey and in its ecological characteristics (Havel, 1975; Heddle *et. al.*, 1980; McCutcheon, 1980; Strelein, 1988; Mattiske and Havel, 1999; Havel, 2000).

The oldest Jarrah trees measured to date by ring counting are 418 years (Whitford, 1998) and 377 years (Burrows *et. al.*, 1995) but the data of Burrows *et. al.* (1995) suggest that relatively few trees reach this age, with most living to about 250 years.

The original area of Jarrah forest was estimated to be about 2.8 million ha of which 65 per cent remains (RFA, 1998a).

2.2 KARRI

The Karri is a tall wet-sclerophyll forest occurring in the southern part of the south west forest area where the annual rainfall exceeds 1,000 mm and the average summer rainfall exceeds 70 mm (Inions, 1990; Christensen, 1992). Most Karri occurs where the summer evaporation is less than 500 mm (Havel and Mattiske, 1999). Within the main climatic zone, Karri occurs mainly on the younger red earths, and the red, brown and yellow podsols, the distribution of which is related to topography. In the northwest it is largely confined to the deeply incised valley systems; in the central area it occurs more broadly over the landscape where the lateritic duricrust is more dissected; and in the south it occurs in both the valley systems and on the soils derived from granite-gneiss inselbergs, interspersed with depositional flats supporting Jarrah woodland and sedges. Thirty per cent of the forest occurs in patches of less than 100 ha (Bradshaw and Rayner, 1997a). Outliers occur on limestone derived soils on the west coast and on specific sites on the south coast with rainfall as low as 700 mm yr^{-1} (McArthur and Clifton, 1975; Bradshaw and Lush, 1981).

About a third of the Karri forest grows as pure stands and the remainder in mixture, predominantly with Marri but also to a lesser extent with Jarrah and with the less common *E. jacksonii* (Red Tingle) and Yellow Tingle (Bradshaw *et. al.*, 1997; RFA, 1998b). The landform and vegetation relationships in the region are described by Mattiske & Havel (1999) and site/vegetation by Inions *et. al.*, (1990). While there is no satisfactory correlation between productivity and classifications based on soil, climate or vegetation, site index classification indicates that there is a 80-100 per cent difference in productivity between the highest and lowest site indices across the range of the Karri forest (Rayner, 1992b).

The oldest Karri tree measured by ring counting to date is 350 years (Rayner, 1992a; Bradshaw and Rayner, 1997a). Estimates of stand age in virgin forest based on a regression of age and diameter suggest that few stands live beyond 250 years (Bradshaw and Rayner, 1997b).

The original area of Karri forest, including the areas outside the RFA area, was estimated to be about 250,000 ha, of which 80 per cent remains. The original distribution and the areas remaining on crown land and private property have been mapped (Bradshaw *et. al.*, 1997- map 'Karri Distribution before European Settlement').

2.3 WANDOO

Wandoo occurs as both a forest and a woodland to the east of the Jarrah forest. It occurs where the annual rainfall is approximately 400-800 mm yr^{-1} in the broader depressions where the soils are relatively shallow to clay (Heddle *et. al.*, 1980; Bradshaw *et. al.*, 1997; Mattiske and Havel, 1999). It also occurs in small patches on the shallow soils of the Darling Scarp. For the purposes of this review, these stands are included with 'other vegetation' as part of the Darling Scarp ecosystem. East of the Jarrah forest, *E. wandoo* tends to give way to *E. accedens* (Powderbark Wandoo) on breakaways and stony ridges where it also occurs in mixture with Jarrah and Marri. *E. accedens* is included with *E. wandoo* in all references to the Wandoo forest in this review. Almost all of the Wandoo in the east of the range has been cleared for agriculture. The forest type referred to in this review relates primarily to that which remains on crown land in the western side of the range.

The original area of the 'western' Wandoo forests and woodlands (contained within the RFA area) was estimated to be about 526,000 ha, of which 42 per cent remains (RFA, 1998a).

2.4 TUART

The Tuart forest and woodland occurs on the Swan coastal plain to the west of the main forest belt. It is confined to limestone-derived soils between the Sabina River in the south and Guilderton to the north contained within a general area of about 100,000 ha (map in WA Woods and Forests Department Annual Report, 1901). It lies within (but does not constitute the whole of) the Yoongarillup, the Cottosloe central and south, the Karrakatta central and south, and the Vasse vegetation complexes. Vegetation complex mapping describes the pre-European condition but the maps do not cover the entire distribution (Heddle *et. al.*, 1980). There are 11,000 ha of Tuart on crown land (Bradshaw *et. al.*, 1997) with a further 12,000 ha on private land, where it now occurs primarily as shade trees in a parkland formation.

Tuart grows in areas with an annual rainfall of 750-1,000 mm yr^{-1} and reaches its best development in the area between the Sabina River and Bunbury in the south of its range on the Yoongarillup and Karrakatta-south vegetation complexes. The forest and woodland is dominated by mature trees. Once described as a savannah forest, particularly in the southern end of its range, it now contains a dense understorey of *Agonis flexuosa* (Peppermint) or *Banksia* which has become a serious impediment to Tuart regeneration (Gardner, 1923; Harris, 1957; Bradshaw, 2000).

Some 23,000 ha of Tuart forest remain, but no reliable estimates have been made of the percentage of the original forest that this represents.

2.5 OTHER NATIVE VEGETATION

Dispersed throughout the forest are a number of other low forest and non-forest vegetation types (Bradshaw *et. al.*, 1997; RFA, 1998b Map 12; Mattiske and Havel, 1999). By far the largest component (76 per cent) is the shrub and sedgeland types that principally occupy the seasonally damp flats that occur in increasing proportions in the southern part of the broader forest estate. The remainder consists of low woodlands of *Agonis flexuosa*, *E. megacarpa* (Bullich), *E. cornuta* (Yate); the mixed Jarrah/Wandoo types of the Darling Scarp; swamps; and the heathlands of the coastal dunes. There are an additional 22,000 ha of sand dunes and rock outcrops within the area of the RFA.

Of the original 557,000 ha of other native vegetation within the RFA area, some 70 per cent remains (RFA, 1998a).

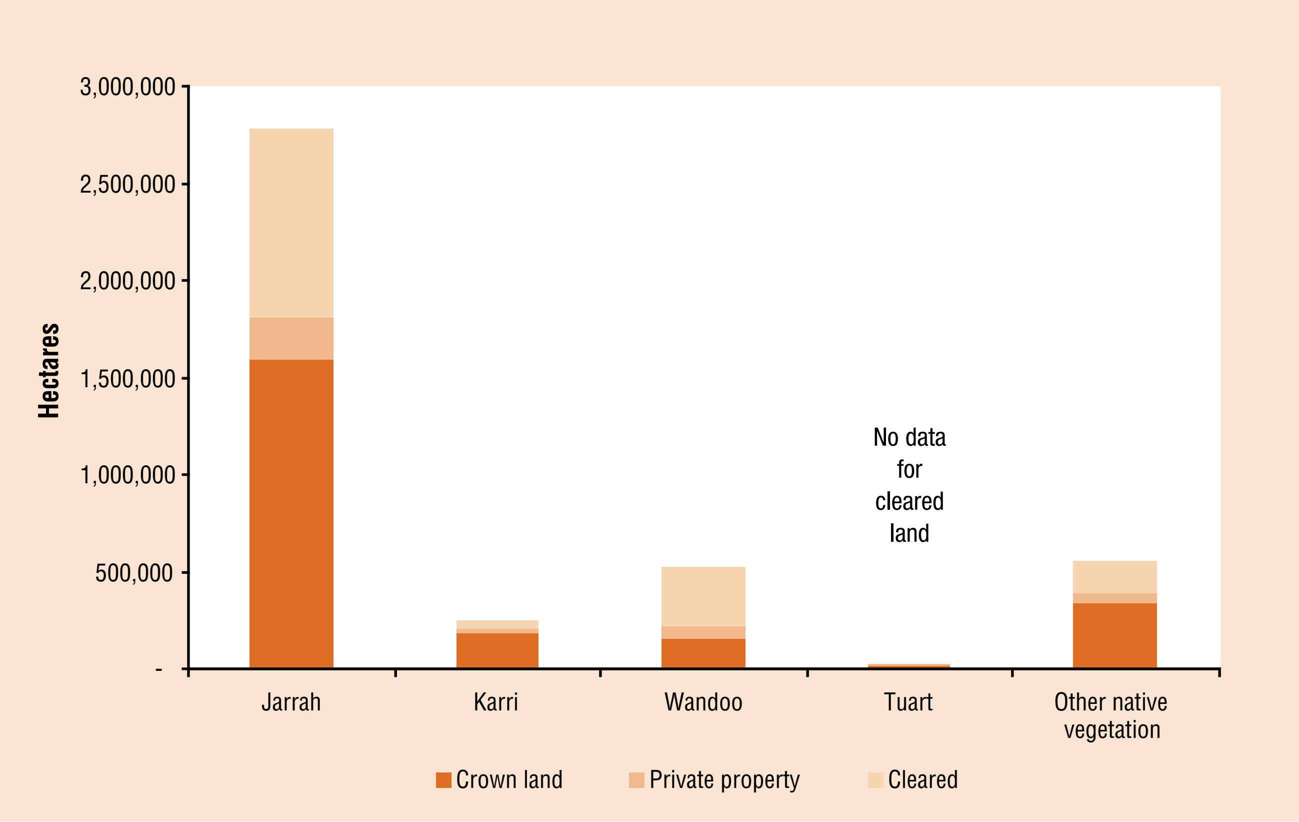

Figure 1. Status of forest land in the SW of WA, showing the existing and cleared area of Jarrah, Karri, Wandoo and Tuart forests and other native vegetation types. Data for Jarrah, Wandoo and other native vegetation refer only to the RFA area. Karri includes additional areas on the south coast. Tuart is outside the RFA area on the Swan Coastal Plain. There is no data for cleared Tuart.

3. FOREST DISTURBANCE BEFORE 1945

European settlement in WA began in Albany in 1826 and in Perth in 1829. Early development and clearing was confined to the coastal plain and to inland areas north west of Perth. Forest disturbance, in the form of clearing for agriculture or logging, did not occur to any significant degree till the 1870s, when sawmills were established in the Jarrah forest and settlers began to seek out the better soils of the river systems inland of the coastal plain. Some seventy mills were established throughout the northern Jarrah forest over the next 30 years. During this time, clearing for agriculture began to encroach into the Wandoo forest from the east and into the more fertile valleys through the central Jarrah forest. In the main, the Jarrah forest was spared from clearing for agriculture because of its infertile lateritic soil (Jarvis, 1986; Heberle, 1997). Logging in the Karri forest began in coastal areas near Denmark and Augusta in the 1880s, but logging and agriculture did not impinge on the main Karri belt until 1911, when railway access reached that area (Bradshaw and Lush, 1981).

Railway sleepers were the dominant timber product until about 1918, and the majority of all wood produced until about 1930 was exported (Forests Department, 1969; Rotheram, 1985). By 1945 about 50 million m^3 of logs had been harvested from crown land and private property (Forests Department, 1970).

Forest reservation began with the passing of the *Forest Act* in 1918, and by 1930 about 50 per cent of the current crown land estate was dedicated as State forest, including almost all of the northern Jarrah forest. The bulk of the remainder was dedicated between 1950 and 1970 (Forests Department, 1969). By 1945 less than 2 per cent of the current crown land estate was dedicated as National Park or Nature Reserve.

Harvesting in the forest, although operating to a minimum girth limit from 1896, was essentially uncontrolled until the proclamation of the Forest Act in 1918. Treemarking gradually replaced girth limit as a means of silvicultural control from about 1923 and a group selection system was implemented for most of the Jarrah forest (Stoate, 1923; Forests Department, 1927b; Kessell, 1934). A wide variety of intensity of harvest was possible under the general prescription of 'selection by groups', with gaps ranging from 0.2 to 1,000 ha in size, retaining as little as 5 per cent crown cover over significant areas (Bradshaw, 1999). Intensive silvicultural treatment, mainly regeneration work, was applied to some 166,000 ha by 1942, much of it achieved under unemployment relief programs during the depression (Kessell, 1934). This work involved ringbarking of cull trees, coppicing of damaged and malformed saplings, partial ring-barking of seedtrees and the burning of debris (Forests Department, 1927b).

Sleeper hewing was a significant component of harvesting till World War II, though it had been prohibited in virgin forest since 1914.

Early logging in the Karri forest near Denmark and Augusta was uncontrolled clearfelling with the intention of conversion to agriculture (Ednie-Brown, 1896; Gabbedy, 1988). Ultimately about half the Karri forest in these areas was converted to agriculture. That which remained on crown land regenerated naturally and the majority is now reserved for conservation. Karri forest logged in the main Karri belt from 1912-1925 was all subsequently alienated for agriculture (Bradshaw and Lush, 1981). The first dedication of State forest in Karri was in 1925. While a girth limit was applied to the harvest, it was in effect a clearfelling with seedtrees. Effective regeneration occurred following burning in a seed year. Cull trees were ring-barked after regeneration to prevent suppression of the regeneration. This practice continued till about 1938, after which a group selection system was introduced (Meacham, 1962; Bradshaw, 1999; Stewart, undated).

Clearing of the Wandoo forest for agriculture was well advanced by the 1930s and most of the Wandoo products (sawlogs, posts etc.) for many years came from these clearing operations. The first major industry based on the utilisation of Wandoo was an industrial extracts factory established in 1937 to distil tannin and other products from Wandoo and Powder Bark Wandoo, which supplied the substantial demand in leather tanning and was used as 'thinners' for oil drilling mud (Bayliss, 1947; Underwood and Hooker, 1968). The wood was largely supplied from clearing on private property. Substantial areas of Wandoo had been dedicated as State forest by 1930, but the last dedications did not occur till the 1970s (Jarvis, 1986).

The Tuart forest near Ludlow (about 3,500 ha) was the first State forest to be dedicated in 1919, some of it having been re-purchased from an original (1842) land grant (Forests Department, 1969). About 400 ha of the forest was converted to pine plantation but with the unusual provision of retaining Tuart seedtrees so that it could revert to Tuart after the pine rotation (Kessell, 1928). The process of removing the pine is currently underway. Selective harvesting (on a 50 cm diameter limit from 1887) occurred in the southern part of the Tuart forest. From 1921 all milling was carried out at a Forests Department mill at Ludlow. Exports of Tuart were prohibited and the timber was reserved for government requirements, principally for the

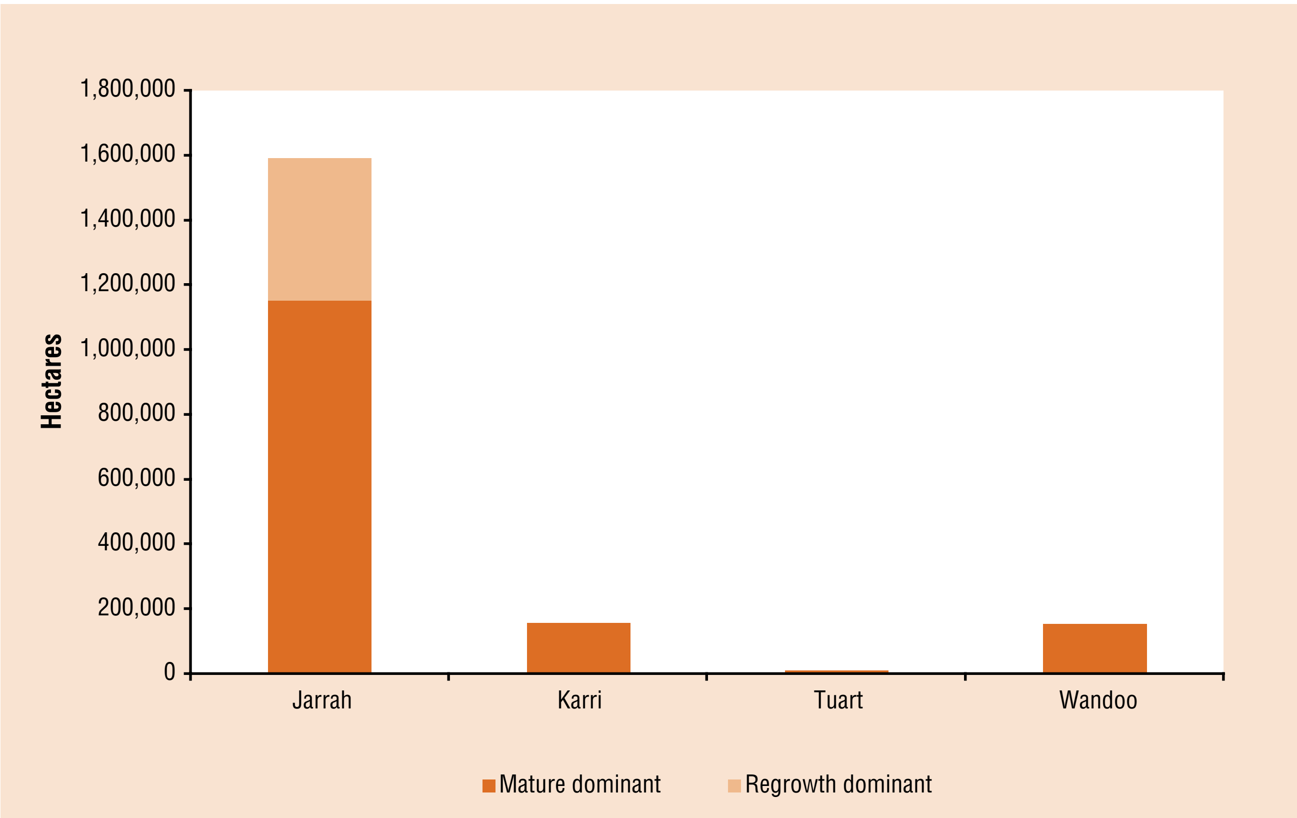

Figure 2. The estimated structural status of crown land forest in 1950. Regrowth-dominated forest includes areas created by harvesting and wildfire, and areas cut heavily enough to allow regrowth to develop and become a dominant component (>50% of the crown cover) of the stand. Most of the regrowth was less than 50 years old at the time.

construction of railway wagons because of its superior ability to withstand abrasion and impact. By 1954, most of the Tuart forest near Ludlow had been cutover to some degree under a form of selection cutting from the 1920s (Weston, 1954).

The estimated structural condition of the publicly owned forests in the south west at the end of this period, in terms of regrowth and mature forest, is shown in Figure 2. These data provide an indication of the proportion of the forest that is in a state of positive carbon accrual compared to that which might be considered to be in a state of equilibrium at this time. See Appendix 1 for the derivation of these data.

4. CHANGES IN SILVICULTURAL AND MANAGEMENT PRACTICES SINCE 1945

A wide variety of management practice has occurred in the forest since 1945. Table 1 provides a summary of the time frame for the most significant of these practices.

4.1 JARRAH

Mainstream Practice

Increased demand for sawn timber in the post-war building boom saw the construction of five large sawmills (covering both Jarrah and Karri) between 1948 and 1952. This shifted the emphasis of harvesting to southern forests, which to that time, had not been significantly exploited for Jarrah.

After Word War II the silvicultural prescription changed from the distinctive group cutting with follow-up cull removal, to one of a light single tree selection cut with no follow-up removal of culls (Bradshaw, 1999). The intensive silviculture treatment was suspended in 1942 and was not to resume again until the mid-1980s. Although the prescription was still ostensibly a group selection aimed at removing 'overmature' trees in groups and leaving vigorous younger trees (Forests Department, 1964), it rarely created gaps in the canopy that were sufficiently large to allow regrowth to develop without suppression. This was partly because much of the cutting was in fact a 'salvage' cut of individual older trees and partly because of the high proportion of 'cull' trees that remained, especially in southern forests with a high proportion of Marri that was unsaleable as sawlog. Satisfactory regeneration following logging in this period was the exception rather than the rule.

The standard management practice was to control burn the proposed harvest area about two years prior to harvest ('advance burning'), mark each individual tree for removal, harvest the area for sawlogs, burn the logging slash with a mild fire aimed at removing only the light fuel and then protect the area from fire while the regrowth was still fire-sensitive. The purpose of the advance burn was to facilitate access for logging operations and to reduce the danger involved in burning the logging slash.

This practice continued until 1961, when major changes were made to fire policy as a consequence of the devastating Dwellingup fires (Rodger, 1961). From the inception of the Forests Department it had been the policy to protect regenerated forest from fire until it was old enough to withstand a fire, while control burning other forest areas to reduce fire hazard (Forests Department, 1927a). Although the intention was to burn regrowth when it was old enough, large areas of protected forest accumulated in the northern Jarrah forest because of the large area that was silviculturally treated and regenerated during the 1920s and 1930s and the inability (with limited resources) to control burn the designated fire buffers around the regrowth compartments.
It was also extremely difficult to burn the heavy fuels beneath the regrowth when the time came to do so, without damaging the regrowth. Attempts to burn under regrowth were curtailed in 1941 until a policy reversal in 1953 (Harris, 1975). By 1953, 0.8 million ha were under protection. It was these heavy fuels that made it impossible to limit the extent and severity of the wildfires of 1961.

The Royal Commission that followed recommended an increase in the use of controlled burning and harvested areas were no longer afforded a post regeneration protection period. In hindsight this was not a serious issue given the dearth of regeneration resulting from harvesting practices of the time.

The next major change to mainstream practice occurred in 1970 when the sawlog cut intensified to maximise the sawlog removal at each cut in order to reduce the area cutover each year. The main reason for this was to reduce the area put at risk of the introduction of *Phytophthora cinnamomi*, the then recently discovered cause of Jarrah dieback (Podger *et. al.*, 1965; Batini and Hopkins, 1972; Forests Department, 1972). Under this prescription, all millable timber was to be removed with the exception of genuine growing stock. Despite this intensification of the harvest, opportunities for regeneration were still very limited because of the high proportion of the basal area occupied by cull trees. The exception to this was in higher quality, purer Jarrah stands where commercial removal was sufficient to create small but effective gaps (at least two times tree height) for regeneration. These were limited, however, and most stands, especially in the south where the Marri component is higher, remained above critical density, even those that had been previously logged (Resource Level Inventory data 1960s and 1970s). Harvest of Marri for pulpwood later overcame this problem in some Jarrah areas, but the application of the prescription resulted in extensive clearfelling of Jarrah unless deliberate limits were placed on it. Pulpwood was removed from about 15 per cent of the harvested Jarrah forest from 1980, and has increased to about 25 per cent at present.

Forest hygiene practices were developed and implemented from the 1970s and have become a dominant feature of forest management since that time (Batini, 1973). In 1975 the 'Forest Disease Regulations' were promulgated, providing the authority to restrict access to those forest areas that were relatively free of the disease. This not only reduced the likelihood of disease spread to healthy areas but also provided a period during which the disease symptoms could be expressed (to facilitate mapping) in the reasonable expectation that there would be few asymptomatic infections present. Harvesting was concentrated for a number of years in both infested and uninfested areas outside the generally dieback-free Disease Risk ('quarantine') Areas (Forests Department, 1982).

A review of silvicultural practice in the mid-1980s saw the re-introduction of a combination of practices that were essentially those of the 1920s (Bradshaw, 1985, 1986; CALM, 1995a; Bradshaw, 1999). Silvicultural practice is based on existing forest structure that varies as a consequence of past harvesting, climate and site type. It aims to apply one of the following objectives to each patch of forest at a minimum size of two times tree height.

In summary it involves the following:

- Where there is sufficient stocking of crop trees or potential future crop trees – thin to promote growth of retained trees;
- Where crop trees are not present or the stocking is inadequate but there is an adequate stocking of ground coppice – remove overstorey to create a gap to allow ground coppice to develop into saplings; or
- Where crop trees are not present or the stocking is inadequate but where there is an inadequate stocking of ground coppice[1] – reduce overstorey competition by partial harvesting to 'shelterwood', reduce understorey competition, establish seedling regeneration and allow it to develop into ground coppice (Bradshaw, 1985; Stoneman *et. al.*, 1989).

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[1] Ground coppice in Jarrah is a lignotuber that is sufficiently advanced in development to grow rapidly into a sapling once released from overwood competition. It usually requires a lignotuber of 5–10 cm in diameter, which may take up to twenty years to develop.

- Habitat-trees are retained throughout, and thinning intensity, size of gaps and return times are varied according to visual amenity values and the risk of salinity (CALM, 1995a).

The preferred minimum gap size for each objective is four times tree height (especially in mature forest) with the object of creating distinct groups. The use of each method is decided by the treemarker at the site. Theoretically all methods may be used within the one coupe. In practice, thinning predominates in the north, where earlier heavy cutting created large areas of regrowth. Gaps predominate in the south, where virgin and lightly cut forest is being harvested. Shelterwood is more common in the east, where the drier conditions result in a smaller lignotuber pool.

Thinning is aimed at reducing the stand to critical density (i.e. the minimum density to maintain maximum stand growth). The retained density varies from 10-20 m^2 ha^{-1} according to the size of the crop trees to be retained. Shelterwoods are reduced to a density of 8-15 m^2 ha^{-1}, depending on site. Maximum gap size, thinning intensity, cutting cycle and the extent of harvest in any second order catchment also varies according to zones based on visual amenity and salinity risk. About thirty different prescriptions flow from the one over-arching guideline (CALM, 1995a).

Trees are marked for retention in proposed harvest areas according to the prescription above. All unmarked trees are available for commercial removal, and the prescription is completed where necessary by non-commercial follow-up that involves the removal of culls by felling, pushing or herbicide application. An integrated operation for all products is used to maximise commercial utilisation and to minimise forest entries and hence the risk of spreading *Phytophthora cinnamomi*.

In areas where harvesting has been such that more than 12 m^2 ha^{-1} of non-commercial culling would be required to complete the operation, culls are left (perhaps until a commercial market for these trees develops) and the area is described as 'selective' cut. No significant regeneration is expected in these areas, and no further significant production is expected until such time as a substantial proportion of the cull trees can be utilised; nor is there expected to be a significant change in the total stand growth of bole wood.

Routine non-commercial silvicultural treatment (thinning, cull removal) began in 1986 and since the mid-1990s has been applied to about 10-12,000 ha yr^{-1}.

Although preferred for silvicultural reasons, advance burning is no longer routine practice because it masks the evidence of *Phytophthora cinnamomi* symptoms in the understorey.

Harvested areas are burnt after logging, the conditions and intensity varying according to whether it is in thinnings, gaps or shelterwood. Regeneration that is released in the gaps is then protected from fire for a minimum of 10 years.

Areas harvested to shelterwood may require soil disturbance in addition to that created by harvesting. Shelterwood areas are burnt in a seed year with the aim of establishing seedling regeneration. A burn of sufficient intensity to scorch the crowns of the retained trees is ideal. Shelterwood areas should then be burnt regularly to stimulate lignotuber development and to provide opportunities for further seedling recruitment. The minimum period of shelterwood retention is expected to be 20 years, the time taken for a seedling to become ground coppice.

A variety of fire strategies may be used in areas containing a mixture of gaps and shelterwood, depending on the priority that is given to the protection of regrowth in gaps relative to the stimulation of lignotubers in shelterwood (Bradshaw, 1986).

Even-aged Jarrah regrowth will attain maximum stand basal area in about 15-20 years from the time of regeneration release (Abbott and Loneragan, 1983b; Stoneman *et. al.*, 1988). The gross bole volume increment of uneven-aged Jarrah forest has been quoted as varying from 0.2 to 1.6 m^3 ha^{-1} yr^{-1} (Abbott and Loneragan, 1983a; CALM, 1992b Table 22). However, the growth rate of fully stocked 40 year-old pole stands may be about 2 m^3 ha^{-1} yr^{-1} (Stoneman *et. al.*, 1989).

Figure 3 indicates the changes that have occurred in silvicultural practice between 1950 to 1999.

In 2001, all old growth forest was withdrawn from harvesting. This will result in significant reductions in sawlog yield in the near future and a shift in emphasis to harvesting in the northern, previously harvested forest. From the end of 2001, Marri was no longer considered acceptable to the traditional buyers of pulpwood. This has resulted in a decreasing proportion of the forest that can be harvested to create gaps for regeneration, and a corresponding increase in the area 'selectively' harvested.

Harvesting in Dieback-affected Areas

Jarrah dieback caused by the root rot *Phytophthora cinnamomi* was first observed in the Jarrah forest in the 1920s, although the causal agent was not identified until 1965 (Podger *et. al.*, 1965). Infections escalated from the 1950s following widespread road construction after World War II. Its greatest impact was in the northern Jarrah forest, where it spread rapidly through the vulnerable (moisture gaining) gully systems and on the concreted laterite sites to the immediate east of the Darling Scarp, where in 1972, up to 30 per cent of the forest was infested (Podger, 1968; Batini and Hopkins, 1972; Dell and Malajczuk, 1989). On many sites dominated by the highly susceptible Jarrah, the endpoint is total mortality of the overstorey, often with near total mortality of the understorey. The most dramatic escalation of the disease impact was during the 1960s and 1970s in the northern Jarrah forest, with rapid, though less severe impact in the Donnybrook Sunklands in the 1970s. Both the spread and impact has been less in southern forests, where the climate is less suitable to the pathogen and the forest contains a higher proportion of non-susceptible Marri (Christensen, 1975). A high proportion of the understorey in the Sunklands and the southern forests is not susceptible to the disease. Disease impact remains low in the drier eastern forest.

Mapping of dieback began in 1965 in the northern Jarrah forest using 1:40,000 black and white photography (Batini, 1973) and later with large scale shadowless colour photography in the southern forest, where symptoms are more difficult to discern (Bradshaw and Chandler, 1978). These maps facilitated a more systematic approach to management and hygiene (Brandis, 1983).

In 1953, Wallace and Hatch estimated that 0.2 per cent of the Jarrah forest was affected by *Phytophthora cinnamomi* (Dell and Malajczuk, 1989). By 1973 mapping with 1:40,000 aerial photographs showed that 5 per cent of the northern Jarrah forest was affected (Batini and Hopkins, 1972); and by 2001, 13 per cent of the whole Jarrah forest had been mapped as dieback-affected (CALM, 2001).

Dead and dying trees salvaged from infested sites became a significant component of harvesting in the late 1960s and dominated the harvesting during the 1970s (Figure 3). In 1989, silvicultural guidelines for the northern Jarrah forest provided for the retention of 15 m^2 ha^{-1} of healthy (preferably resistant) trees with the objective of preventing an increase in soil moisture that may exacerbate the impact of the disease (CALM, 1989b).

During the 1960s until the mid-1970s many of these infested sites in the northern Jarrah forest were planted with exotic species resistant to *Phytophthora*. These were principally the gully sites with better soils.

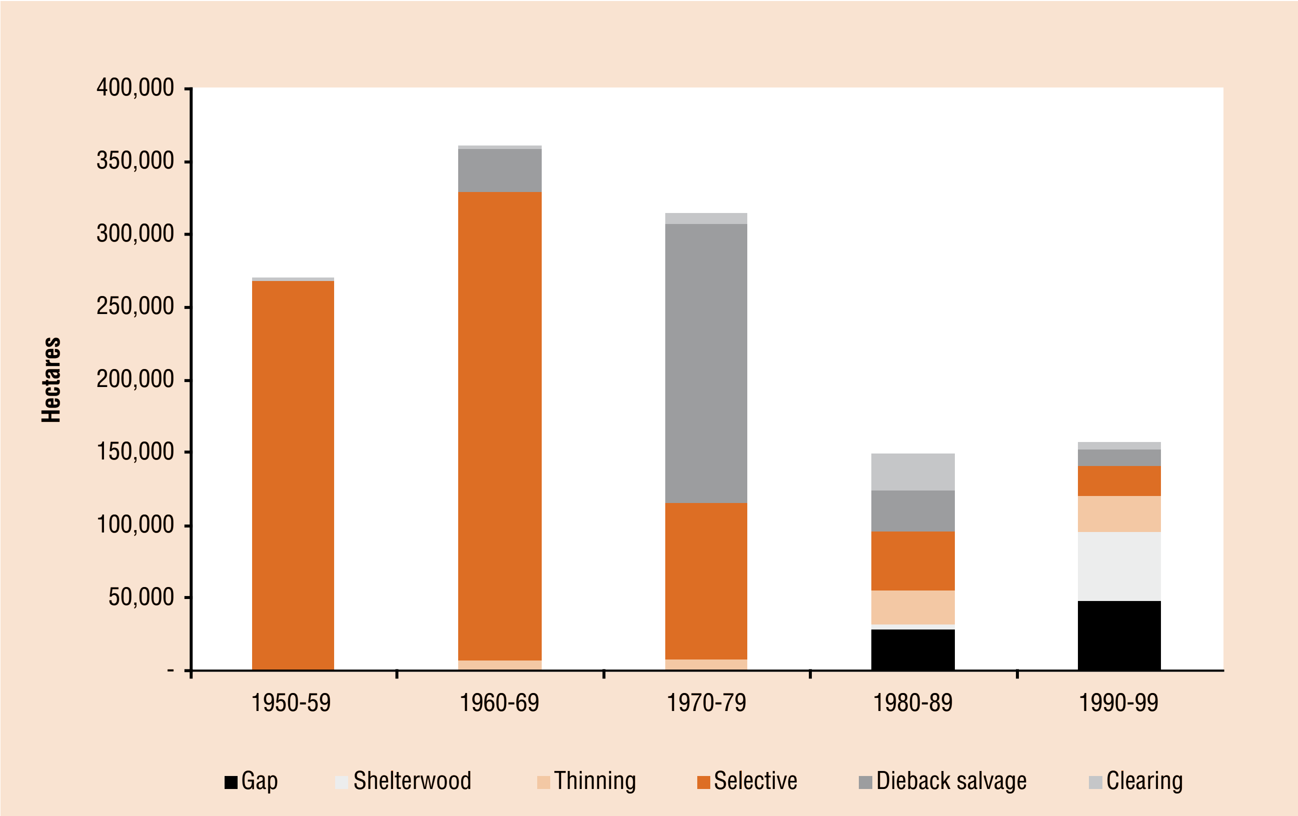

Figure 3. Type of Jarrah harvesting. The area of Jarrah on crown land harvested by different methods since 1950. Clearing includes land cleared for pine plantations, utilities and mining.

Left untreated, natural regeneration (mostly Marri) will occur but its development can be very slow, especially on heavy laterite sites, many of which have acquired only a woodland density many years after infection.

Non-commercial Thinning

Although some 25,000 ha of northern Jarrah forest was thinned during the 1930s as part of intensive regeneration treatments, it probably had little long-term benefit. This is because very strong coppicing by Jarrah quickly restores competition. Most of this thinning was undertaken in sapling stands since there were few pole stands in existence at that time. The availability of herbicides made it possible to undertake effective non-commercial thinning and some 15,000 ha of the highest quality 30-40 year-old pole stands were thinned by stem injection during the 1960s and 1970s (Kimber, 1967). Injected trees were left standing.

Since 1985, commercial thinning with non-commercial follow-up has become a routine part of silvicultural practice and has accounted for 15 per cent of the harvesting in the last decade (Figure 3). Thinning aims to reduce pole stands to 'critical' density (basal area of 10-15 m^2 ha^{-1}), at which point the total stand basal area growth rate may be up to 30 per cent greater than it is for unthinned stands, while the diameter growth of crop trees is increased by 75 per cent (Stoneman *et. al.*, 1989). In practice, only the unwanted trees within four metres of the crop tree are removed, providing for effective thinning for the crop trees without unnecessary culling. In the patches that are thinned, about 5-15 m^2 ha^{-1} would be removed (most of it left to waste) in stands up to 50 years old. In most cases thinning is done by injection of herbicide, with limited areas being felled and stump-poisoned (CALM, 1991; Whitford *et. al.*, 1995).

Harvesting of Electricity Transmission Poles

The removal of electricity transmission poles and bridge piles occurred as an independent harvesting operation until the mid-1980s, after which time it was integrated with other harvesting. Removal of these high value poles was highly selective, removing only those trees that met exacting standards. These removals reached their peak in the late 1970s (53,000 m^3 yr^{-1}) and for the most part were restricted to the pole stands created by the silvicultural treatment of the 1920s and 1930s in the northern Jarrah forest. Although the best trees were removed, the operation represented only a light thinning, which would have resulted in no change to stand growth rate. Availability of long poles progressively diminished and from the 1990s concrete and steel poles became more common. Karri thinnings provide some larger poles, but they are not significant volumes.

Sleeper Mills

In addition to the main general-purpose sawmills, a number of sleeper mills operated in the lower quality forest east of the 800 mm rainfall isohyet. These were specifically designed to cut sleepers from the shorter boled trees in these areas. They generally operated to a 'girth' limit of 40 cm diameter in Jarrah and specific advance and top disposal burns were not generally undertaken. Harvest intensity varied with the quality of the forest and the size of the sleepers required. A significant proportion of the regeneration is from coppice growth.

Industrial Wood for Charcoal Production

In 1947, a charcoal-iron industry was established at Wundowie to the northeast of the main forest area. For the first decade it operated at a very small scale making charcoal from sawmill waste from its associated sawmill (Tonk, 1967). As its operations expanded it used increasing quantities of wood in the form of dry logs on the ground, dead trees and the tops of trees fallen for sawlogs. Tops were allowed to dry for two years before removal from the forest. Only small quantities were acquired from private property clearing and for a number of years part of the supply came from areas of State forest that were being cleared for pine plantations.

From the late 1960s the demand exceeded that which could be supplied from the tops of sawlog operations within reasonable distance of the plant and a shift was made towards increasing volumes of charlogs coming from cull trees felled for the purpose. Cull trees over 30 cm DBHOB were felled and allowed to dry for two years before hauling to the plant. Forests harvested for charlogs were protected from fire until the logs had been removed. The proportion of culls in these forests was such that the operation initially resulted in a virtual clearfelling, retaining a basal area of less than 5 m^2 ha^{-1}. Concern for the potential impact on salinity in these low rainfall areas resulted in changes to the prescription to ensure the retention of 50 per cent of the basal area or 20 per cent canopy cover (Forests Department, 1973) but cull trees as small as 20 cm DBHOB were removed for charlogs (Anon, 1969). These stands now support in excess of critical density and are close to their original density.

From the declaration of Disease Risk Areas (DRA) in 1975, harvesting for charlogs was restricted to areas east of the DRA. By the time the plant closed in 1981, most of the Jarrah forest east of the 750 mm isohyet from the Great Southern Highway to the Albany Highway had been harvested in this fashion. During its life it used some 1.6 million t of firewood (See Tables 3 and 4) with a recovery of about 33 per cent of charcoal (Earl and Mabonga-Mwisaka, 1970).

In 1989, a silicon metal industry, which required charcoal as a reductant, was established near Bunbury. Charlog operations recommenced in the central forest area using mainly dry Jarrah ground logs and dead trees. The plant also purchases about 32,000 t yr^{-1} of Jarrah sawmill waste.

Firewood

Reliable data for firewood usage are not available. The significance of firewood usage in terms of the forest carbon budget is difficult to assess relative to the alternative of leaving it on the forest floor, partly to be burnt over a period of time and partly to decompose.

Firewood has been sourced from direct round log operations in the field and as sawmill waste. It has been used as boiler fuel on site (at sawmills), or at other locations, and as domestic firewood. No records have been kept of firewood sourced from private land, or of firewood collected by individual (non-contract) firewood collectors. The data provided in Table 3 and Figure 8 include only wood from licences and from that produced by early Forests Department operations. Firewood for sawmill boiler fuel has been excluded from the data because it is waste wood from sawn timber recovery that was either burnt in a waste heap or used as fuel. Diesel or electricity began to replace firewood as a source of sawmill boiler fuel from the 1950s though it was not completely phased out until the 1980s.

Consumption of firewood in the south west (all sources) was estimated (Forests Department, 1950, 1960) to be between 270,000 and 500,000 green t yr^{-1} for domestic and industrial use (other than in sawmills). This is approximately five to ten times the volume officially recorded at that time. At the present time, about 45,000 t yr^{-1} are sold under license in the south west (Table 3). The increase in recorded volumes for the last decade is a reflection of the greater control and the use of larger contractors for firewood supply. However, usage estimates in the Perth metropolitan area alone have been put as high as 270-450,000 t yr^{-1} (Bartle, 1995). This estimate has been based on the known sales of wood-fired space and water heaters and their estimated unit consumption.

The use of some Jarrah sawmill waste for silicon metal production has reduced the availability of domestic firewood from that source. Air pollution concerns are placing greater restrictions on the use of firewood for domestic use in Perth, which could see a reduction in consumption in the future.

Bauxite Mining

The northern Jarrah forest from Collie to north of Perth is covered by State Agreement Act leases for bauxite mining (RFA, 1998b; Map 9). Alcoa began open cut mining for bauxite in 1962 and in 1982 Worsley Alumina began operating in the north east in Wandoo and Jarrah forest. To 2001, 14,100 ha has been cleared for mining, of which 11,300 has been rehabilitated (Conservation Commission, 2002).

Operations consist of:

- Removing all sawlogs, poles or other major forest products up to five years prior to mining;
- Clearing all vegetation prior to mining, removing for sale as much minor forest produce (posts, firewood) as possible, windrow and burn the remainder;
- Removing the seed-rich 100 mm top soil for transfer to newly rehabilitated sites, to avoid loss of viability of seed in stored soil;
- Removing and stockpiling the remainder of the overburden;
- Removing bauxite for processing;
- After mining is complete, shaping the edges of the mine pit, replacing overburden, replacing top soil from a new mine area if possible and deep ripping the site;
- Seeding with native tree species (Jarrah, Marri, Blackbutt) and a variety of native understorey species (Bartle and Slessar, 1989).

Prior to 1977, understorey seeding was not part of the practice and tree replacement was primarily achieved by planting with dieback resistant exotic species. Since then, understorey species composition has been refined and there has been a trend towards the use of local tree species and seeding rather than planting. Since 1991, only local tree and understorey species have been used in rehabilitation (Gardner, 2000). Some early-rehabilitated sites have been re-cleared and rehabilitated with the new techniques.

Seedlings established on the bauxite pits grow rapidly through the lignotuber stage, and basal area growth over the first 10 years is similar to that on natural forest 10 years after the release of the lignotubers.

The issue of re-introduction of routine prescribed burning in these young stands with heavy understorey fuel loads is yet to be resolved. So too is the question of the timing of first thinning.

4.2 KARRI

Karri was managed under a group selection system from 1938. Thirty to fifty per cent of the basal area was removed in gaps that were typically half a tree height (about 30 m) in diameter (Meacham, 1962; Bradshaw, 1999). No cull felling was done initially and effective gaps for regeneration were often not achieved in mixed Karri/Marri stands. Concerns about the fire hazard represented by large areas of slash that would need to be held over for the irregular seed year (Loneragan, 1979), initially led to slash burning being carried out every year regardless of seed supply (Stewart, undated). This practice was later changed with slash held over until the seed year. This meant that relatively large areas had to be burnt in a narrow window of suitable conditions. Most of the regeneration burns in this period were done in 1951, 1957 and 1963. Cull felling, in association with group selection harvesting, was introduced in the mid-1950s (J. Meacham, *pers. comm.*[2], Forests Department, 1964). Although regeneration occurred in these small gaps, mature trees remained the dominant strata.

Clearfelling was resumed in 1967 because of the problems associated with selection cutting in these forests, viz. regrowth suppression, difficulties in using hot regeneration burns in selection cut forest and damage to regrowth in subsequent harvests (White and Underwood, 1974; Bradshaw, 1999). Seedtrees were retained and slash burning was initially confined to the irregular seed years. (1968/69, 1972, 1976/77, 1981, 1985/86 and 1994 were major seed years). The slash is broadcast burnt with the aim of removing as much limb debris as possible, creating an ashbed and stimulating seed fall (Christensen, 1970, 1971; White, 1974). Seedtrees are removed within two years of the regeneration burn to prevent suppression of the regrowth (CALM, 1995b).

To minimise the cull felling that was necessary to complete the clearfelling, logging was concentrated as far as possible in pure Karri stands where the proportion of sawlogs is relatively high. Following the establishment of the export wood chip industry in 1975, clearfelling for both sawlogs and pulpwood was integrated and it was possible to effectively harvest mixed Karri/Marri stands. Sawlog-only harvesting with cull removal continued for a further five years in the extreme south west until pulpwood harvesting was possible in those areas as well. Pulpwood removals in Karri harvesting account for about 140 t ha^{-1} of additional utilisation. All areas harvested for sawlogs have also been harvested for pulpwood from 1981 until 1998, when a reduction in the demand for pulpwood saw some areas only partially clearfelled.

Planting, initially with transplanted wildlings, was trialled in 1969 (Christensen, 1969) and clearfelling and planting with nursery-raised seedlings became a significant component of the regeneration program from 1978. This had the effect of smoothing out the regeneration burning programs from year to year. Very little seedtree regeneration has been used since 1995. Regeneration, either from seedtrees or planting, is surveyed in the first summer and any understocked areas are ripped and planted in the following winter (CALM, 1990).

[2] John Meacham, Divisional Forest Officer at Pemberton from 1951-1961.

A further change to practice occurred in the mid-1990s when ripping to overcome soil compaction became routine practice for all areas harvested in winter. Ripping is carried out after the broadcast slash burn. In recent years about 80 per cent of the area harvested has been ripped.

Regenerated areas are protected from fire for at least 20 years, preferably until after the first thinning.

Even-aged regrowth stands are thinned for sawlog and pulpwood. The first (delayed thinnings) were carried out in the 1970s for small sawlogs used for tile batten production but effective thinning was not possible until integrated sawlog/pulpwood thinning began in 1980. This was also a delayed thinning of 50 year-old regrowth which was effectively completed by 1993. (CALM Annual report 1999, Appendix 1). Under normal schedules, thinning of regrowth will occur when the regrowth has developed its maximum 'clean' bole (i.e. maximum density is maintained until the co-dominant height of the regrowth is 30 metres, about 20 years old for average quality stands), at which time it is thinned to 'critical' density (CALM, 1992a; Rayner, 1992a). The first of these early thinnings, which yield mostly pulpwood, occurred in 1993.

Following a two-year delay to allow time for nutrients to be released from the tops, the area is burnt with a low intensity fire to reduce fuel loads. Logging debris is minimal and the fire consumes about 60 per cent of the 15 t ha^{-1} of material above 50 mm and 75 per cent of the fine slash fuel (McCaw *et. al.*, 1996; McCaw *et. al.*, 1997; O'Connell

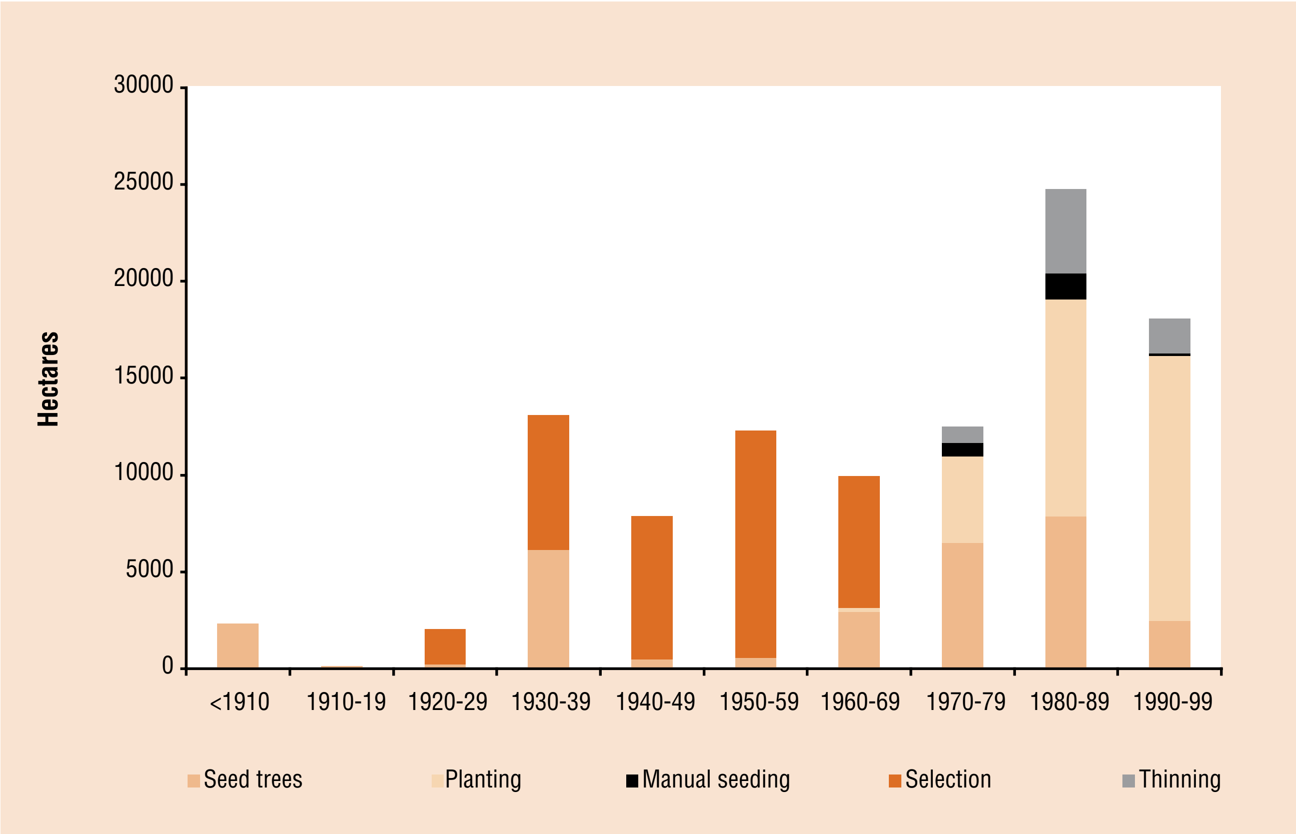

Figure 4. Karri harvesting, regeneration and thinning. The area of Karri forest on crown land harvested by clearfelling with seed trees; clearfelling and planting or manual sowing; group selection harvesting; and the areas thinned, for various time periods since 1880.

and McCaw, 1997). This constitutes the first post-regeneration burn, which thinning facilitates by flattening the understorey and increasing the drying rate of the fuel relative to the surrounds.

One or more further thinnings are scheduled, with sawlogs becoming an increasing component in later thinnings. Final harvest for most of the forest available for production is at 100 years of age (Turner *et. al.*, 1989; CALM, 1994).

Even-aged Karri approaches maximum basal area by 40 years of age. The mean annual gross bole increment over 120 years is 7 m^3 ha^{-1} yr^{-1} for fully stocked, average quality stands. Gross bole volume culminates at the onset of maturity at about 120 years (Rayner, 1992a; Rayner, 1992b).

In 2001, all old growth forest was withdrawn from harvesting. Most remaining forest that has been selectively cut will be harvested again over the next twenty years. Harvesting that occurs beyond that time will mostly be in regrowth forest, the oldest of which is now 70 year-old. The inability to sell Marri as pulpwood from the end of 2001 will mean a significant reduction in the area clearfelled and regenerated in the future, with an increase in the proportion that is 'selectively' harvested.

The area of Karri forest harvested and regenerated under different methods, from 1880 to 1999 is shown in Figure 4.

4.3 WANDOO

Wandoo forests have been utilised for sawlogs, charlogs, tannin distillation and fence posts.

Sawlog harvesting reached a peak of more than 70,000 m^3 yr^{-1} in the 1960s. Private property contributed more than 50 per cent of the sawlog production until the mid-1980s (Tables 3 and 4). Sawlog production has declined rapidly since the 1970s and for the last decade has averaged about 500 m^3 yr^{-1} from State forest with a similar amount from private property.

As the haulage distance for charlogs increased, some Wandoo was felled for use in charcoal production. The records do not distinguish between the species harvested in terms of quantity removed, but Wandoo was only a minor component.

The most significant industry dependent on the Wandoo forest was distillation for tannin and a variety of other products (Bayliss, 1947). Three distillation plants operated for different periods from 1937 to 1972, and the majority of the logs came from the clearing of private property, particularly during the period 1945-1960. In the late 1960s, as the resource from private property clearing reduced, areas of forest containing more than 50 per cent Wandoo were reserved from charlogging to provide a resource for the distillation plant. 430,000 t of extract logs were removed from State forest from 1945-1972, together with more 725,000 t from private property (Tables 3 and 4).

Most of the Wandoo forest has been cut several times, with a progressively reducing 'girth' limit, reaching 25 cm DBHOB in the 1970s (Hart, 1980). The virgin Wandoo forest averages about 15 m^2 ha^{-1} of basal area and sawlog removal would account for no more than a 15 per cent reduction. However, forest harvested for distillation products used a clearfelling with seedtree system (Underwood and Hooker, 1968). From the early 1970s, basal area removal was limited to 50 per cent for areas harvested for charlogs. Despite that, the Wandoo forest still contains a relatively large proportion of veteran trees. This is because trees above about 50 cm DBHOB frequently develop a hollow pipe making them unsuitable for sawlogs and in many cases they were also rejected as charlogs.

Seedling regeneration of Wandoo is critically dependent on ashbed, and the clumped nature of these woodlands is a reflection of the survival of seedlings on the ashbed resulting from the burning of fallen tree crowns (Campbell, 1956). However, Wandoo also coppices freely and much of the regeneration following heavy harvesting is in that form.

The limited data for Wandoo suggest that the growth rate of fully stocked stands is substantially better than Jarrah in a similar rainfall zone.

In 1989, silvicultural practice was changed with the objective of maintaining a specific stand structure. This was a stand represented by three age classes, viz: regeneration, intermediate and veteran in specified proportions. A re-emphasis was also placed on ensuring that burning was carried out in conditions that would create ashbed from felled tops (i.e. in autumn) and at a time when seed was available (CALM, 1989a). Relatively small areas have been harvested in this fashion because of the reduction in the harvest of this species in recent years.

4.4 TUART

Harvesting in the Tuart forest has always been on the basis of single tree selection, and at a relatively small scale. Only about 22,000 m^3 of sawlogs had been removed between 1945 to the mid-1970s when harvesting came to an end. Problems with regeneration were recorded as early as 1903 and most areas, whether natural or cutover, have not regenerated satisfactorily. The

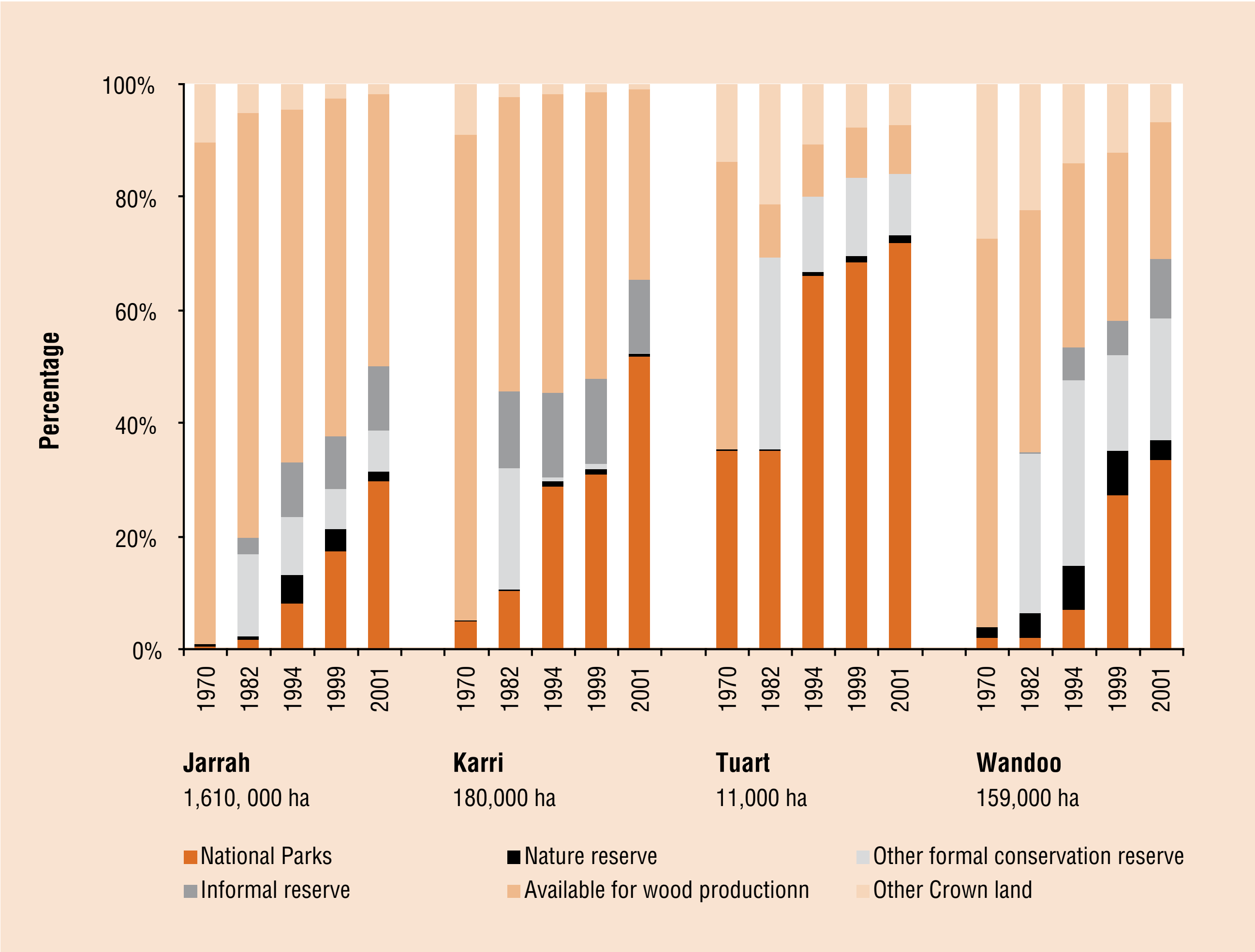

Figure 5. Changes to forest reservation status since 1970. The data represent management intent (i.e. actual and proposed tenure) rather than tenure, which usually lags a few years behind changes to management practice. 1970, 1982 and 1994 represent Forest Management Plan proposals. 1999 reflects the Regional Forest Agreement. 2001 represents proposals for the new Forest Management Plan for SW WA. Areas relate only to crown land.

primary impediment is the dense understorey of Peppermint *(Agonis flexuosa)* that appears to have developed to its present level since the cessation, in the 1860s, of frequent aboriginal burning. Regeneration can be satisfactorily established if the Peppermint is mechanically removed (CALM, 1988; Bradshaw, 2000). So far, 200 ha have been regenerated in this way, together with 170 ha of the area previously planted with pine.

The majority of the Tuart forest has been protected from fire for many years and much of it has been annually grazed.

Because of its location and soil type a considerable proportion of the original Tuart forest has been cleared for market gardens or urban development. More than 90 per cent of Tuart on crown land is now in National Park or proposed National Park. A recent outbreak of insect attack (borers) has resulted in patches of high mortality in the central Tuart forest (Bradshaw, 2000) and the long-term outcome of this is uncertain.

4.5 CLEARING FOR PINE PLANTATIONS

The majority of the *Pinus radiata* plantation establishment during the late 1950s and 1960s was on re-purchased farmland with relatively small areas on fertile gullies that had been cleared in State forest. In the 1970s, a major program of plantation establishment began on mainly *Phytophthora cinnamomi* infested Jarrah forest in the Donnybrook Sunklands. This program continued until the mid-1980s when clearing of native forest for plantations was stopped. Establishment of *P. radiata* plantations in the Sunklands continued till the mid-1990s on areas that had previously been planted with other species and were re-cleared. An estimated total of 21,000 ha of native forest have been cleared for pine plantations since 1945 (Table 2).

The other major plantation program in WA involved the establishment of *P. pinaster* on *Banksia* woodlands on the coastal plain mainly north of Perth. Since this did not involve the primary clearing of high forest they are not covered in this review.

4.6 OTHER CLEARING OF NATIVE FOREST

A further 11,000 ha of native forest on crown land within the area covered by this review has been cleared, almost all of it since 1945, and most since 1970. This is made up of 5,000 ha for utilities (power lines, dams and other infrastructure); 4,000 ha for coal mines and overburden dumps; 1,360 ha for gold mines; 250 ha for sand mines and 670 ha for tin mines (CALM, 2001; Conservation Commission, 2002). The majority of this clearing was located in the Jarrah forest. About 23 per cent of it has undergone some form of rehabilitation.

4.7 PRIVATE FOREST

Approximately 310,000 ha of forest remain on private land, about two thirds of which is Jarrah forest. About 1.3 million ha have been cleared, Wandoo being the most severely impacted (60 per cent cleared within the RFA area) and Karri the least (20 per cent cleared). While there are no reliable data on the original area of Tuart forest, clearing has probably been in the order of 60 per cent.

Harvesting of trees for various wood products from private property has primarily been associated with land clearing, for on-farm fencing and building material, and opportunistic exploitation. There is almost no native forest managed for ongoing timber production on private land.

Until 1945, private land contributed about 25 per cent of the total timber production but since that time it has gradually become less important. From a post-war peak of 30 per cent in the 1950s, it has continued to fall until by 1999 it has almost ceased, with the exception of an unknown quantity of firewood (Figure 6).

There are no reliable data on the rate of clearing of private property. However, in terms of intensity of clearing, in the Wandoo forest and other areas

Figure 6. Total log removals from crown land and private property by 5-year periods. Crown land statistics to 1965 include logs owned by the crown but removed from private land (referred to as PPTR).

where cropping was undertaken, initial clearing involved complete removal of trees. In areas intended for grazing, ring-barked trees remained for many years and dominated the rural landscape until the 1950s and beyond. These gradually deteriorated and in the 1960s the availability of heavy machinery and improved economic conditions saw the clearing finally completed. The timber on some private property was reserved to the crown because timber harvesting could not keep ahead of land settlement. Though it could be ring-barked or removed in clearing, it could only be sold by the crown. Some sawmills were established specifically to remove this timber before it was lost to clearing and before the crown rights expired in 1965. This timber (known as PPTR) is included within the crown land log removal statistics.

Most of the forest remaining on private property has been 'high-graded' over many years and has little immediate timber production potential without substantial investment in silviculture. Controls imposed by the Water Authority, the Environmental Protection Authority and many local Shires means that future clearing is likely to be minimal and silvicultural practices necessary for on-going timber production are also likely to be limited.

5. CHANGES IN RESERVATION STATUS

By 1945, more than two million hectares of crown land were reserved as State forest and Timber Reserves, together with a very small area of National Parks (Forests Department, 1945). All of State forest and Timber Reserves were considered to be available for timber production. Major changes to the use of forests began in the 1970s (Figure 6) when the State forest was divided into

Management Priority Areas that provided for various forms of conservation reserve within State forest. Many of these were later to become National Parks (Underwood and Bradshaw, 2000). By 1982, the area of National Parks or proposed National Parks had doubled but they still represented only a small proportion of the total forest on crown land. However, the proportion of Crown land that was reserved from harvesting had risen to about 25 per cent when formal and informal reserves within State forest were included (CALM, 1992b, Map 2). Substantial additional reservation occurred under the 1994 Forest Management Plan and again under the RFA of 1999. By that time, the proportion of crown land forest in National Park or proposed National Park was about 20 per cent, with a further 20 per cent in other forms of conservation reserve. Significant changes have occurred since the RFA (1999), with the reservation of all remaining old growth forest and additional areas of previously harvested forest. Figure 5 shows the change in reserve status at different periods from 1972 to the present. Data indicates management intent rather than actual tenure change, which usually lags several years behind the change to management practice. The status of management intent shown for 2001 is that proposed in the draft Forest Management Plan for forests of SW WA.

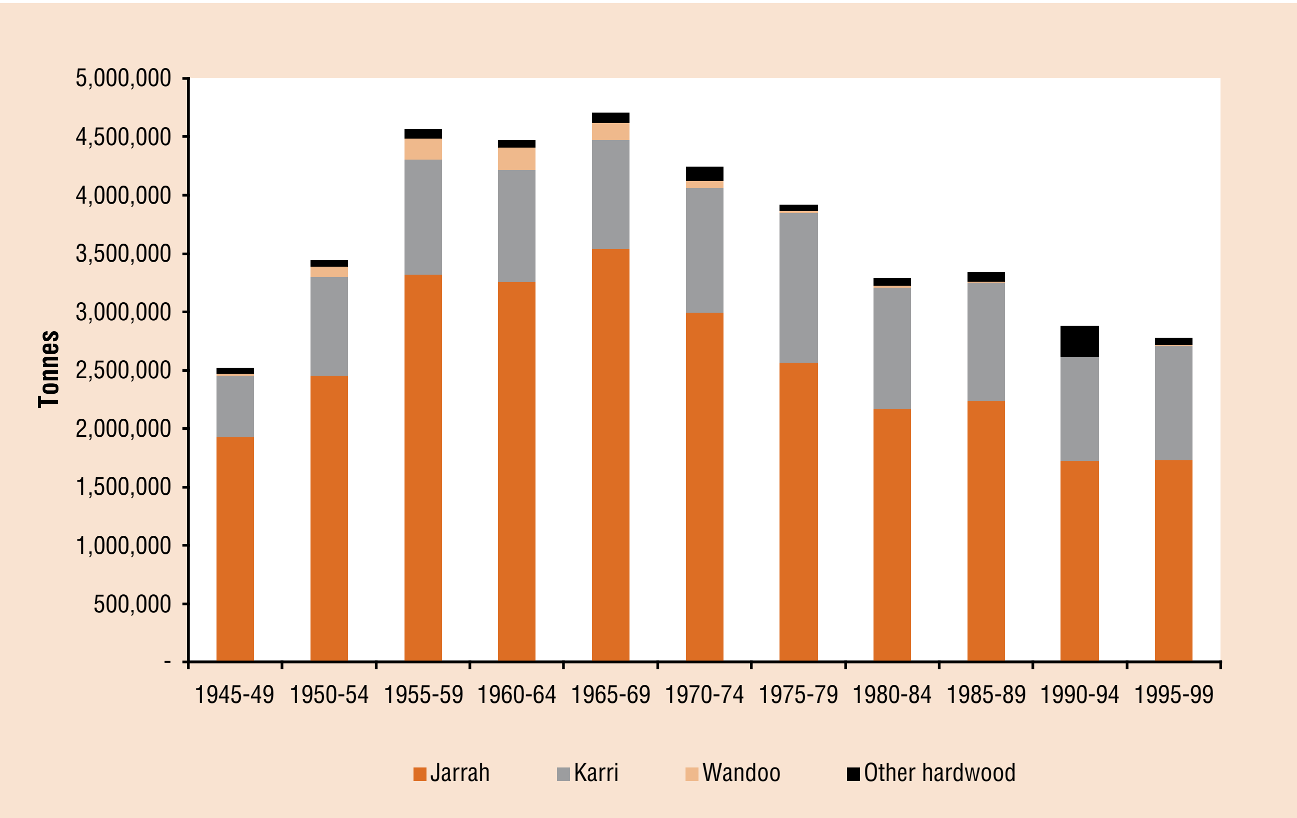

Figure 7. Sawlogs (includes timber from private land where the timber was reserved to the crown). Sawlog removal from crown land. Tonnes of wood removed (total for the 5-year period) from crown land since 1945.

6. DISCUSSION OF THE IMPLICATIONS OF PAST FOREST MANAGEMENT FOR CARBON BUDGETS

6.1 REMOVAL OF WOOD PRODUCTS

The post-war building boom was responsible for an increase in timber harvest from the south west forests. An increasing proportion of it was used in the domestic market. From the late 1950s, wood removal from the forest (crown land and private property) has been more or less constant at about 1.3 million t yr^{-1}. The contribution of private property (mainly associated with permanent land clearing) has reduced from a peak of about 30 per cent in the early 1950s to less than 5 per cent since 1995 (Figure 5). From the late 1970s there has been a decreasing proportion of the log removals being used for long-term carbon storage products, with sawlogs, poles and hewn timber accounting for approximately 77 per cent of total log production in the late 1940s, 92 per cent in the 1950s and 45 per cent in the late 1990s (Figures 7 to 10). The quantities of various log products removed by five year time periods are shown in Tables 3 and 4.

The Jarrah forest has provided the majority of sawlogs, poles, charlogs and firewood throughout the post war period as it did before, producing some 35 million t of sawlogs and poles and 5.2 million t of other logs since 1945. In addition, approximately 2.5 million t of Marri pulpwood have come from the Jarrah forest. In all, about two thirds of the total log production has been sourced from the Jarrah forest, together with an additional unknown quantity of domestic firewood collected from the forest by private individuals. Since 1980, about a quarter of the logs produced from the Jarrah forest has been Marri pulpwood.

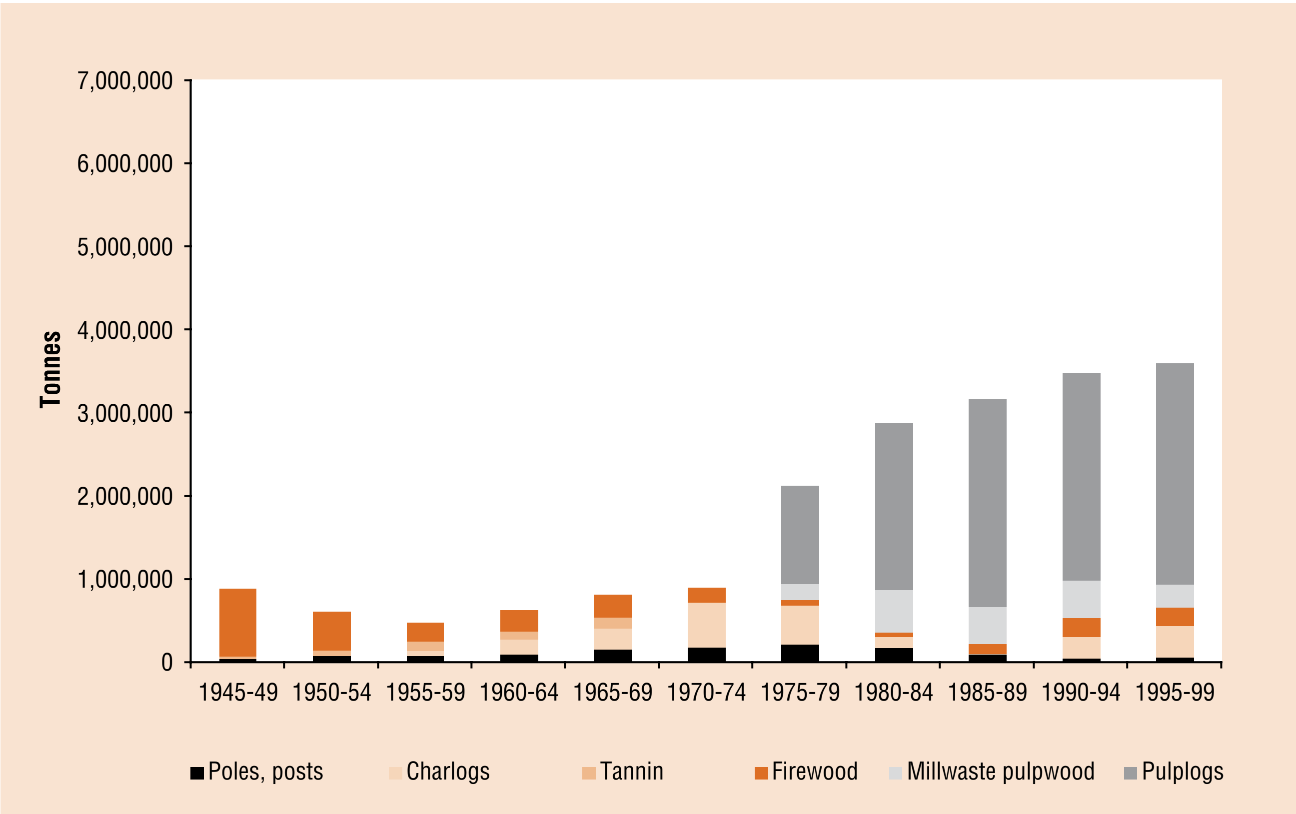

Figure 8. Removal of other products (total for the 5-year period) from crown land since 1945. Firewood includes only that collected under license.

Additional wood volume has been 'removed' by non-commercial silvicultural operations. Since 1945 some 64,000 ha of Jarrah forest has been thinned, generally with a combination of commercial harvesting followed by a non-commercial follow-up operation to achieve the final result. Non-commercial thinning operations generally employ stem injection with herbicide which leaves those trees standing. Their rate of deterioration depends on their size. About 77,000 ha of gaps have also been created since 1985. Many of these have also involved limited cull removal using either stem injection, coppicing or pushing over with a bulldozer. The majority of the bole wood of those that have been pushed generally remains on the forest floor after the post-harvest burning.

The production of Karri sawlogs also increased with the post war boom, but has been relatively stable since 1950, at just over 200,000 t yr^{-1}, producing a total of 11.4 million t since 1945 and an additional 640,000 t of Marri sawlog, almost all of which has come from the Karri forest. A substantial volume of cull material was burnt to waste between 1967 to 1975 before the export pulpwood industry was established. Utilisation of pulpwood resulted in an increase in total log production from 1975, with the bulk of the Marri and Karri pulpwood (about 10 million t) coming from the Karri forest type. Since 1975, nearly 2 million t of sawmill waste has also been used for pulping instead of being burnt to waste.

The Wandoo forest has contributed only a small volume of wood products relative to the Jarrah and Karri forests, producing 1.7 million t of sawlog and 1.2 million t of wood for industrial extracts since 1945. The majority of this was a product of land clearing until the mid-1970s.

The Tuart forest has produced a negligible volume of timber since 1945 (95,000 t), mostly from the clearing of private land. All production ceased in the mid-1970s.

Extrapolation from estimates of gross bole volume on State forest (CALM, 1992b) suggests there was an estimated 203 million t of standing eucalypt biomass on crown land in 1992.

6.2 SILVICULTURAL USE OF FIRE

Fire is an integral part of silvicultural practice in WA. It is used for hazard reduction associated with harvesting, to facilitate treemarking, for seedbed preparation and for stimulating seed fall. Fire has also been used as a means of strategic fuel reduction to reduce the wildlife/hazard particularly since 1961. There is an increasing trend towards the more formal integration of silvicultural fire for strategic fire protection. This section summarises the way in which the use of fire as a silvicultural activity has changed over time. The use of fire in a broader context is dealt with elsewhere.

In the Jarrah forest it has been routine practice to conduct an 'advance' burn prior to harvest to improve access, reduce the fire risk from post-harvest burning and to improve the visibility of lignotubers. This has remained fairly standard practice until recently. Its use is now discouraged because it conflicts with dieback hygiene measures by masking disease symptoms. Immediate post-harvest burning has remained essentially unchanged over the period. Its aim is primarily a hazard reduction measure to remove the excess of light slash fuels that result from harvesting, though it also has a role in promoting rapid seed shed and creating seedbed where shelterwood harvesting is involved. Burning aims to remove debris to 2.5 cm diameter in thinned stands or 7.5 cm in gaps or shelterwood areas, though these limits are probably exceeded in most areas.

The timing of the re-introduction of prescribed hazard reduction burning after regrowth has become established has changed over time. From 1945 to 1961, regrowth forests, including those established before 1945, were to be protected from fire until they were old enough to withstand prescribed burning. However, a large proportion

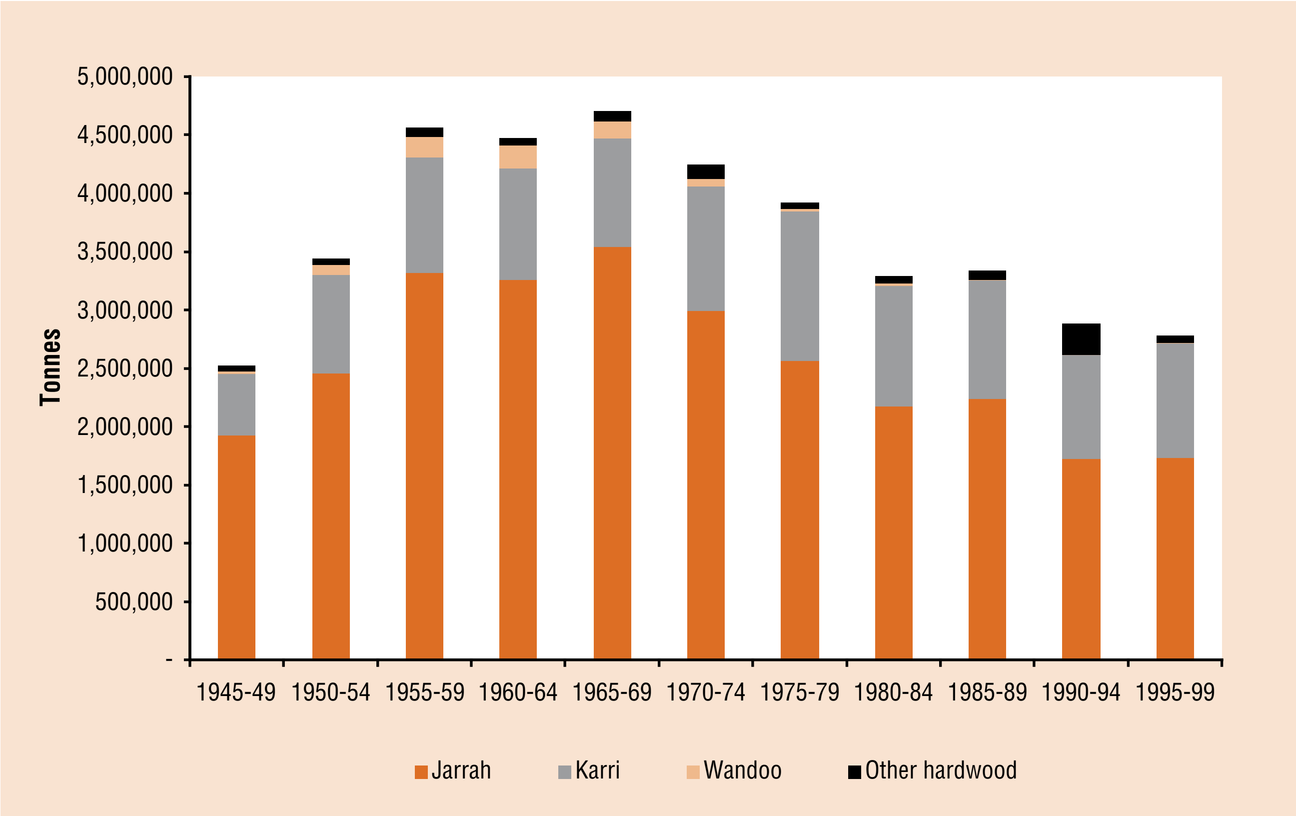

Figure 9. Sawlog removals (total for the 5-year period) from private land forest since 1945.

of these stands were burnt by wildfire in 1961, and as a consequence of the long period of protection, were burnt at very high intensity. From 1961 to the mid-1980s, as a consequence of this experience, the withholding period was dispensed with and prescribed burning of harvested forest was resumed on the basis of normal fuel reduction cycles (5-8 years at that time). From the mid-1980s, newly released regrowth (in gaps) is afforded protection for 10-15 years before a resumption of routine prescribed burning. This represents a relatively minor disruption to routine prescribed burning over a small part of the forest estate at any one time.

Future silvicultural burns in Jarrah are likely to be in the order of one third of that of the past decade because of reductions to harvest levels as a consequence of recent forest reservation changes.

The use of fire for silvicultural purposes in Karri has remained essentially the same since 1945, despite changes to the silvicultural system. Regeneration burns after harvesting aim at removing as much debris as possible, creating ashbed and stimulating seed fall. The objective is the same for both selection cutting and for clearfelling, though the net area burnt at this intensity (the actual gap) in the selection cut forest is only about a half of its gross area. Until the mid-1970s, regeneration burning was more irregular, to coincide with seed years, but the area burnt is nevertheless equal to the area harvested in the medium term. The increase in the area of regeneration burning since about 1975 is associated with increased removal of wood volume in the form of pulpwood (and consequent decrease in log debris fuels) during the same period. The increased use of ripping for regeneration

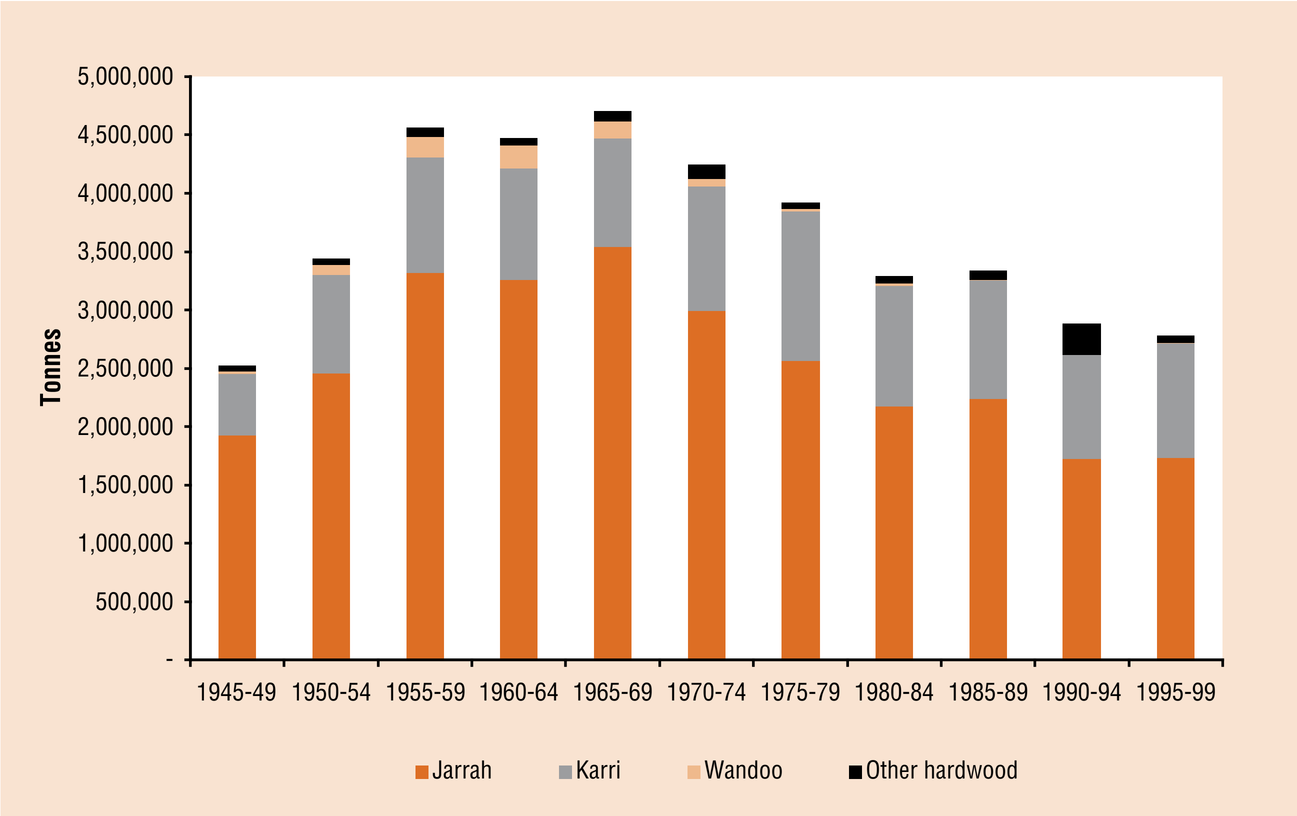

Figure 10. Removal of other products (total for the 5-year period) from private land forest since 1945. There are no records of firewood removal from private forests.

preparation in the last decade may have resulted in some increase in release of soil carbon, though this occurs on less than 1,000 ha yr^{-1}.

Regenerated Karri forest is not subject to fuel reduction burning for at least 20 years after it is established, by which time it is able to withstand mild fire. While this represents major difficulties in terms of strategic fire protection, it represents only a minor impact on the overall area that is fuel reduced in the forest as a whole each year. Thinned forest is burnt about two years after harvesting as a fuel reduction measure, removing only light slash fuels from logging tops in addition to the normal understorey fuels.

With the expected change in the resource available for harvesting as a consequence of recent reservation changes, the gross area requiring regeneration will reduce to about 10 per cent of that which has prevailed for the last decade. The prescription of removing Marri as pulpwood will further reduce the net area that is regeneration burnt in the future.

While fire is an essential element in the regeneration of Wandoo forest, the small area harvested each year represents an insignificant impact on carbon balance.

A large proportion of the Tuart forest on crown land has been managed under a system of complete fire protection since the 1920s and the remainder has been subjected to very infrequent prescribed burning. Although the mechanical removal and burning of the *Agonis* understorey is essential for Tuart regeneration, only a few hundred hectares have been treated in this way. Since the Tuart forest is now National Park or proposed National Park it seems unlikely that significant areas will be deliberately regenerated by this means in the future.

The clearing of native forests for pine plantations or for agriculture is always associated with windrowing and burning. However, agricultural clearing has reduced to very low levels since the 1970s. Although no data are available for the rate of clearing on private property, the relative rate can be inferred from wood product removals (Figure 5). However, it should be noted that these data underestimate the volume actually removed from private land because PPTR (timber reserved to the crown on private land) was included in the crown land data until the provision expired in 1965. Clearing of native forest for pine plantations has involved relatively small areas and ceased in the mid-1980s (Table 2).

The principal objective of prescribed burning has only been differentiated in the Department of Conservation and Land Management annual reports since 1992. Silviculture is the primary reason for initiating about 15 per cent of prescribed fire used in the native forests on crown land at the present time but it should be viewed as a component of the broad prescribed burning program rather than as an addition to it (i.e. a similar area is likely to be burnt for hazard reduction if it were not burnt for silvicultural purposes). Factors that influence the use of prescribed fire in the future, such as availability of funding, public opinion and smoke over populated areas, are likely to impact on the areas burnt to a much greater degree than the expected reduction in silvicultural burning in the future.

The seral or structural condition of the understorey at the time of burning is a function of the time since the last burn and the proportion of it that is burnt. This is the same for silvicultural burns as it is for hazard reduction burning. The potential impact of fire on carbon balance is dealt with in more detail in this volume by Gould and Cheney (2007) and Raison and Squire (2007).

6.3 FUTURE GROWTH POTENTIAL

Changes to the intensity of harvest in both Jarrah and Karri forest since 1945 have influenced subsequent growth and therefore the accumulation of carbon stocks. In addition to that is the changing condition of forest that was regenerated before 1945.

Substantial areas of Jarrah forest were regenerated during the 1920s and 1930s, and by 1950 about one quarter of the Jarrah forest consisted of stands dominated by 20-30 year-old regrowth (Figure 2). By the time well-stocked regrowth stands are 40 year old they will have reached maximum density and total stand growth will have slowed. These stands require non-commercial thinning to maintain good growth, which can be maintained at the maximum rate for about 30-50 years if thinned to 10-15 m^2 ha^{-1} (Stoneman *et. al.*, 1989). Under present practice, non-commercial thinning of these stands occurs in association with the commercial harvesting of the mature component of the stand, which is either regenerated or thinned.

Harvesting of Jarrah forest from 1945-1970 removed an estimated average of 20 per cent of the stand basal area. From 1970-1985 it was about 40 per cent (See Appendix 1 for the source of this estimate). The removals tended to be uniformly distributed rather than grouped. This was effectively a thinning and was generally not intensive enough to allow for the establishment and persistence of regeneration except in very small gaps. It could be expected that growth would continue for perhaps 25-50 years following such a harvest until the stand again approached maximum density and eventually reached equilibrium biomass. However, the experience has been that the scattered regrowth that did develop during this period was often damaged or demolished in future harvests so that the gains in growth were short-lived.

From 1985, the gap sizes created in harvesting were sufficiently large for regeneration to develop into pole stands, which can be expected to maintain growth until maturity. In forests available for timber production, thinning is planned to maintain stand growth rate within the maximum range. Stands that have been 'selectively' cut during this period will behave in the same way as that described for selection cut stands above.

In 2000, 27 per cent of the Jarrah forest on crown land (19 per cent of conservation reserves) was dominated by regrowth and therefore in a condition of positive carbon accrual until the regrowth component reaches maturity (Figure 11). In the Jarrah forest there has been a net reduction in regrowth-dominated forest since 1950 because significant areas are affected by dieback. The majority of the regrowth in the 30-120 year-old category is 60-80 year-old. More than 15 per cent of the forest is old growth and expected to be in carbon balance. The growth status of the remaining Jarrah forest is variable but it would be expected that most of it would be in a state of net carbon accrual, albeit at a relatively low level.

The majority of the dieback-affected forest has been salvage harvested and would now be in a condition of positive carbon gain, though at very low levels. Areas of multiple-use forest affected in the future would also be salvaged but areas of conservation forest that in the future would be left undisturbed, resulting in a net carbon loss in the long-term.

Harvesting in the Karri forest from 1945-1967 involved the removal of 30-50 per cent of the basal area in a group selection harvest. It could be expected that these stands would have returned to

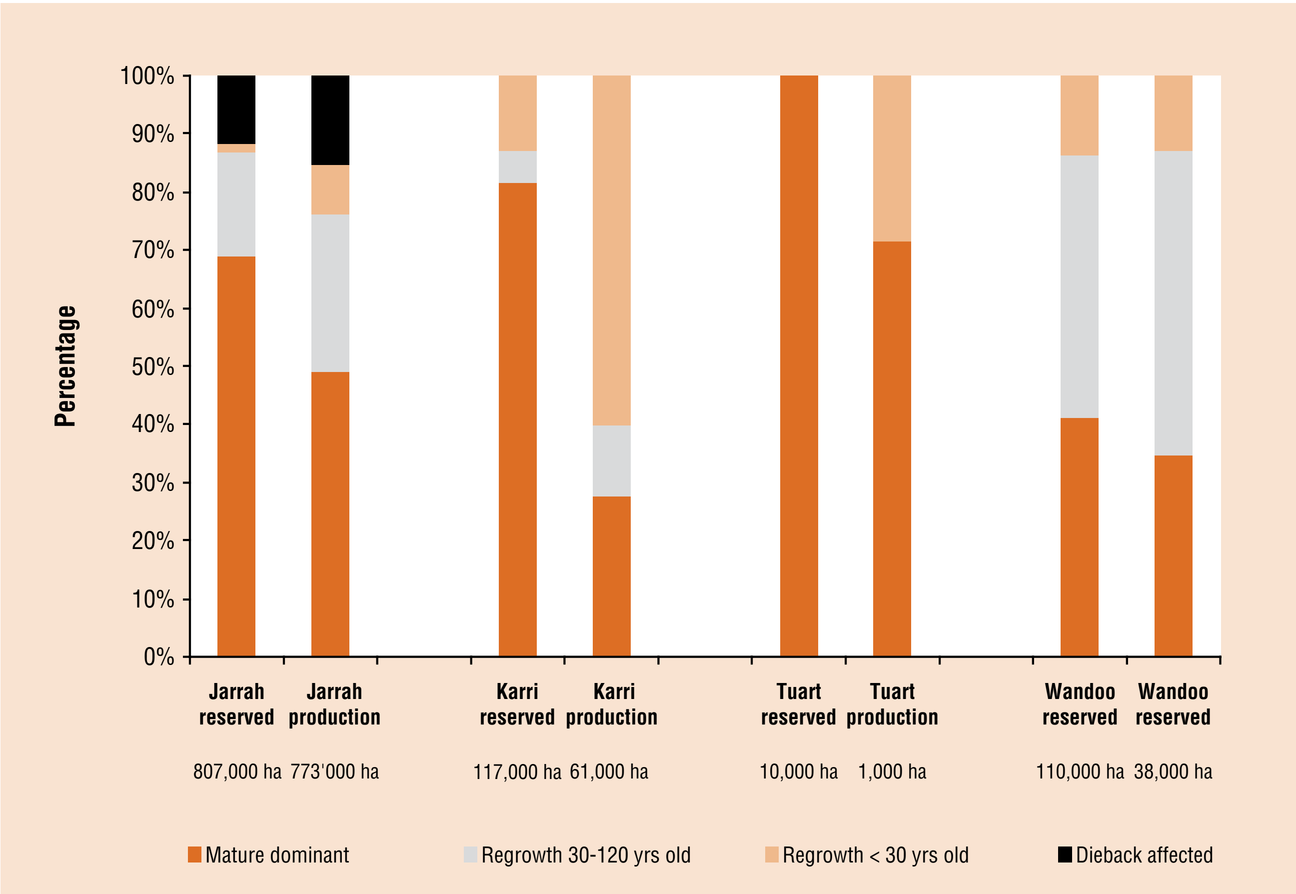

Figure 11. The estimated proportion of each forest type that is dominated by either mature or regrowth forest, in reserved forest and forest available for wood production. The data refer to land managed by the Department of Conservation and Land Management and is based on the reservation status proposed in the recent Forest Management Plan for SW WA forests.

their original density within 20-30 years and from that time on be in a state of relative equilibrium. All existing selection cut stands will by now have reached that point.

All of the selection cut Karri stands in areas available for wood production are expected to be harvested over the next 10-20 years but the inability to market Marri as pulpwood will prevent the clearfelling of all of these stands. The growth of new stands created from 2001 will therefore be expected to have a substantially lower growth than existing regrowth stands.

All of the even-aged regrowth stands (created before 1940 and after 1967) in areas available for wood production will be maintained within the density range for maximum growth rate by regular commercial thinning, before final harvest at about 80-100 years of age (CALM, 1992a). In 2000, 72 per cent of the Karri forest available for production was in this condition, and the oldest of this regrowth is 70 years old (Figure 11).

All of the existing mature forest in conservation reserves (both old growth and selection cut forest) would be expected to have zero net growth, while the 18 per cent that is regrowth could be expected to accrue volume until it reaches maturity (nominally from 120 year-old) at which time it would reach a point of equilibrium. The oldest of this regrowth is almost 120 years old.

Substantial areas of Wandoo were heavily cut from the 1950s to the 1970s. Regrowth has been effective and most of these stands are now approaching maximum density. Given their present condition, their relatively low growth rate and productivity, and limited area available for production, these stands are not expected to make a significant contribution to an increase in carbon stocks.

Almost all of the remaining Tuart forest on crown land is now within National Park or proposed National Park. There are serious concerns regarding the ability of Tuart to regenerate under present management regimes. Unless changes are implemented, the Tuart forest can be expected to decline to a condition of negative net growth and declining carbon storage.

7. CONCLUSION

The data relating to product removal, area harvested and silvicultural practice have been well documented for the south west forests, and the records are of high standard. Records of log removals from private property are of a similarly high standard but there are virtually no data for the rates of clearing or the unsold wood volumes removed in the process. Records for firewood removal from both crown land and private property seriously underestimate the actual volumes removed. The changing use of fire in silviculture is well known and documented.

The forest condition as a consequence of clearfelling is well understood, but the condition of selection cut forests (especially Jarrah) is more complex, partly because of the wide range of silvicultural practice that is applied but also because of the wide range of sites within the Jarrah forest. Growth predictions for uneven-aged forests are less reliable for similar reasons.

A number of interacting factors will influence the accumulation of carbon stocks in the future. A greater proportion of the forest is in the form of immature stands than in 1945, and this trend will continue in the multiple-use forests, increasing the area that is accumulating carbon stocks. However a greater proportion of the forest is now in conservation reserves of one form or another, and although a proportion of these forests are immature, the management intention is to allow them to grow on to maturity. Eventually these forests would reach an equilibrium in terms of carbon accumulation, except for the impact of episodic wildfire events that will both release carbon and initiate a new cycle of carbon accumulation.

The total production of sawlogs and pulpwood from the forest is expected to fall to about a third of the level of the previous decade, though the proportion of sawlogs to pulpwood is expected to remain relatively unchanged. It is understood that only a small proportion of the firewood production has been accounted for in the past, but if usage continues at the levels estimated at present it could become the largest single use of forest products.

Changing policies, funding arrangements and pressure from the urban public are likely to result in less fuel reduction burning and increasing difficulty in achieving silvicultural burns in the future. The expected outcome is an increase in wildfires. The net impact on carbon release is uncertain, but is likely to be insignificant when taken over the very long term.

8. ACKNOWLEDGEMENTS

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Table 1. Timeframes of forest disturbance in the four main forest types in WA. Asterisks denote years when the activity occurred.

Activity		1950-59										1960-69										1970-79										1980-89										1990-1999									
Jarrah	light selection harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*																		*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	heavy selection harvest																					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*													
Jarrah	gap harvest																																						*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	shelterwood																																						*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	commercial thinning																																						*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	non-commercial thinning															*	*	*	*	*	*	*	*	*															*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	selective SEC pole thinning	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*													
Jarrah	charlog removal	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*									*	*	*	*	*	*	*	*	*	*
Jarrah	bauxite mining														*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	dieback salvage														*	*	*	*	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	remove pulpwood																												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	cull removal for regeneration																																						*	*	*	*	*	*	*	*	*	*	*	*	*
Jarrah	protection of regrowth from fire	*	*	*	*	*	*	*	*	*	*	*	*																							*	*	*				*	*	*	*	*	*	*	*	*	*
Jarrah	clearing for pine plantations	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*															
Karri	selection harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*																																	
Karri	clear fell or C/F with seedtrees																		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Karri	remove pulpwood																										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Karri	non-commercial cull removal						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*																				
Karri	ripping for site preparation																			*	*	*																				*	*	*	*	*	*	*	*	*	*
Karri	commercial thin (sawlog only)																																																		
Karri	commercial thin (sawlog and pulpwood)																															*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Karri	commercial thin (pulpwood only)																																															*	*	*	*
Wandoo	sawlog harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Wandoo	tannin/charlog harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*																		
Tuart	light selection harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*																									

10. APPENDICES

10.1 APPENDIX 1

DATA SOURCES AND ASSUMPTIONS

This appendix summarises the sources of information and assumptions that have been used in the preparation of figures and data tables.

Stratification for data tables

The four major forest types (Jarrah, Karri, Wandoo and Tuart) are the primary strata used in this review. Most historical and current area data are based on these types. Inventory data are based on these broad types and most volume removal data can be reasonably related to them. Further subdivision is based on the timing of significant changes to practice indicated in Table 1, and on those practices that result in significantly different long-term outcomes (e.g. *Phytophthora cinnamomi* infested forest). Thirteen strata have been derived in this way and used as the basis for the data tables (See Table 5). While further refinement of strata is possible to reflect a range of site quality within the forest, historical volume removal data could not be reliably attributed to these strata and such an approach has not been pursued for this reason.

Forest Types and Tenure

The forest type boundaries and definitions used in this report are derived from the following sources:

Jarrah forest: An amalgamation of the following ecosystems used for the Western Australian Regional Forest Agreement – Jarrah Blackwood, Jarrah Leeuwin, Jarrah Mt. Lindesay, Jarrah north east, Jarrah north west, Jarrah/Rates Tingle, Jarrah/Red Tingle, Jarrah sandy, Jarrah south, Jarrah Unicup, Jarrah woodland, Jarrah/Yellow Tingle (RFA, 1998b, Map 12)

Karri forest: An amalgamation of the following ecosystems used for the Western Australian Regional Forest Agreement – Karri main belt, Karri/Rates Tingle, Karri/Red Tingle, Karri west coast, Karri/Yellow Tingle (RFA, 1998b, Map 12) plus additional extant Karri to the south and east outside the RFA boundary (Bradshaw *et. al.*, 1997); (Map 3, Karri Distribution Before European Settlement).

Wandoo forest: An amalgamation of the following ecosystems used for the Western Australian Regional Forest Agreement – Wandoo forest, Wandoo woodland (RFA, 1998b, Map 12).

Tuart forest: Derived from 'Tuart on crown land' (Bradshaw *et. al.*, 1997) (Map 1, Forest Associations of the South West of WA – Central and North).

Other native vegetation: An amalgamation of the following ecosystems used for the Western Australian Regional Forest Agreement – bullich and yate; Darling scarp; Peppermint and heath; shrub, herb, sedge; swamp (RFA, 1998b, Map 12).

The principal source for these maps was air photo interpretation dating originally from 1951 and updated by various projects to the present time (Bradshaw *et. al.*, 1997). Interpretation and mapping resolution is two hectares.

The Department of Conservation and Land Management is the owner and custodian of the digital source data for these maps.

Table 2. Estimated areas (ha) of crown land native forest cleared for establishment of pine plantations since 1950 by decade.

1950-59	1960-69	1970-79	1980-89
2,200	2,200	7,400	8,800

Timeframes of Forest Disturbance

A wide variety of harvesting, silvicultural and management activities have taken place in the forests of WA. These have been discussed in section 5 and are summarised in Table 1. The activities listed in Table 1 may have occurred on the same area in the same time frame or on different parts of the forest in the same time frame.

Area data

Area data used in this review have been derived from the following sources:

- Existing and cleared land by forest types used in Figure 1 have been derived from RFA data (RFA, 1998a) with the exception of Karri and Tuart (Bradshaw *et. al.,* 1997). Private property forest type areas, other than Karri and Tuart, are not directly mapped but have been derived by analysis of the relationship between forest type and vegetation complex which was mapped for all of the RFA area.
- Forest structure data used in Figures 2 and 11 have been derived from the Department of Conservation and Land Management's (CALM) GIS database (FMIS) using overlays of forest structure from air photo interpretation (API) maps from photos taken from 1951 to 1961, harvesting records, regeneration records and mapped dieback occurrence. Additional data were derived from Karri forest age class mapping (Bradshaw and Rayner, 1997a). Regrowth-dominated Wandoo forest is assumed to be that cutover from 1950-1970 and apportioned to reserved and multiple use forest. In this review, regrowth-dominant stands are defined as those where regrowth constitutes more than 50 per cent of the canopy cover. While this does not represent silvicultural dominance, it indicates that the majority of the stand growth is accruing on immature trees in these stands.

Table 3. Products (dry tonnes) removed from crown land for each 5-year period since 1945.

Period	Sawlogs Jarrah	Karri	Wandoo	Other hardwood◊	Poles, posts, Hewn◊◊	Charlogs #◊◊	Wandoo for distillation	Pulplogs ◊◊◊	Firewood ◊◊	Pulpwood from Karri sawmills
1945-49	1,926,000	527,400	16,800	49.600	46,100	3,400	28,200		814,100	–
1950-54	2,452,000	845,500	86,800	56,000	87,700	700	58,900	–	475,100	–
1955-59	3,321,400	984,600	179,900	77,100	92,300	52,400	112,000	–	227,500	–
1960-64	3,325,700	958,600	197,900	61,000	103,300	181,100	91,100	–	261,200	–
1965-69	3,540,000	930,900	148,100	86,600	167,600	247,600	131,500	–	274,700	–
1970-74	2,994,500	1,063,000	66,900	119,200	190,100	527,900	12,900	–	174,400	–
1975-79	2,567,300	1,278,200	19,300	55,800	218,100	473,800	–	1,186,600	69,600	187,200
1980-84	2,170,100	1,042,000	11,400	61,400	184,900	126,200	–	2,004,200	58,700	508,000
1985-89	2,239,300	1,012,000	8,300	77,890	106,700	1,900	–	2,500,600	115,700	446,600
1990-94	1,725,400	887,500	2,100	269,700	58,000	258,000	–	2,500,700	224,200	449,000
1995-99	1,730,200	982,100	3,800	62,900	62,000	381,600	–	2,661,500	224,900	276,000

for use in steel production to 1981 and for silicon metal from 1989.

◊ includes Tuart, Marri, Blackbutt, Red and Yellow Tingle, Sheoak and Banksia.

◊◊ mostly Jarrah.

◊◊◊ Marri and Karri

- Areas affected by *Phytophthora cinnamomi* referred to in section 5.1.2 are derived from existing maps of occurrence held by the Department of Conservation and Land Management. The currency of these maps varies from the 1970s to the present. Areas planned for harvesting are routinely mapped and maps of these areas are the most accurate and current. The actual area affected by *Phytophthora cinnamomi* will always be greater than the area recorded but there are no data on the magnitude of this difference.

- Method of harvesting for Jarrah forest (Figure 3) has been derived from interrogation of CALM's FMIS and SILREC (Silvicultural recording system) databases using overlays of harvesting history and method, and mapped dieback occurrence. Method of harvest from 1950 to 1985 is based on an understanding of practice at the time, from 1985 to 1990 on the interpolated method derived annually and from 1990 by annual interpretation and mapping of harvest intent.

- Method of harvesting for Karri forest (Figure 4) has been derived from interrogation of the FMIS database for date and method of harvesting, except for clearfelling, where the dates of regeneration and thinning were derived from CALM annual reports.

- Tenure and management intent data (Figure 5) were derived from interrogation of the FMIS database using current forest type data against tenure and management intent overlays applicable to the time. Data for 1970, 1982 and 1994 were the management intent approved under the Forest Management Plans of those dates. 1999 relates to the agreed outcomes of the Regional Forest Agreement (RFA, 1999).

Table 4. Products (dry tonnes) removed from private land for each 5-year period since 1945.

Period	Sawlogs Jarrah	Karri	Wandoo	Other hardwood[†]	Poles, posts, Hewn[††]	Charlogs[# ††]	Wandoo for distillation	Pulplogs[†††]	Firewood[††]
1945-49	625,600	112,800	53,800	64,300	37,100		158,800	–	N/A–
1950-54	1,147,000	96,800	122,500	46,300	48,800	16,800	224,300	–	N/A
1955-59	1,248,000	101,500	229,700	33,700	53,100	9,000	140,400	–	N/A
1960-64	975,300	85,700	199,100	15,300	43,100	–	74,500	–	N/A
1965-69	811,000	61,900	158,800	25,500	32,300	–	55,000	–	N/A
1970-74	368,000	75,500	90,700	17,700	9,900	–	71,600	–	N/A
1975-79	262,200	145,800	39,600	13,300	7,400	–	–	13,300	N/A
1980-84	224,700	106,900	36,400	25,400	9,300	–	–	180,700	N/A
1985-89	135,300	85,600	13,100	30,200	11,700			401,300	N/A
1990-94	35,700	34,300	3,900	27,900	5,300	7,600	–	354,500	N/A
1995-99	17,700	11,900	900	11,400	4,400	5,100	–	254,700	N/A

[#] for use in steel production to 1981 and for silicon metal from 1989.
[†] includes Tuart, Marri, Blackbutt, Red and Yellow Tingle, Sheoak and Banksia.
[††] mostly Jarrah.
[†††] Marri and Karri

The year 2001 is the intent that is indicated in the current draft Management Plan that has yet to be confirmed. 'Other crown land' refers to unvested crown land or land vested in other authorities such as shires or water management authorities. The reserves in 2001 include Commonwealth land (Bindoon Army training area) reserved under the RFA.

- The area of native forest cleared for pine plantations (Table 2) was derived from CALM's database of plantations, excluding those areas known to have been established on previously cleared private land. Adjustments have been made to estimate the date of the original clearing of plantations now in their second rotation.
- Areas of intensive silvicultural treatments of the 1920s and 1930s (Section 4) are from interrogation of the FMIS database. Source data is from 1:15,840 maps of treatment prepared at the time.
- Gap size data for early harvesting (Section 4) have been derived from an analysis of structure mapped from air photo interpretation in the 1950s and 1960s.

Removal of Forest Products

Log volume removals have been derived from Forests Department annual reports from 1945 to 1984 and Department of Conservation and Land Management annual reports from 1985. Since these data have been the basis for royalty payments, the information has a high degree of reliability for all major species and products and has been subject to regular audit.

The tonnage removed from crown land and private property by five year periods is shown in Tables 3 and 4 and summarised in Figures 6 to 10.

The following qualifications are relevant:

- Wandoo and Tuart sawlogs have been included with minor species at different times in the past. Wandoo and Tuart volumes have therefore been estimated within the total of minor species for 1945 to 1953 and Tuart has been estimated for 1963 to the mid-1970s.
- Produce from private property that was reserved to the crown (PPTR) is included in the crown land volume removals. This reservation condition ceased from the end of 1965.
- Firewood removals included here are confined to that acquired under license, or that produced by the Forests Department. It includes firewood for the Goldfields Water Supply pumping stations numbers 1 and 2 only.
- While firewood could include Jarrah, Karri, Tuart or Wandoo, firewood collected from the forest (as opposed to sawmill waste) is almost exclusively Jarrah.
- Charlogs for steel production were both Jarrah and Wandoo, but are not separated in the record. However, the majority of charlogs were Jarrah.
- Poles, posts and hewn bridge timbers could include Jarrah, Marri, Karri, Blackbutt or Wandoo. The majority was Jarrah and has been assumed to be such for this review.
- Pulpwood consists of Marri and Karri. The proportion of Marri derived from the Jarrah forest has been estimated.
- Removals from private land do not include that which has been used on-farm or sold as firewood.

In the source data, sawlogs and pulpwood are recorded as underbark volume, firewood as tonnes, distillation products as tonnes, posts as numbers and poles as linear measure. All data have been converted to air dry tonnes (12 per cent moisture content) using the following conversion factors:

Table 5. Summary of the approximate ratio of utilised volume to slash used in the data tables.

Silvicultural practice	Ratio
Jarrah selection harvest	1:0.8
Jarrah gaps and shelterwood with TSI	1:1
Jarrah thinning	1:0.5
Karri selection harvest	1:1
Karri clearfell – sawlog only	1:3
Karri clearfell – chipwood removed	1:0.7
Karri thinning	1:0.3
Wandoo	1:0.25
Tuart	1:0.8

- 1 m^3 = 0.82 t (Jarrah); 0.90 t (Karri); 1.1 t (Wandoo); 0.93 t (other hardwood); 0.87 t (pulpwood); pulpwood and other hardwood have been derived as a mean of the constituent species (Pearson *et. al.*, 1958).
- 1 t 'dry' charlogs (assumed to be Jarrah at 25 per cent moisture content) = 0.91 t.
- 1 t green Wandoo = 0.86 t.
- Posts assumed to be 0.072 m^3 each (100 per cent recovery) – used the Jarrah conversion factor to air-dry tonnes.
- Poles assumed to be 0.09 m^3 lm^{-1} (100 per cent recovery) - used the Jarrah conversion factor to air-dry tonnes.
- Hewn timber – assumed a 75 per cent recovery (the net figure is given in the Table) – used the Jarrah conversion factor to air-dry tonnes.

The annual report summaries indicate that sawn timber recovery from sawlogs to average 35 per cent to 1995, then 38 per cent. However this is an underestimate because several lower value sawn products are not included in the standard recovery figures that are reported.

The removal of different species is not confined to the forest type of the same name. However, there is a relatively small overlap and for the purposes of this review it is assumed that products are sourced from the type of the same name. 'Other hardwoods' have been included with Jarrah in the data tables.

The data for tonnage per hectare removed used in the data tables have been derived by the division of the tonnages indicated in Table 3 by the estimated areas cutover during the period in the strata. These areas are shown in Table 6 and have been derived as indicated in Section 11.3. Since these represent the mean t ha^{-1} for the whole strata they do not necessarily indicate the tonnage removed from a particular part of it or that the whole strata was harvested for a particular product (e.g. charlogs); nor does it indicate the range of tonnages that might be expected from different parts of the whole strata.

Estimates of basal area ha^{-1} removed during selection harvesting in the Jarrah forest for the period 1945 to 1985 have been derived from an examination of basal area by crop tree status and marketability classes from stratified random plots established by the Forests Department for the resource level inventory of the 1960s. Nine virgin and 13 previously harvested strata across the range of the Jarrah and Wandoo forest are represented by a total of 3458 plots. These data suggest that 20 per cent of the basal area would be removed on average from stands harvested from 1945-1970 and 40 per cent from stands harvested from 1970-1985. Because the removals were generally not based on distinct groups, and no follow-up culling was undertaken during this period, patches available for regeneration are very limited even in the more heavily harvested areas.

Estimates of Harvesting Slash

Estimates of slash quantities and burn efficiency used in the data tables have been derived from an interpretation of several data sources (Jones, 1978; Anon, 1980, 1985; Smith and Neal, 1993; Burrows, 1994; McCaw *et. al.*, 1997). These data were based on plots established in specific sites and types that do not necessarily represent the mean of any strata. The data have been used to derive a ratio of harvested volume to biomass removed (felled), and hence an estimate of slash volume associated with a known harvested volume.

Based on the data of Smith and Neal (1993) for Karri clearfelling with chip removal, and assuming a 40 per cent burn consumption (Jones, 1978), the ratio of harvested volume to biomass removed is approximately 1:1.66. This is based on the

Table 6. Area of forest cut over by forest type and time.

Strata	Type	Period	Estimated area cutover in period (ha)*
1	Jarrah	1945–70	680,000 **
2	Jarrah	1970–85	166,000
3	Jarrah	1985–99	210,000
4	Jarrah – dieback	1960–85	250,000
5	Jarrah – dieback	1985–99	30,000
6	Jarrah cleared and rehabilitated bauxite mining	1965–99	17,000
7	Jarrah cleared for pine plantations	1950–85	17,000
8	Karri	1945–65	31,000
9	Karri ***	1965–75	13,500
10	Karri ***	1975–99	57,000
11	Wandoo	1945–80	129,500
12	Wandoo	1980–99	6,700
13	Tuart	1945–79	4,700

** includes areas cutover more than once in the period

*** no distinction between clearfelling with seedtrees clearfelling for planting (all seedtrees removed within two years) assumption that the background slash (i.e. the volume of old logs on the ground from natural treefall in the past) is represented by the volume >600 mm in these data. The ratio of 1:1.66 is consistent with other wet forest (Snowden *et. al.*, 2000). A study that measured the slash generated by clearfelling for sawlogs followed by cull felling of the remainder (Jones, 1978) indicates a ratio of harvested volume to biomass of 1:4 when background slash is taken into account.

For Karri first thinnings, the ratio of harvested volume to biomass removed has been estimated at 1:1.3 (McCaw *et. al.*, 1997). The same ratio has been assumed to apply for subsequent thinnings. These data are consistent with gross bole (underbark) volume to biomass ratios of 1:1.22 and 1:1.36 for regrowth Karri and mixed Karri/Marri forest, respectively (Hingston *et. al.*, 1979).

The ratio of harvested volume to biomass removed for a southern Jarrah stand that had pulp removed (Marri only) and TSI[3] treatment was estimated to be 1:3 when adjusted for estimated 'background slash' (Anon, 1980). This is reasonably consistent with Snowden *et. al., (*2000), when it is considered that only one species in the mix has been pulped. The ratio has been adjusted to 1:2 for the whole Jarrah forest to account for the difference to be expected in northern and eastern forest. Without TSI, the ratio is estimated at 1:1.8.

Data derived from a thinning and complete TSI in the northern Jarrah forest (Stoneman, 1986) indicated a ratio of harvested volume to biomass removed of 1:3 with chipwood removal or 1:4 without. This trial involved a much more complete follow-up treatment than is normal practice and for that reason a ratio of 1:1.5 has been used for Jarrah thinning since most non-commercial follow-up thinning consists of herbicide treatment of standing trees which remain standing for a number of years and do not generate immediate slash.

Table 5 summarises the ratios used in the tables to estimate slash generated by harvesting. They do not include understorey slash.

'Background slash' (including stump mass in harvested areas) has not been included in the data sheets but it could be expected to be in the order of 180 t ha^{-1} for Karri, 35-80 t ha^{-1} for Jarrah and 10 t ha^{-1} for Wandoo (Jones, 1978; Anon, 1985; Smith and Neal, 1993; Burrows, 1994).

Burn efficiency estimates in the data tables have been interpolated from two studies in mature Karri and Jarrah and one in Karri regrowth (Jones, 1978; Anon, 1980?; McCaw *et. al.*, 1997).

Understorey and litter biomass have not been included in these tables because their condition at the time of harvesting is dependent on the time since its last burn. However, the maximum accumulation of understorey and litter biomass could be expected to be about 70 t ha^{-1} for Karri, 10-20 t ha^{-1} for Jarrah and 8-14 t ha^{-1} for Wandoo (Anon, 1985; Burrows, 1994), though periodic fire typically maintains it at about half to one third of that level (McCaw *et. al.*, 2002).

Estimates of Growth

Estimates of growth rates of even-aged Karri stands have been based on growth model data (KARSIM) for average quality stands (Rayner, 1992a). Estimates of growth rates for even-aged Jarrah stands are based on the yields from an unpublished model used by CALM for yield projections with adjustment made for lower quality stands.

Rotation lengths are based on those used for the current Management Plan (Turner *et. al.*, 1989) except for selection cut stands. The period to which MAI is applied in uneven-aged stands in the data tables is based on the estimated time after harvest for the stand to again become fully stocked (i.e. the product of the MAI and the 'nominal rotation' is equal to the gross bole volume removed in the previous harvest).

[3] Timber stand improvement. Includes non-commercial thinning or the culling of unwanted trees to promote regeneration.

Estimates of the growth of uneven-aged stands have been interpolated from published (Abbott and Loneragan, 1983a; CALM, 1992b) and unpublished growth data and models. There are more than 500 permanent growth plots in uneven-aged Jarrah or Jarrah/Marri forest but a detailed analysis of these data was not possible within the scope of this review.

There are no reliable broad-based estimates of growth for Wandoo and Tuart and these have therefore been estimated from limited and not necessarily representative data. However, they do not represent significant volumes.

No estimates have been made of the growth rate on private forest.

Representative Sites

The records of disturbance by harvesting that are maintained by the Department of Conservation and Land Management since 1970 are generally of a high quality and are more detailed after 1990. However, this information is not considered adequate for the purposes of training remote sensing imagery without qualification. The reason for that is:

- There is wide variation in the intensity of the final outcome of harvesting within the same prescription,
- There is similarity between the appearance of different forest conditions and their long term management (e.g. between selective cutting, shelterwood and thinning; between clearfelling and clearing for bauxite mining).

For this reason the nomination of a limited number of sites would be misleading and therefore, has not been included in this review. A more systematic and comprehensive analysis is required for a reliable interpretation.

SECTION 6

Queensland

Ross Florence

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

QUEENSLAND

This Report contributes to a national and comprehensive effort to model change in carbon stocks in Australian forests. It does so by:

- Describing changes in forest management practices in Queensland, 1945 to 2000, which are likely to have had significant impacts on carbon stocks in the forest estate;
- Analysing these changes in relation to a stratification of forests involving important forest types, management practices and time periods;
- Providing data tables which summarise, by forest types and time periods, information on management practices and their impacts on forests and carbon stocks; and
- Discussing trends in forest practice since World War II that have affected wood removals, carbon pools in biomass and harvest residues, and post-harvest forest growth.

SUMMARY

The current commercial native forest estate is limited to the eucalypt (hardwood) forests within the south-east region of the State, and the Cypress Pine forests of south-west Queensland. The North Queensland rainforests, and the southern *Araucaria*-dominated rainforests contributed substantially to wood supply in the past, but are now withdrawn from wood production.

Silvicultural practice in the North Queensland rainforests, and in the hardwood and Cypress Pine forests, has been based on rigidly applied single tree selection harvesting prescriptions, with follow-up ringbarking treatment or reject (cull) tree felling. As in New South Wales (NSW), selection practice recognised a serious log supply deficit, and the need to conserve, at any one harvest, growing stock for future continuing harvest.

A very limited program of enrichment planting designed to maintain the productivity of cutover wet sclerophyll forest was begun in the late 1960s, but discontinued 20 years later. Mild post-harvest burning has been carried out, mainly to reduce slash levels.

The current limited sawlog harvest and low levels of commercial wood increment are a consequence of the relatively light selection harvesting applied to the hardwood forests, the accumulation of poorly formed or weak-crowned growing stock with little or no sawlog potential (the inevitable consequence of light selection logging), the failure to adequately regenerate wet sclerophyll forest, and the general withdrawal of post-harvest silvicultural treatment after 1980. The Cypress Pine forests remain in a productive condition, though there has been a decline in the diameter of trees available for harvest.

Information on harvest yields and forest growth (by forest types and time periods) was derived largely from discussions with Queensland foresters. While information on merchantable stand increment is reliable, data for total biomass production in variable uneven-aged forest is lacking.

The future role of public hardwood forests in wood production remains uncertain. The Government has placed high priority on nature conservation and plans to phase out wood production within two decades. Private native forests continue to make an effective contribution to wood supply, though, again their future role is uncertain.

The cumulative effect of past management has been a decline in carbon stocks and low rates of carbon accession. There is an opportunity to restore carbon stocks, and to achieve other associated social and environmental benefits, consistent with public commitment to the principles of ecologically sustainable forest management.

1. INTRODUCTION

Native forests of current commercial significance are located in the south-east (predominantly eucalypt forest), and in the south-west of the State (the Cypress Pine forests). The Tropical Rainforests of coastal North Queensland, and the *Araucaria*-dominated Subtropical Rainforests of southern Queensland, were a significant commercial wood resource until logging was withdrawn in the 1980s.

The eucalypt (hardwood) and Cypress Pine (*Callitris glaucophylla*) forests do not differ greatly from those of the Coastal Regrowth and Cypress Pine zones of New South Wales (Florence, 2007). However, Queensland does not have the equivalent of the Mountain, Tablelands, Silvertop-Stringybark, Alpine Ash and River Red Gum forests of NSW. There is a much more limited range of hardwood forest types in Queensland.

Queensland's forest resource management strategies have not differed fundamentally from those applying in NSW. Management has been based predominantly on harvesting prescriptions which can be placed under the broad single tree selection umbrella. These prescriptions recognised the historic wood supply deficits in Queensland, and were designed, at any one harvest, to retain growing stock for continuing harvest. Apart from some areas of 'moist' even-aged forest (mostly traceable in origin to fire events), both the eucalypt and Cypress Pine forests of southern Queensland are generally uneven-aged.

This Report is in two Parts: the main report presents an account of the Queensland forests and their management history, and an Appendix describes a set of supporting data tables and assumptions made in deriving them.

2. QUEENSLAND FORESTS

2.1 THE FOREST RESOURCE

Over 60 per cent of Queensland's land surface is covered by forest or woodland. However, a substantial proportion of this (woodland forest types) has no value for wood production, occurring in more remote and drier northern and western regions of the State. The bulk of the commercial forest, apart from Cypress Pine and some dry sclerophyll types, is confined to that part of the coastal belt receiving in excess of 750 mm of rain per annum.

Queensland has 11,786,000 ha of land classified as forest (excluding woodland). This can be placed in six broad categories as follows (Queensland Government, 1990):

Rainforest:	1,237,000 ha
Eucalypt forest Productivity Class 1:	205,000 ha
Eucalypt forest Productivity Class 2:	1,290,000 ha
Eucalypt forest Productivity Class 3:	3,290,000 ha
Tropical eucalypt/paperbark:	4,078,000 ha
Cypress Pine:	1,686,000 ha

The geographic distribution of forest regions is shown in Figure 1. Table 1 lists the area of each forest type within regions.

Productive native forest in 1990 covered a total of 7.7 million ha (that is, excluding the Tropical Eucalypt/Paperbark Type), of which 6.5 million ha were in public ownership. In terms of land tenure, public forests were distributed as follows during the study period:

1. 3.1 million ha of State Forest, 2 million ha of which were being managed for long term sustained wood production;
2. 2.7 million ha of Crown leasehold lands (available for logging, but not necessarily managed for sustained timber production); and

3. 0.71 million ha were in National Parks and other nature reserves.

The bulk of the rainforest is in North Queensland (856,000 ha), with other major occurrences in the Mackay region (183,000 ha), and 150,000 ha in the south-east of the State.

Queensland has a relatively small area of high quality (Productivity Class 1) eucalypt forest, (205,000 ha or 4 per cent of the total eucalypt forest). The bulk of this is in the south-east part of the State. There are other limited occurrences in North Queensland/Mackay (17,000 ha) and the Central Coast district (21,000 ha).

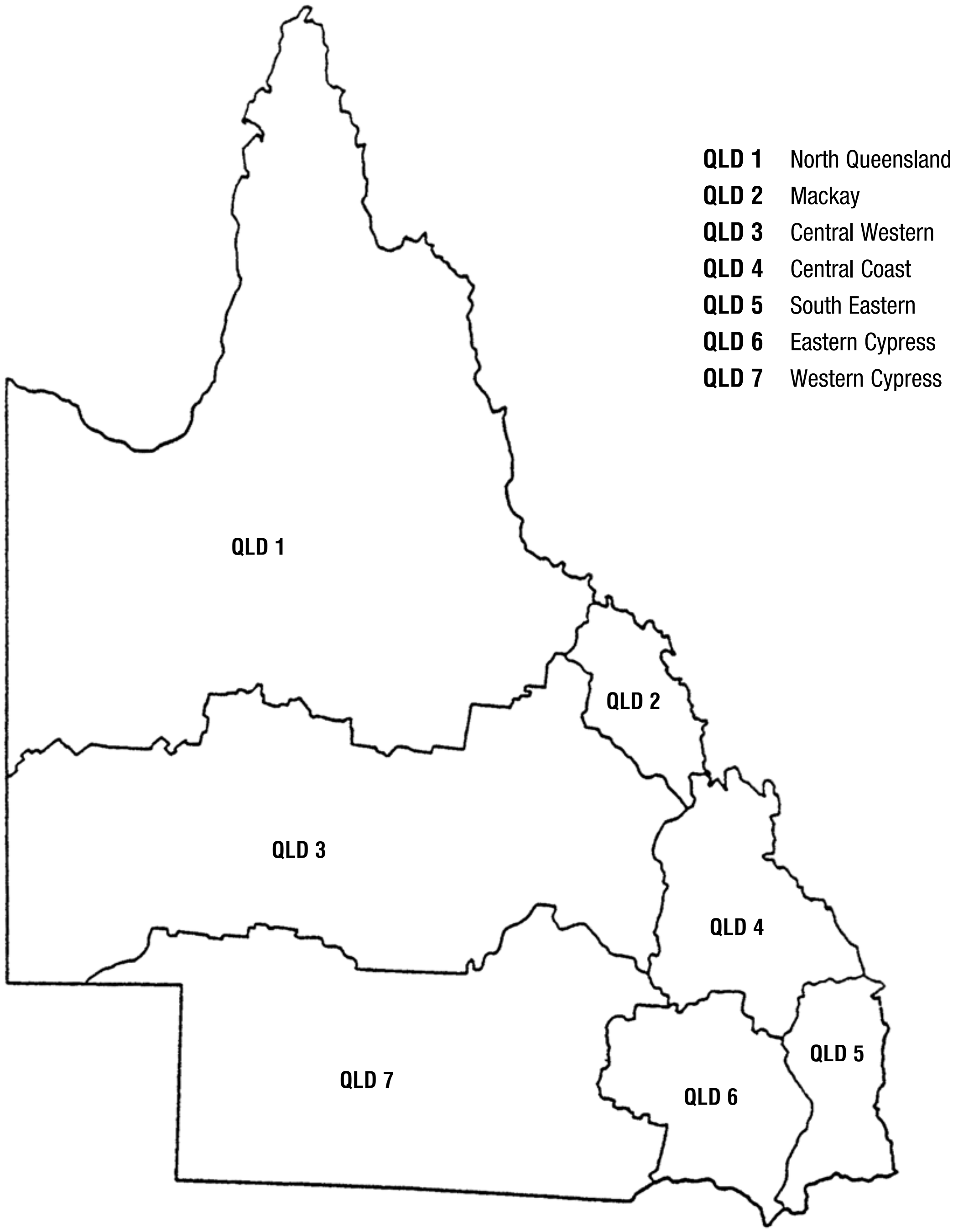

Figure 1. Forestry regions within Queensland (Queensland Government, 1990).

In contrast, there are 3.29 million ha of low quality (Productivity Class 3) eucalypt forest. This is widely distributed through most parts of the State, and represents 68 per cent of the total eucalypt forest resource. Most of the 1.2 million ha of Productivity Class 2 eucalypt forest is in the South East and the Central Coast Regions (Figure 1). These data indicate clearly the limitations of the eucalypt forest as a wood production resource in Queensland.

There are 1.6 million ha of Cypress Pine forest, 0.77 million ha within the 'Eastern Cypress' Region, and 0.86 million ha within the 'Western Cypress' Region. This is an important distinction because the Western Cypress remains largely unexploited for wood production.

2.2 ATTRIBUTES OF THE FOREST COMMUNITIES

The attributes of the main commercial and non-commercial forests are as follows:

The North Queensland Rainforest

Rainforests occur in a discontinuous belt along the coastal strip from the south Queensland border to north of the Atherton Tableland. The most extensive areas occur in North Queensland where the forests contain a wide range of cabinet woods – some of the more important species to the timber industry having included *Flindersia brayleyana* (Queensland maple), *Flindersia pubescens* (Queensland Silver Ash), *Cardwellia sublimis* (Northern Silky Oak), *Endiandra palmerstonii* (Queensland Walnut) and *Toona ciliata* (Red Cedar). An area of about 160,000 ha was managed for wood production under a selection system prior to its listing as a World Heritage area.

The Araucarian and Other Rainforests of Southern Queensland

The subtropical rainforests of southern Queensland are dominated by *Araucaria cunninghamii* (Hoop Pine), and to a lesser extent *Araucaria bidwillii* (Bunya Pine). The 'Hoop Pine scrubs' were widespread throughout the southern region. Other south Queensland rainforests include the Cool Temperate type dominated by *Nothofagus moorei* (Antarctic Beech) on the Main Dividing Range and McPherson Range; 'gully rainforest' types extending coastward on sands in the vicinity of Fraser Island; and lowland rainforest types on sandy substrates in Cooloola National Park and elsewhere.

The softwood sawmilling industry was established in Queensland in the late 19th century based on harvest of the high quality natural stands of *A. cunninghamii*, *A. bidwillii* and *Agathis robusta*

Table 1. The Queensland forest estate (ha), by forest type and region (Queensland Government, 1990).

Forest Species Groups	Forest Region North Queensland	Mackay	Central Western	Central Coast	South East Queensland	Eastern Cypress	Western Cypress	Total
Rainforest	856,000	183,000	–	48,000	150,000	–	–	1,237,000
Euc. Prod. 1	15,000	2,000	–	21,000	167,000	–	–	205,000
Euc. Prod. 2	42,000	6,000	90,000	720,000	292,000	100,000	40,000	1,290,000
Euc. Prod. 3	555,000	338,000	431,000	978,000	600,000	338,000	50,000	3,290,000
Tropical Eucalypts/ Paperbark	4,078,000	–	–	–	–	–	–	4,078,000
Cypress Pine	–	–	1,000	50,000	5,000	770,000	860,000	1,686,000
Totals	**5,546,000**	**529,000**	**522,000**	**1,817,000**	**1,214,000**	**1,208,000**	**950,000**	**11,786,000**

(Kauri Pine). These forests yielded a high proportion of large-sized, defect free timber suitable for plywood, joinery and building materials. Prior to World War II this industry provided the whole of the State's softwood requirements for a period of more than 30 years. At one stage, Queensland supplied over 70 per cent of Australia's plywood and veneer market. However, this was not sustainably harvested and, coupled with the clearing of rainforest areas for cropping and dairying, the annual harvest of *A. cunninghamii*, *A. bidwillii* and *Agathis robusta* declined, ceasing altogether by the end of the 1980s.

In anticipation of the eventual depletion of the native softwood resource, the Queensland Forest Service initiated plantation trials as early as the 1880s. Small experimental plantings of *A. cunninghamii* and *A. bidwillii* were established in 1911, and the first commercial plantations were developed in 1920-21 in the Mary Valley of southern Queensland, and on the Atherton Tableland in North Queensland. Since 1920, plantation establishment has been a cornerstone of timber resource policy in the State.

Initial plantation management was greatly influenced by the early sawmilling activity based on supplies of high quality native softwoods. The high premium then paid for increasing size and log quality influenced plantation silviculture, with the principal aim being to produce high quality wood in the shortest rotation with minimum sacrifice in volume production.

The Hardwood Forests

Commercial eucalypt forests are located primarily within South Eastern and Central Regions shown in Figure 1. The area is divided into 14 Allocation zones (Fig. 2) which provide the bulk of the hardwood timbers harvested within the State (DPI Forestry, 1998).

Queensland hardwood forests may be classified in a number of ways: as 'Tall Open' and 'Open' forests, or as 'Wet', 'Moist' and 'Dry' forests. A description of these categories follows.

Tall Open forest: These high quality tall eucalypt forests grow in higher rainfall areas along the coastal plain and off-shore islands north to Fraser Island, and on coastal/sub-coastal ranges. Elsewhere there are very scattered occurrences along coastal ranges north to Gladstone, and as outliers on isolated tablelands (e.g. Blackdown Tableland). In north-central and northern Queensland, Tall Open forest forms a narrow band along the drier western fringe of the rainforest massifs of Eungalla, Atherton Tableland and Windsor Tableland.

Open forest: Open forests are widely distributed in eastern districts south of the Tropic of Capricorn, extending into inland areas on siliceous soils in hilly country and steep residual soils on plateau crests. In dry coastal corridors north of the Tropic, Open eucalypt forest is restricted to the coastal ranges. The sclerophyll communities of low altitudes may exhibit a Tall Woodland rather than an Open forest structure.

While the Department of Primary Industries-Forestry (DPI-Forestry, 1998) recognises the vegetational complexity of the eucalypt forests, it has been convenient simply to divide the commercial eucalypt forests into three broad classes: 'wet', 'moist' and 'dry', distinguished by the presence of particular species associations and certain structural features. An account of these classes as they relate to south-east Queensland follows.

'Wet' and 'Moist' forest generally occur on the better soils of the coastal strip. Important timber producing species include *E. pilularis* (Blackbutt), *E. grandis* (Rose Gum or Flooded Gum), *E. saligna* (Sydney Blue Gum), *E. microcorys* (Tallowwood), *E. propinqua* (Grey Gum), *E. drepanophylla* (Grey Ironbark), *E. acmenoides*

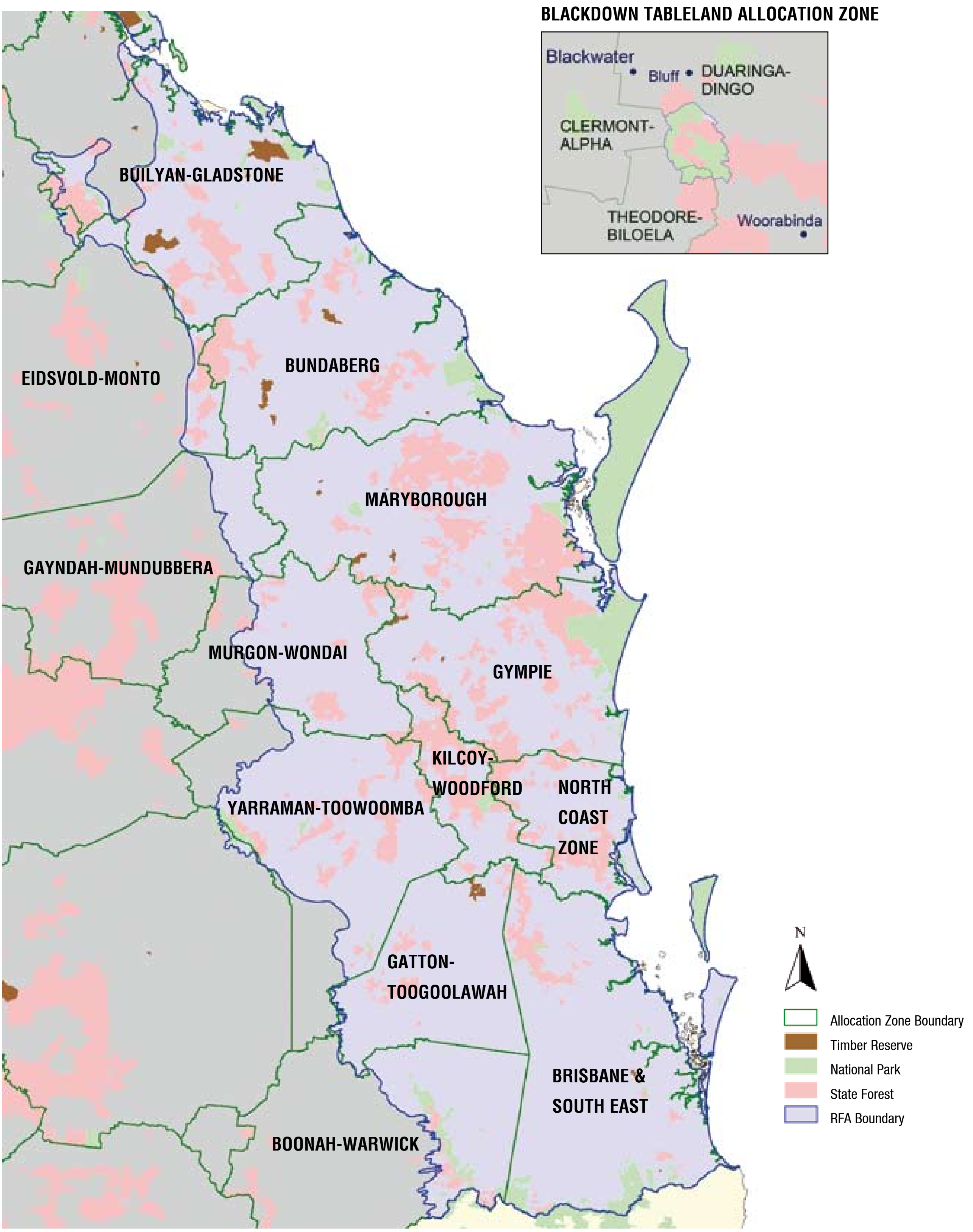

Figure 2. The south-east region of Queensland showing 14 forest Allocation Zones. This area represents the South Eastern and Central Coast Regions of Figure 1, and supplies the bulk of eucalypt timbers harvested in Queensland.

(White Mahogany), *E. cloeziana* (Gympie Messmate), *E. resinifera* (Red Mahogany), *Corymbia intermedia* (Pink Bloodwood), *Syncarpia glomulifera* (Turpentine) and *Lophostemon confertus* (Brush Box). The understorey can be characterised as a gradient from 'grassy with sclerophyll shrubs', to that with a well developed rainforest stratum.

'Dry' forest types cover a very broad geographic range. As well as the vast low rainfall areas of south-east Queensland, 'dry' types may also be found in complex association with 'moist' forest, especially where average rainfall exceeds 1000 mm. The most important species of the drier forests are *Corymbia variegata* (Spotted Gum), *C. citriodora* (Lemon Scented Gum), *E. drepanophylla* (Grey Ironbark), *E. crebra* (Narrow-leaved Red Ironbark), *E. fibrosa* (Broad-leaved Red Ironbark), *E. tereticornis* (Forest Red Gum), *E. acmenoides* and others. Understorey is typically grassy with sclerophyll shrubs.

Some of the dry forest eucalypts also occur in association with Cypress Pine (*Callitris glaucophylla*).

The eucalypt forests are also classified in terms of productivity classes:

Productivity Class 1 eucalypt forests are Tall Open forests which occur on the better soils and moister slopes of the coastal strip. The species are those listed under 'Moist' and 'Wet' forest.

Productivity Class II and III forests are Open forests, generally with a grassy, shrubby or layered understorey, which occur in drier situations or on less fertile soils. These forest occur in both coastal and inland regions – with *C. variegata* and the Ironbarks (*E. drepanophylla*, *E. fibrosa*, *E. crebra*) forming the major commercial communities.

Cypress Pine Forests

Cypress Pine forests are widely distributed through the drier inland areas of both NSW and southern Queensland. Their distribution is shown in Figure 4 in the NSW Report (Florence, 2007), that is, largely west of the 700 mm isohyet.

The Queensland Cypress Pine forests have been divided into two regions (Figure 1): the Eastern Cypress and Western Cypress Regions. The importance of this will be discussed later.

C. glaucophylla occurs as either pure stands or in mixture with *C. variegata* and *E. crebra*. The Cypress Pine forest has traditionally supported a sawmilling industry which fulfils the dual roles of providing general purpose sawn timber products and much needed rural employment (Johnson and Jennings, 1991).

Non-commercial Hardwood Forests

Non-commercial forests are dominated by species which are unsuited for sawlog production such as the Bloodwoods, (e.g. *C. intermedia* and *E. signata* -Scribbly Gum). Sometimes commercial species exist, but harsh environments such as hill slopes with shallow soils, swampy soils severely limit stand development, rendering the forest non-commercial.

3. PROBLEMS ARISING FROM LONG-TERM SHORTAGE IN WOOD SUPPLY

3.1 EARLY OPERATIONS AND THEIR IMPACTS

The impacts of early logging on Queensland's hardwood forests are similar to those in New South Wales, and it is useful to refer to the NSW Report (Florence, 2007). In summary, the following activities occurred:

- Logging of hardwood forests was highly selective, that is, removing only large, straight and relatively defect-free boles.
- Initially, species with stronger and more durable woods were the preferred species for harvest. Species such as *E. microcorys*, *E. drepanophylla*, *E. acmenoides* and *E. propinqua* could meet the demand for sleepers, poles, piles, girders and heavy construction timber, and *C. variegata* had special value in ship building.

- Highly selective cutting was just one of the factors which degraded the forests. Following settlement, forest fires increased in intensity and frequency, causing great damage to the forest growing stock.
- Early harvesting and sawmilling industries accepted only high quality boles. Thus silvicultural treatment to remove non-commercial trees, and to conserve and release advance growth, was a vital component of early forest management.
- Logging and ringbarking programmes were applied to increase productivity, but they could not fully offset the problem caused by substandard growing stock. There remained in most forests a component of old-growth trees, trees with marginal sawlog potential, and in some forests, a 'growth-restricted' stratum of tolerant species.
- Where logging and ringbarking approached clearfelling in intensity, a planned fire or wildfire prompted the creation of near-fully stocked even-aged regrowth stands. Examples include the even-aged *E. pilularis* regrowth forests on Fraser Island originating from planned fire during the 1930s (Florence, 1964), and the regrowth *E. pilularis* forest on the Blackall Range after wildfire in 1923.

In summary, by the time World War II intervened, good progress had been made in bringing the more accessible and often substantially degraded forest under improved management. The war placed great pressures on forest resources, many forests were over-cut and management prescriptions virtually ignored. Thus the resource was not sufficiently productive to service the expanding timber demand associated with post-war development.

3.2 IMPENDING SAWLOG SUPPLY DEFICIT AFTER WORLD WAR II

During the 1950s Queensland recognised an impending wood supply deficit, and saw its ultimate resolution in an expansion of a plantation softwood program based on native *Araucaria* species and exotic pines. The following is from the 1957/58 Annual Report of the Queensland Forestry Department:

> *On a basis of sustained yield management, little increase in the annual cut from native Crown lands can be expected in the near future. It is therefore a very real problem in maintaining existing production, quite apart from making provision for increasing future demand.*
>
> *It is essential therefore that reforestation work – both plantations and silvicultural treatment of our natural forests – be continued and expanded if the Department is to properly fulfil its function of assuring timber supplies to Queensland.*

In the 1950s Queensland did not have (in contrast with the situation in NSW), a large and relatively untapped mountain and tableland resource to draw upon. Hence it was deemed necessary to maintain an essentially conservative approach to native forest management in order to sustain sawlog supply from existing growing stock, and to place priority to investment in the softwood planting program.

4. MANAGEMENT PRACTICES 1945 TO 2000

The reasons for the continued application of selection harvesting methods are similar to those applying to New South Wales (Florence, 2007). Broadacre clearfelling may have been ecologically inappropriate in forests of low productivity, or those having a considerable complexity of species and community patterns (Florence, 1996). Moreover, the limited sawlog resource and impending resource deficit made it inappropriate to remove growing stock which would make future sawlogs.

This philosophy is expressed in the rather rigid selection prescriptions applied to rainforests, eucalypt forests and Cypress Pine forests.

4.1 MANAGEMENT PRACTICE IN QUEENSLAND RAINFORESTS

Emphasis was mostly on commercial wood production.

The *Araucaria* component of south Queensland rainforest was progressively exploited over time and these forests are no longer harvested. Given that seedling and sapling *Araucaria* are usually present on the forest floor, these forests should recover in the long term.

In comparison, the North Queensland rainforests were seen as a sustainable resource. Their management was based on tree-marking to achieve full utilisation of the merchantable timber consistent with the aim of maintaining a stock of actively growing trees of the best species at reasonable spacing. Where this growing stock was inadequate, seed trees of the most desirable species available were retained.

The silvicultural guidelines established an order of priority for retention of species as part of the ongoing growing stock. The more valuable species (Group A) included *Endiandra palmerstonii* (Black or Queensland walnut), *Flindersia brayleyana*, *Toona ciliata*, *Agathis palmerstonii* (Kauri Pine), *Cardwellia sublimis*, *Endiandra pubescens*, *Flindersia ifflaiana* (Hickory Ash), and *Flindersia acuminata* (Silver Silkwood). There were three other groups (B,C,D) in order of priority, each with an increasing numbers of species.

Different cutting limits (based on stem girth) applied to species in these groups. For example, a very vigorous and well-formed *E. palmerstonii* would be retained until it was 120 inches in girth (approx. 95 cm DBHOB). Other Group A species would be retained to approximately 80 cm DBHOB, Group B species to 70 cm DBHOB, and Group C and D species to 60 cm. Thus a concerted effort was made to conserve the higher value trees of the forest, and to retain all possible trees below 60 cm DBHOB as the prospective crop.

Other tree-marking rules related to the size and spacing of seed trees, thinning on a merchantable basis of trees smaller than the cutting limit (unequivocally favouring retention of the more valuable species), and salvage cutting of damaged trees.

Post-harvest silvicultural treatment was designed to remove non-commercial trees and species, and to provide reasonable space to the most desirable stems. Minimum size limits were set to prevent removal of useful trees. Where an area was inadequately stocked with regeneration, the treatment rules provided for brushing and raking around seed trees of the valuable species.

Given the very large number of species, the silvicultural guidelines were complex, requiring operators with a well-developed understanding of the forests and the component species. However, as resource availability declined, and a second harvest began (that is, reharvest of areas logged some 20 to 30 years previously), amendments to the logging prescriptions were necessary to maintain supply to the sawmill industry. Under the 1987 ‘recut rules’ cutting limits could be reduced to 50 cm DBHOB, and defective logs salvaged at a diameter of 40 cm, where 20 m^3 ha^{-1} of wood could not be obtained under the standard prescription for virgin forest.

4.2 MANAGEMENT PRACTICE IN THE HARDWOOD FORESTS BETWEEN 1945 TO 1968

Management practice within the hardwood forests has, since the 1930s, been based on selection-type silviculture embodied in prescriptions for both harvesting and silvicultural treatment.

In the early decades of forest management it was necessary to sustain local industry and the flow of sawnwood to the market for as long as possible. Until the late 1960s this objective was pursued simply by imposing a diameter (or girth) limit in logging, that is, all trees of commercial quality above a specified diameter were harvested. Prescriptions required as complete a stocking as possible be retained in size classes above 40 cm DBHOB (the immediate prospective future crop), irrespective of quality. Trees in this size range could be harvested only where permitted by tree spacing rules. This applied to the harvest of poles, piles and girders.

Post-harvest silvicultural treatment continued this theme. Indeed, no tree between 40 and 60 cm DBHOB could be removed which was 'capable of making a minimum length of 2.7 m of log except where it is obvious that the tree will die in 5 years' (from Department of Forestry treatment prescriptions). The treatment involved ringbarking of non-commercial old-growth trees, making sure that patches of advance growth had room to grow; coppicing of poorly developed advance growth; and thinning within regrowth patches.

The use of a diameter-limit cutting regime in conjunction with a silvicultural improvement treatment might be seen as a logical first step in managing the eucalypt forests. Any more sophisticated practice than this was generally impossible, given the objectives of management, limited knowledge of the complex ecology of eucalypt forests, and the lack of technically trained personnel.

Despite their conservative thrust, the harvesting and treatment prescriptions could have a highly variable effect on forest condition. For example, where applied to virgin or highgraded forest with a relatively simple structure, the operation could approach 'clearfelling with seed trees' in intensity. Where a substantial amount of regrowth developed (sometimes in response to controlled fire or wildfire), there may now be a good resource of sawlogs and other products. This result has been most apparent in higher quality *E. pilularis* forest, examples including the forests on Fraser Island and the Blackall Range (Mapleton State Forest).

The effects of the diameter-limit harvest and silvicultural treatment prescriptions have been much less satisfactory where the forest had a more complex structure, for example, an upper canopy of large-boled trees and a secondary stratum of more light tolerant species – often in a stagnant condition. Florence (1970) describes the impact of these regimes on old-growth *E. pilularis* forest with a large component of *Syncarpia glomulifera* and *Lophostemon confertus*. Most of the large eucalypts were harvested or ringbarked, and most of the *Syncarpia* and *Lophostemon* retained, despite their weak crowns and the likelihood they would fail to respond to release.

The silvicultural practice was also unsatisfactory in the typical *Corymbia variegata* forest (Central Coast Region), where the larger and often more productive trees were harvested, and persistent intermediate and suppressed components of the forest retained (Florence *et. al.*, 1970). Given the crown-shy nature of the species, these latter trees often had weak, imbalanced crowns and rather crooked boles. Lignotuberous advance growth might respond to the logging, but given the level of competition, could, in turn, develop towards suppression.

4.3 MANAGEMENT PRACTICES IN THE HARDWOOD FORESTS FROM THE LATE 1960S

By the mid-1960s it was clear that a change in the basis of tree selection was needed – from one based on tree diameter to one based on tree quality. This would provide the opportunity to harvest substandard or slow-growing trees which had reached minimum usable size, but would still take a long time to reach the standard cutting diameter.

A logging and silvicultural treatment prescription along these lines was tested under a range of stand conditions in the *C. variegata* forests of the Maryborough district. This made provision for the retention of trees, irrespective of size, meeting specified standards for bole and crown quality; the harvest of substandard trees through the full range of commercial sizes; minimum spacing for retained trees of commercial size; and prescribed standards for post-logging silvicultural treatment (Florence *et. al.*, 1970). The Queensland Department of Forestry adopted harvesting and treatment schedules along these lines, which have formed the basis of native forest silviculture since 1968.

It is also appropriate here to describe the practice of enrichment planting which began about this time, the use of managed fire in the forests, and a limited (but discontinued) eucalypt planting program.

Selection Management Principles and Prescriptions

Selection management since 1968 has been designed to periodically remove the accumulated growth 'capital' of the forest while retaining a forest structure which is consistent with sustaining the yield of sawlogs. This is done by managing species composition to improve growth and sawlog quality; encouraging growth on favoured trees by removing competing, poorly formed or slower growing trees; encouraging regeneration, and by complying with defined environmental guidelines.

Silvicultural practice in Queensland native forests is based on prescriptions specific to a number of broad forest types (DPI-Forestry, 1998). These types are:

Wet sclerophyll forest: tall eucalypts and/or Brush Box and/or Turpentine forest with a well developed rainforest understorey

Dry sclerophyll forest: Open eucalypt forest with an understorey of grasses, and a normally sparse understorey of woody sclerophyll species.

Blackbutt forest: forest where more than 50 per cent of the stems greater than 20 cm DBHOB are *E. pilularis*. Blackbutt stands occur as both wet and dry sclerophyll forest.

Tree-marking Prescriptions

All tree marking prescriptions call for:

1. The retention of seed trees of preferred species where there are insufficient lignotubers or advance growth, or when enrichment planting will not be carried out;
2. Priority to be given the retention of preferred species, or heavier than normal logging where the stand is composed almost entirely of species which are unacceptable for retention. This applies mainly to wet sclerophyll forest where enrichment planting will be carried out;
3. The removal of trees of marginal quality and retention of trees in all size classes which are capable of vigorous growth following logging;
4. The automatic harvest of all trees above a prescribed diameter (e.g. 90 cm DBHOB), and retention of acceptable stems at a prescribed spacing, which varies with tree size. The characteristics of an 'acceptable stem' (again varying with tree size) are defined in terms of bole and crown conditions; and
5. A common-sense interpretation of the various guidelines (although the principles and philosophies behind the guidelines must be observed at all times).

Within this framework, the guidelines applied to specific forest types vary in a number of ways, for example, with respect to the attributes of seed trees, the upper diameter limit for tree retention, bole quality standards for retention, and tree spacing within size classes. Tree-marking guidelines can also be varied in accordance with past logging history, the stand's stage of development, the presence of adequate advance growth, and the planned application of post-logging enrichment planting.

Enrichment Planting

A review of enrichment planting in south-east Queensland forests is drawn from the document prepared by the Queensland CRA/RFA Steering Committee (1997).

Enrichment planting has been carried out where natural regeneration was unlikely to develop in wet sclerophyll forest. Areas proposed for enrichment planting were demarcated on a map, though it would sometimes become apparent that an area should be enrichment planted only after logging had commenced. This would apply, for example, where virtually all trees were being removed because of a high level of wood defect. In any case, where enrichment planting was intended, tree-marking rules could be amended to allow heavier than normal removals, and to provide a higher standard of tree retention. In general, enrichment planting was confined to small (less than 10 ha) non-contiguous cutting units.

In the 1970s and 1980s when enrichment planting was at its peak, only around 80 to 100 ha yr^{-1} were being treated in this way. It was usually confined to sites with high timber production potential (wet and moist sclerophyll forest), where the forest was largely dependent on regeneration by seedlings rather than lignotubers. Planting was required where natural germination and seedling survival were limited by a dense understorey, usually of rainforest species, but sometimes by other species, notably lantana.

The most substantial enrichment planting program was in the Conondale Range in the 1980s, an area carrying a range of eucalypt forest communities (wet sclerophyll and dry sclerophyll forest) and subtropical rainforest (Queensland Department of Forestry, undated). Rainforest was not to be logged or disturbed by logging except for narrow strips less than 40 m wide adjacent to hardwood stands. Selection logging was to apply in all eucalypt forest, though it was recognised that in overmature wet sclerophyll forest carrying *E. grandis*, *E. saligna*, *E. microcorys* and *L. confertus*, the effect of the selection prescriptions would be to remove most of the trees. Such operations were subject to guidelines aimed at minimising visual impact and maintaining the integrity of the rainforest areas. Post-harvest top-disposal burning was carried out at mild to moderate intensity (below a prescribed Drought Index), and the area enriched with 200 to 300 seedlings ha^{-1} of *E. microcorys*, *E. cloeziana*, *E. grandis*, and *E. saligna*.

The small-scale nature of enrichment planting resulted in relatively high nursery and establishment costs. Survival rates were often low. Only *E. pilularis*, *E. cloeziana* and *E. microcorys* provided consistently good survival and growth on a range of sites. Therefore, while the practice had the potential to re-establish productive forest where natural regeneration was deficient, the practice was not considered economically viable. The practice has not been used in the State since the late 1980s.

The Use of Fire in Native Forest Management

Until the late 1950s, forest service policy was to totally exclude fire from the forests. This policy was impossible to implement effectively and extensive areas of forest were damaged in the periodic, although infrequent, severe fire seasons. The practice of regular fuel reduction burning (prescribed burning) was introduced in 1959 and gradually widely adopted as the most effective and efficient means of reducing wildfire damage.

Forest policy in Queensland recognises the potential for adverse environmental effects if fuel reduction burning is too frequent. Hence a fire-free period of around seven to ten years is recommended. Current trends are to a reduction in the use of prescribed burning in native forest management, generally in response to increasing economic, environmental and social constraints (Queensland CRA/RFA Steering Committee, 1997). Summaries of fire research in south-east Queensland have indicated that changes in plant species richness, plant growth, vegetation structure and fuel types may occur as a result of prescribed (fuel reduction) burning procedures (House, 1995).

Fire is also used to stimulate regeneration in both dry and wet sclerophyll forests, principally by top disposal burning (burning of the felled heads of trees) following harvesting. This is carried out at as low an intensity as possible (based on Queensland discussions).

4.4 HARDWOOD PLANTATIONS

The Department of Forestry began establishing eucalypt plantations in the 1930s and has about 1,800 ha, of which 1,100 ha are located in the south-east part of the State. The plantations are predominantly *E. grandis*, *E. pilularis* and *E. cloeziana* and were generally established on degraded farmland that had been incorporated in State forest. The land was cleared of regrowth, rotary-hoed and planted at stockings of 1,000 to 1,500 stems per ha.

Plantation eucalypts were frequently attacked by psyllids (particularly lerps), greatly reducing growth. Wood borers caused severe damage in *E. grandis*, greatly reducing the commercial value of the timber. This species is particularly susceptible to borer attack when planted 'off-site'.

Eucalypt plantation establishment was abandoned in the mid-1960s, due to a combination of three factors: lack of markets for thinnings, the poor performance of *E. grandis* and *E. pilularis* when planted off-site, and difficulties in sawing the small eucalypt logs. Economic resources were concentrated on establishing the more productive Pine species in plantations (Queensland CRA/RFA Steering Committee, 1997).

4.5 MANAGEMENT PRACTICE IN THE CYPRESS PINE FORESTS

Of the 1,686,000 ha of Cypress Pine forest in Queensland, the Forest Resources Committee (1987) estimated 696,000 ha were on State forest land managed for multiple use including wood production; 773,000 ha were on Crown land or occupied under lease on which harvesting can be carried out under government control; 6,000 ha were in National Parks, and 211,000 ha on private property.

Resource Management Policy

Early Cypress Pine management policies, including fire protection, resulted in the aggressive expansion of the species in terms of 'wheatfield' regeneration on already stocked areas, and the total area covered by the species. The obvious need to thin this regrowth was recognised, and subsequently confirmed by research investigation (Johnson, 1975). Large work gangs were employed on manual thinning from 1940 to 1970, and from 1963 using herbicide treatment on competing hardwood. However, the requirement for thinning to waste subsequently diminished under the influence of the high standing basal areas which were encouraged in the overwood, and these treatments declined from the early 1970s.

From the early 1980s the desire to reduce costs associated with silvicultural treatment directly conflicted with the need to continue protection of the forests from the ravages of wildfire. It was argued by some that employment levels must be maintained in order to provide fire protection. While this remained a dilemma for the forest service, the Cypress Pine forests have not suffered major fire damage. This is attributed to the generally heavy stocking levels maintained in the forests, and to the infrequent and scattered logging activities which have limited fuel accumulation (Johnson and Jennings, 1991).

Johnson and Jennings (1991) believed a move away from the practice of complete fire exclusion was technically feasible, although any such move would necessarily involve the implementation of widespread fuel reduction measures such as prescribed burning and cessation of silvicultural treatment.

The managed Cypress resource is largely east of the Leichhardt Highway, running from Theodore to Goondiwindi. While this resource may be managed sustainably, there has been a continuing trend towards smaller sized logs. Hence there is growing interest in the 'western cypress' resource (shown in Figure 4 in the NSW report), located west of the Leichhardt Highway and generally north of the towns of Miles and Roma. This resource, both State forest and leasehold land, is very substantial and largely unlogged because of its isolation. Industry is being encouraged to explore its potential utilisation.

Selection Practice

A standard selection prescription has been applied to the Cypress Pine forests to improve the average stand condition by retaining trees over 39 cm DBHOB only where required as seed trees; by removing poorer formed, less vigorous trees or trees which may die before the next cutting cycle; by merchantable thinning through the size classes to improve overall growth rates; and by building up growing stock in the largest retained class, 29 to 39 cm DBHOB (36 to 48 inches girth).

5. HARVESTING AND TREATMENT STATISTICS

5.1 SAWLOG YIELD FROM CROWN FORESTS

A summary of the output of sawlogs from Queensland Crown forests (hardwood forests, rainforests, Hoop, Bunya and Kauri Pines, and the Cypress Pine forests) is given in Table 2.

The hardwood sawlog volume in Table 2 is made up of 'Crown compulsory' and 'Crown optional' sawlogs. Compulsory sawlogs have a small end diameter >50 cm underbark (Class A), or a small end diameter between 30 and 50 cm underbark (Class B). An optional sawlog will not meet Compulsory Grade standards but, nevertheless, may be accepted by a purchaser. There is no minimum standard for optional logs and uptakes vary from purchaser to purchaser.

As a proportion of the compulsory log harvest, the optional log harvest has been increasing in recent decades. Within the south east part of the State it was around 10 per cent in the early 1980s, and 16 per cent during 1990 to 1995. This reflects improvements in utilisation practices, the need to maintain the scale of milling in the face of reductions in Crown compulsory allocations, acceptance of lower quality logs in the face of competition from landscape and salvage timber operations, and the relatively low price of optional logs.

Despite changes in utilisation standards, the total sawlog harvest from Queensland forests has declined substantially, for example, from around 600,000 m^3 yr^{-1} during the 1950s, to around 300,000 m^3 yr^{-1} in the 1990s.

Table 2. Sawlog volumes removed from Queensland public hardwood forests (m^3 yr^{-1}) between 1945 and 2000. Data are from Annual Reports of the Queensland Department of Forestry and DPI-Forestry.

Time period	Hardwood forest	Cypress pine forest	Rainforest (Nth Qld)	Hoop, Bunya and Kauri (Sth Qld)
1945/46 to 1949/50	168,500	49,080	157,790	238,700
1950/51 to 1954/55	205,720	75,900	163,151	177,040
1955/56 to 1959/60	236,460	72,520	176,740	127,330
1960/61 to 1964/65	200,738	80,900	162,280	81,500
1965/66 to 1969/70	207,740	82,650	192,320	65,750
1970/71 to 1974/75	189,403	97,340	199,650	53,930
1975/76 to 1979/80	228,150	119,600	154,000	43,800
1980/81 to 1984/85	222,720	111,570	128,700	34,629
1985/86 to 1989/90	232,860	121,780	53,200	17,040
1990/91 to 1994/95	217,000	130,140		940
1995/96 to 1999/00	189,000	127,460		148

During the 1950s and 60s the largest volume of sawlog in Queensland came from the rainforests (around 350,000 $m^3\ yr^{-1}$). This included both the North Queensland rainforests and native conifers from the southern rainforests. This compares with the 200,000 $m^3\ yr^{-1}$ from the hardwood forests, and around 70,000 $m^3\ yr^{-1}$ from the Cypress Pine forests at this time.

The rainforest harvest (including that of rainforest conifers) subsequently declined, and during 1980-85 (163,000 $m^3\ yr^{-1}$) had fallen below that of the hardwood forests (223,000 $m^3\ yr^{-1}$). The Cypress Pine harvest had increased to around 110,000 $m^3\ yr^{-1}$.

The southern Queensland *Araucarias* were logged heavily in the 1940s (238,000 $m^3\ yr^{-1}$), but removals declined rapidly thereafter to around 50,000 $m^3\ yr^{-1}$ by the 1970s, and ceased in the mid-1980s. Logging of rainforest in North Queensland ended following the Commonwealth Government's nomination of the Wet Tropics to World Heritage listing in 1988.

Sawlog production from hardwood forests reached a peak in the late 1980s. The withdrawal of the Fraser Island forests resulted in a decline in allocations of 6,500 m^3 in 1990, and a further 17,000 m^3 when logging ceased completely in 1992.

5.2 HARVEST OF NON-SAWLOG PRODUCTS

Non-sawlog products include girders, piles, poles, corbels and sils, railway sleepers, landscape and fencing timbers, mining timbers, and roundwood timbers. The harvest of these materials can be presented only for the decade 1990 to 2000 when Annual Report records, for all components, were given in cubic metres. Before 1985, the harvest data were presented in a range of units (cubic metres, linear metres, pieces, tonnes). The data for the 5-year period 1985 to 1990 were given in cubic metres, but do not include the significant volumes harvested as girders, piles, and poles.

It is presumed in the following analysis (Table 3) that almost all non-sawlog products are derived from the native hardwood forests. For example, in 1997/98, the Dalby (Cypress Pine) District produced only 4,600 of the 65,000 m^3 of non-sawlog material in the State, and most of this (landscape material, fencing, and roundwood) would have been hardwood.

The non-sawlog products (37 and 26 per cent, respectively, of total production from native hardwood forests) constitute a greater part of the total harvest than in NSW. Individual components of non-sawlog production for two years include:

	1993/94 (m^3)	**1997/98 (m^3)**
Railway sleepers	9,707	3,401
Landscape/fencing	13,827	30,989
Mining	1,784	950
Girders, piles and others	10,504	8,535
Poles	7,001	8,547
Hardwood roundwood	39,837	12,123

The greatest components are landscaping/fencing materials and hardwood roundwood timber. Undoubtedly this reflects the rapid development and population growth in south-east Queensland in recent years. The public forests have an important role in servicing this demand.

Table 3. Non-sawlog and sawlog removals ($m^3\ yr^{-1}$) for two five-year periods.

Period	Non-sawlog volume	Hardwood forest sawlog volume	Non-sawlog plus sawlog volume	Non-sawlog as a per cent of the total hardwood forest volume
1990 to 1995	128,015	217,000	345,015	37
1995 to 2000	65,418	189,000	252,418	26

Unfortunately the Annual Reports do not provide information on the non-sawlog harvest from private property forests. This may also be a substantial part of total production.

5.3 SILVICULTURAL TREATMENT OF PUBLIC FORESTS

Earlier reference has been made to the silvicultural treatment of forests (ringbarking of then non-commercial trees, felling of reject trees, thinning of regrowth and coppicing of non-vigorous advance growth), and decline in treatment from around 1980. This is reflected in the areas treated, by decades, between 1950 and 2000 (Table 4).

Eucalypt forest treatment declined from a peak 6,540 ha yr^{-1} in the 1950s, to 1,065 ha yr^{-1} in the 1980s and just 190 ha yr^{-1} in the 1990s. Treatment of the Cypress Pine forests built up to 9,050 ha yr^{-1} in the 1970s, and was maintained to a greater extent during the 1980s than in the eucalypt forests. However, this also more or less ceased by 1990.

Silvicultural treatment ceased because of competition for resources from other forest development projects, for example, plantation development (DPI-Forestry 1998).

5.4 PRIVATE PROPERTY FORESTS

Harvesting statistics for private property forests are taken from Annual Reports of the Queensland Department of Forestry, and more recently, its successor, DPI-Forestry. A limited amount of information about the private forest estate is also drawn from the report of the CRA/RFA Steering Committee (1999) and from Ryan *et. al.*, (2002).

Fifty three per cent of native forest in the south-east part of Queensland is privately owned. This forest has played an important role in wood production (Ryan *et. al.*, 2002). Figure 3 shows a rapid increase in wood production from private lands, reaching a peak in excess of 900,000 m^3 yr^{-1} in the early 1950s. There was a declining trend thereafter to around 500,000 m^3 yr^{-1} by 1975, and 340,000 m^3 yr^{-1} by 1980. The log harvest subsequently fluctuated before dropping below 300,000 m^3 yr^{-1} during 1995 to 2000.

At its peak, total sawlog production from private property exceeded that from public land to a substantial extent, for example, 900,000 m^3 yr^{-1} from private property compared with about 600,000 m^3 yr^{-1} (Figure 3) from public land. However, by the late 1990s there was a broadly similar log supply from the two sectors (around 300,000 m^3 yr^{-1}).

Table 4. Average area (ha) of eucalypt forest and Cypress Pine forest silviculturally treated annually by 10 year periods, 1950 to 2000.

Period	Eucalypt forest	Cypress Pine forest
1950-1960	6,540	3,830
1960-1970	5,660	4,440
1970-1980	4,330	9,050
1980-1990	1,065	5,455
1990-2000	190	540

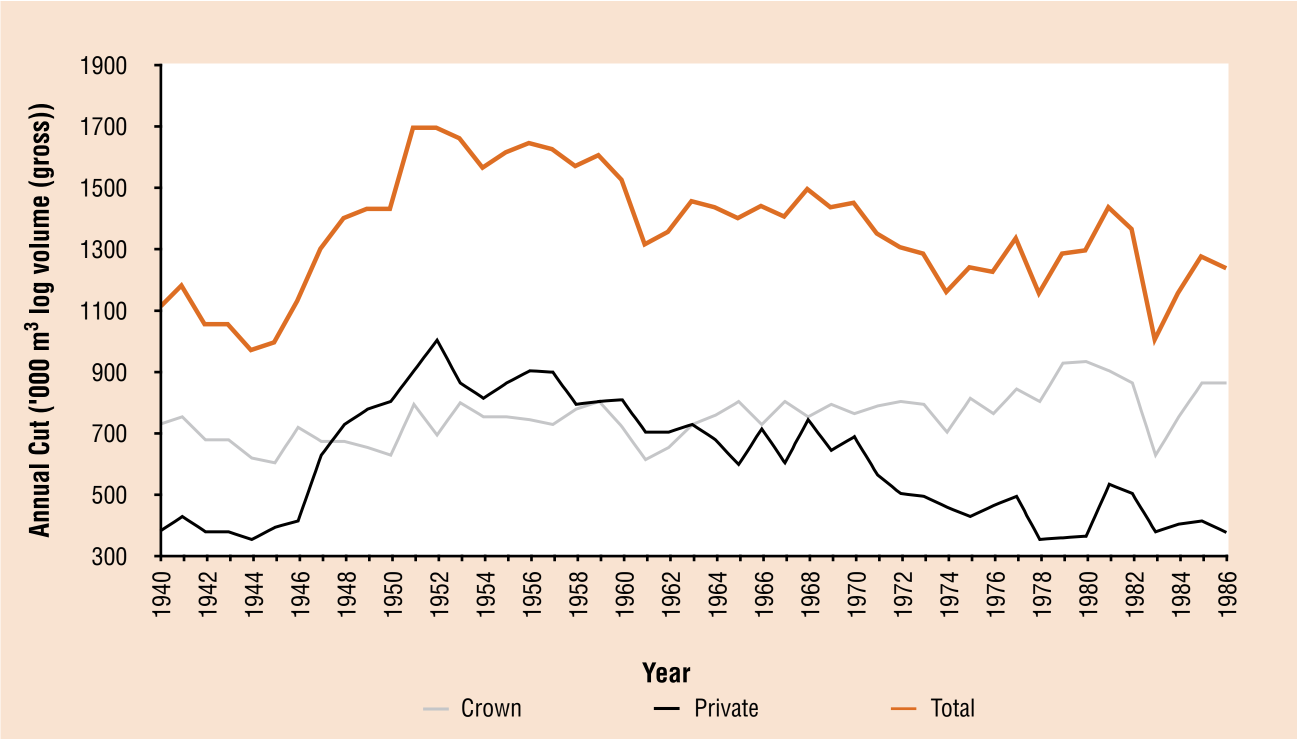

Figure 3. Trends in log timber production from Crown and private lands from 1940 to 1986. (Note that the Crown log production trend incorporates both native forest and softwood plantation production).

The high levels of log production from private land during the 1950s and through to 1970 has to be placed in perspective. Much of the production in the post-war period came from land clearing for agricultural development and not from forests managed for sustainable wood production. Since 1957 much of the cut has in fact resulted from capitalisation of timber stands following conversion of Crown leases to freehold, partly to offset freeholding costs incurred by landholders. The sharp decline in private land wood supply from the 1970s may be related to earlier over-cutting, and to concentration on alternative agricultural pursuits.

There is a poor understanding of the proportion of the current private property wood supply which is derived from managed forest and land clearing, respectively. Sawmillers surveyed in south-east Queensland estimated that approximately 62 per cent of their timber accessed from private property was derived from forest managed for ongoing timber production, 16 per cent from the partial clearing of stands to enhance grazing, and 15 per cent from clearing for agricultural development (Ryan *et. al.*, 2002).

The quantity of sawlogs harvested from private lands is likely to be more variable over time than that harvested from Crown lands. The intake of private logs is dependent in part on levels of new housing estate development and clearing associated with rural development. A surge in housing developments can temporarily place large volumes on the market but this cannot be sustained.

6. THE EFFECT OF MANAGEMENT PRACTICES ON THE CONDITION OF THE FORESTS

The Queensland hardwood forests are lower-yielding than those in other parts of Australia. This reflects, in part, the longer dry periods and higher temperatures to which much of the subtropical forest is exposed. Moreover, the timber is often poorer in quality and smaller in size than that in southern forests (Queensland Government, 1990).

6.1 THE CROWN FORESTS

An analysis of the forest growing stock within the 14 Allocation Zones of the south-eastern region (Figure 2) provides a perspective on the forest condition (DPI-Forestry, 1998).

The average total standing sawlog volume (trees>40 cm DBHOB) for all zones is only 10.7 m^3 ha^{-1}, and the average loggable volume is 5.3 m^3 ha^{-1}. There is a wide range in both total standing sawlog volume (5.6 to 31.8 m^3 ha^{-1}) and loggable volume (3.3 to 17.3 m^3 ha^{-1}). The largest standing sawlog volumes are associated with the wet sclerophyll forests of the North Coast Zone and the smallest with the dry sclerophyll forests of the Eidsvold-Monto Zone.

Under the low-intensity single tree selection system, a relatively large part of the stand is retained as 'growing stock capital', so that recently logged areas may still contain a substantial volume of logs. Thus, throughout the 14 Zones, the current allocated harvest of 108,693 m^3 is very small in relation to the current standing volume (5,958,957 m^3) and the merchantable volume (2,969,896 m^3). It also means that areas with low merchantable volumes, or which currently have insufficient volume to produce an economically viable sale quantity, should have the potential to grow into a productive state, and be available for harvest in the future. However, because of poor tree condition, there are critical limits to this.

The NSW State Report (Florence, 2007) refers to the tendency for growing stock with limited growth potential to accumulate under a selection system (Keady, 1978; Florence, 1996). This is also reflected in an analysis of the growing stock condition in the forests of south-east Queensland. There is a low percentage of sawlog trees or smaller trees with potential to become sawlogs. Anywhere between two thirds and four fifths of the stems on potentially productive public forest in south-eastern Queensland, are of non-sawlog standard, and these actively compete with trees that will produce sawlogs. Moreover, an analysis of the percentage of non-sawlog components by size class suggests that the number of sawlogs is likely to decline, and that stands will be increasingly dominated by low quality stems (DPI-Forestry, 1998).

The net sawlog volume growth in the typical Queensland hardwood forest is also low, partly a consequence of poor soils and other environmental stresses, and partly because of the poor condition of the growing stock. Key factors limiting growth are the structure of the growing stock, inappropriate tree size distribution patterns, the accumulation of 'growth-restricted' trees, and high inter-tree competition.

In a recent internal (undated) report to DPI-Forestry, D. Mannes and D. Taylor recognise that the unsatisfactory forest condition reflects the relatively light selection harvesting applied to the forests, and the withdrawal of post-harvest silvicultural treatment from about 1980. These authors and others (e.g. DPI-Forestry, 1998) see the need for an 'enhanced silviculture' program to improve timber production while maintaining other multiple use values. Enhanced silviculture would involve integrated multiple value planning at the landscape level, harvesting a greater proportion of the non-sawlog grade material, and creating canopy gaps of sufficient size (i.e. at least 40 m in diameter) to encourage and maintain good regrowth.

6.2 PRIVATE PROPERTY FORESTS

Management practice on private property tends to be based on selective harvesting with a minimum diameter limit for cutting. In some cases silviculture on private forests mimics that on public forests, often resulting in the highgrading of the forest, leaving sub-dominant, defective and suppressed trees and non-commercial species (Ryan *et. al.*, 2002). There is, however, wide variation in management, from complete protection to permanent clearing for agriculture.

Current native forest management practices on private land are considered to be unsustainable (Queensland CRA/RFA Steering Committee, 1999). Changes in the allocation of public timber resources are affecting private native forests, causing a substantial transfer of harvesting to the private estate over the long term. This also applies, but to a lesser extent, to the Cypress Pine forests.

The Private Lands Working Group (1999) for the Queensland CRA/RFA process has recommended a range of institutional changes to support sustainable forest management. These are currently being pursued within the development framework for a proposed new Queensland forest practices system.

7. ENVIRONMENTAL ASSESSMENT

Queensland participated in the initial stages of a Commonwealth/State Comprehensive Regional Assessment (CRA) and Regional Forest Agreement (RFA) processes.

In 1997/98 the State and Commonwealth signed the Interim Forest Management Agreement to ensure options for a nature conservation system were protected pending the completion of the RFA for Crown native forests in south-east Queensland.

As part of the CRA process, vegetation mapping across all tenures was undertaken for the whole south-east Queensland region. In respect to wood production, the State provided scientifically-based assessments of the timber resources and of forest productivity; developed Codes of Practice for ecologically sustainable management; funded some relevant research; and developed its Environmental Management System (EMS) to a standard suitable for independent certification to ISO 14001 standard.

A Regional Forest Agreement has not been negotiated with the Commonwealth Government. Rather, the Queensland Government determined that the forests were to play a more significant role in nature conservation than in wood production. The National Parks and Wildlife Service now oversees all public native forest, and hardwood production is to be phased out within 20 years. The implications of this for carbon storage are addressed in the discussion.

Conservation and timber values of the private forest estate have not been adequately protected in the past, however, appropriate planning processes and regulatory mechanisms are now being put in place. These include strategic regional biodiversity planning for most of the south-east Queensland region, the integration of nature conservation needs into new local government planning schemes under the *Integrated Planning Act 1999*, the introduction of tree-clearing controls under the *Vegetation Management Act 1999*, and State and Local government extension and management services for nature conservation.

8. DISCUSSION

Compared with other States, Queensland did not inherit a substantial and productive native forest resource. In the early post-war years the rainforests were the principal contributor to wood supply. For example, during 1945-1950, 400,000 m^3 yr^{-1} of rainforest timber was harvested compared with just over 200,000 m^3 yr^{-1} of wood from the eucalypt and cypress forests.

It was always recognised that the harvest of the *Araucaria* rainforests of southern Queensland involved progressive liquidation of that resource. However, it did generate a native conifer planting program, mainly on former rainforest sites, of outstanding quality.

The harvest of the North Queensland rainforests was also carried out at a rate that could not be sustained, resulting in a progressive reduction in the allowable cut before the Commonwealth Government intervened and nominated the resource to the World Heritage Register. Consequently, the volume of wood harvested declined appreciably during the 50-year period. By the early 1980s, the annual rainforest harvest (both southern and North Queensland) had declined from 400,000 m^3 to 160,000 m^3 and, perhaps in compensation, the hardwood-cypress harvest had increased from 200,000 to 350,000 m^3.

In retrospect, the management of Queensland forests has been sub-optimal. As in NSW, the State's long-term wood supply strategy focused heavily on investment in the softwood program, greatly limiting financial input to native forest management. The small and eventually aborted enrichment planting program during the 1970s and 80s had little remedial impact on redressing the problems of not having post harvest treatment in wet sclerophyll forests.

It was anticipated that there would be ample opportunity to restore the productivity of the wet sclerophyll forests when the softwood program entered its mature phase, and generated positive financial flows. However, as is the situation in NSW, investment in restoration of the hardwood forests has not happened.

The highly prescriptive approach to selection management failed to recognise important ecological attributes of the eucalypts – notably, their intolerance of competition and the failure of growth-restricted stems to respond to release. As a consequence, there is now a 'large burden of non-productive, non-sawlog grade material which is limiting both growth and regeneration' (DPI-Forestry, 1998).

Mild post-harvest burning has been carried out in Queensland forests, though not in a consistent way. This burning has been used more to reduce fire hazard than to create seedbeds for regeneration.

The lack of conventional forest type mapping in Queensland forests may create problems in assessing change in carbon stocks within the forests (see Appendix 1). The data tables (Appendix 1) divide the hardwood forests into 7 broad community groupings. There may be difficulties in linking these groupings to the mapping of 'forest ecosystem' units at a fine scale of resolution by a number of public Agencies in Queensland. This will need to be further addressed.

Information on management practice recorded in the data tables has been derived largely from discussions with Queensland foresters. Advice from different sources tended to be consistent, and there is a good level of confidence in the data. However, it should be appreciated that there are difficulties in presenting the full range of growth information. While information on merchantable yield can be regarded as reliable, that relating to total biomass is more problematic given the light selection harvest regimes and the limited growth potential of much of the growing stock. This is also a matter which will need to be further addressed.

The current yields and cutting cycles reflect the forest condition. The current selection harvest of 20 m^3 ha^{-1} from the Blackbutt forest, and an MAI of 1.0 to 3.0 m^3 ha^{-1} yr^{-1} is well below the forest potential. However, it is the Spotted Gum forest which is in the poorest condition, with an estimated yield of 6 m^3 ha^{-1} at a single harvest, a 40 year cutting cycle, and an MAI of only about 0.2 m^3 ha^{-1} yr^{-1}.

The response of the Queensland Government to the Comprehensive Regional Assessment process, that is, placing high priority on nature conservation, and planning to phase out wood production from public lands, could reflect both the declining productivity and operational viability of the forests, as well as environmental considerations.

Previous practices have undoubtedly depleted carbon stocks in Queensland forests, and rates of carbon accession are low. Both the softwood and the more recent hardwood planting programs (the latter mainly on private land), will contribute to increased carbon stocks. However, there is also a case to restore carbon stocks in the public native forests, particularly where this is also justified in broader social and environmental terms. Implementation of the 'Enhanced Silvicultural Option' (DPI-Forestry, 1998), and progressive restoration of the wet sclerophyll forest, would be one sensible approach to this.

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10. APPENDICES

10.1 APPENDIX 1

BACKGROUND TO AND ASSUMPTIONS USED IN COMPILING THE DATA TABLES

Management information used in preparing the data tables has been derived from Annual Reports (1945 to 2000); DPI-Forestry and CRA / RFA documents cited earlier; and discussions with Queensland foresters, including retired senior administrators, Peter Kanowski (Snr) and Dick Pegg, and current management and research personnel, David Mannes, Jane Siebuhr and David Taylor. As for NSW, management information required to compile the data tables was not readily available from Departmental records.

Forest Types

There has been no formal mapping of 'Forest Types' in Queensland, which may create problems in assessing carbon stocks and carbon flux. A number of Queensland Agencies (Queensland Herbarium, National Parks and Wildlife Service) have mapped vegetation ('forest ecosystem') units at a fine scale of resolution, which should be available in digitised form. Some effort may be needed to determine how best to link these units with the broad community groupings used in preparing the data tables, particularly where there is a complex of 'Wet', 'Moist' and 'Dry' forest with variable species composition.

Based on the way DPI-Forestry classifies the hardwood forest for management purposes, the data tables recognise seven broad community types. The 'hardwoods' terminology used here is similar to that used in the NSW State Report. The forest types used are:

1. North Queensland Tropical Rainforest.
2. Subtropical *Araucaria*-dominated Rainforests of southern Queensland.
3. Blackbutt forest – This is defined here as any forest with an *E. pilularis* component. For the purposes of this project, small occurrences of *E. cloeziana* in the Gympie District should also be included in this Type. Blackbutt forest occurs as both Open forest and as Tall Open forest with a rainforest understorey, as near pure stands, and in mixture with many of the species listed within the 'Mixed Hardwoods forest'.
4. Mixed Hardwoods forest - This is the 'Dry Hardwoods Type' in NSW terminology and 'Moist' forest in Queensland terminology. The Type contains various combinations of *E. acmenoides*, *E. microcorys*, *E. drepanophylla*, *E. resinifera*, *Lophostemon confertus*, *Syncarpia glomulifera*, and others. As for the Blackbutt forest, it occurs as both Open forest, and Tall Open forest with a rainforest element understorey.
5. Moist Hardwoods forest - This is the 'Wet' forest in Queensland terminology. Moist Hardwood forest may contain *E. saligna*, *E. grandis*, *L. confertus*, together with species of the Mixed Hardwood forest. There will normally be a well-developed rainforest understorey. This forest does not occur extensively in Queensland, rather it was described in Queensland discussions as 'fringes around the Blackbutt and Mixed Hardwoods forests' and might be 'best included with these forests'. Because parts of the Moist Hardwoods forest have become silviculturally degraded in the absence of adequate post-harvest regeneration treatment, and hence difficult to define from air photographs and satellite images, it may be appropriate to adopt this advice.
6. Spotted Gum forest – This is the 'Dry Forest' of Queensland terminology, comprising *C. citriodora*, *C. variegata*, *E. drepanophylla*, *E. fibrosa*, *E. acmenoides*, and others.
7. Cypress Pine forests of south western Queensland, with *Callitris glaucophylla*, and associated 'Western Hardwoods', *C. variegata*, *C. citriodora*, *E. crebra* and others.

Time periods and management practices

It is appropriate in Queensland to consider only two time periods:

1. 1945 to 1980:

During this period, silviculture was based on a minimum cutting diameter until 1968, and thereafter on harvesting through the full range of commercial sizes. Both selection regimes were designed to maintain growing stock for future harvest. There would have been little difference between the regimes in the proportion of basal area removed. It was during this period that silvicultural treatment (ringbarking, reject tree felling, thinning of regrowth) was associated with harvesting.

During this period, relatively small areas of wet sclerophyll forest were subject to enrichment planting.

2. 1980 onwards:

Silviculture during this period was based on retention of trees meeting defined crown and bole quality standards, and the harvest of trees not meeting those standards. There was no (or very little) silvicultural treatment during this period – although limited enrichment planting was maintained until the late 1980s.

Quantitative information in the data tables

The compilation of the data tables describing management faced many of the difficulties described in the NSW State Report, notably, the lack of readily available recorded information in an appropriate form, and the need to reach concensus on the data required. Thus, this Report should be read in conjunction with Appendix 1 of the NSW State Report. A brief account only is given here of the processes and assumptions used in compiling the data tables.

Percentage of basal area and canopy removed

Silvicultural practice in Queensland native hardwood forests has been broadly similar to that in the Coastal Regrowth Zone in NSW, though subject to more rigid prescriptions. Nevertheless, the percentage of basal area removed, and the extent of canopy opening has been just as variable, particularly during the earlier period when post-harvest treatment was carried out.

During the earlier period, only small to moderate canopy openings were made in some circumstances (e.g. 20 per cent canopy removed), and in others, openings were more extensive, for example, 50 per cent or more of the canopy was removed. The larger canopy disturbances could be associated with more intensive treatment in *E. pilularis* forest, leading to stands with a large component of even-aged regrowth. One subjective estimate (based on Queensland discussions) is that some 50 per cent of the current *E. pilularis* forest has a substantial even-aged component. This constitutes the most productive of Queensland's hardwood forests.

Greater canopy disturbance could also be associated with the application of prescriptions to old-growth forest, where a high proportion of growing stock was above the diameter cutting limit, or was subsequently removed in silvicultural treatment (e.g. the Conondale Range forests).

From the late 1960s, the quality stem retention regime permitted retention of trees above the original cutting diameter. However, supply pressures at the time, and difficulties in interpreting the condition of crowns and boles, meant that few larger trees were retained – often leaving a mix of small and intermediate sizes with varying increment potential (Section 4.3).

The cessation of ringbarking treatment beyond 1980, and withdrawal of enrichment planting in the late 1980s, restricted levels of canopy disturbance. DPI-Forestry (1998) suggested that approximately 80 per cent of the stand basal area was being retained under the current tree-marking rules for sawlogs - without follow-up silvicultural treatment.

The level of canopy disturbance in the Cypress Pine forest would have been 30 to 40 per cent in very good stands, and 20 per cent in lower-yielding forest.

Harvesting and growth statistics

North Queensland Rainforest. An analysis of a number of North Queensland rainforest sites (Queensland Department of Forestry, 1985) describes the impact of rainforest logging.

The data emphasise the large size of trees harvested from virgin stands (average 3.5 m^3 per tree), and the substantial volume harvested (59.9 m^3 ha^{-1}) in a selection operation. Some 30 stems ha^{-1} were destroyed or severely damaged during harvest. There was still an appreciable volume harvested, some 20 to 30 years later in recut operations (32.5 m^3 ha^{-1}), although these may have also involved harvest of residual patches of virgin forest (based on Queensland discussions). It was agreed in discussions that these statistics may represent harvest of above-average stands, and tonnages in the data tables are based on selection harvest volumes of 50 and 25 m^3 ha^{-1}, respectively. The merchantable mean annual (sawlog) increment of the North Queensland rainforests was estimated to be around 1.5 m^3 yr^{-1}.

***Araucaria*-dominated rainforests of southern Queensland.** Because it is now more than 30 years since large volumes of the native *Araucaria* species were harvested, it has not been possible, in the time available, to obtain reliable advice on the average volume harvested per hectare. In any case this would be difficult to obtain. The *Araucaria* species occurred as tall, large-boled emergents from a rainforest stratum. The stocking was very variable, with a tendency for the conifers to be concentrated on ridges and upper slopes, and with more scattered occurrences elsewhere. Moreover, in the latter years it was the lower-yielding 'dry scrubs' of Central Queensland which were harvested. Overall, it was agreed in discussion that an average harvest volume of 60 m^3 ha^{-1} could be appropriate.

Hardwood forests: Information on harvest yields and forest growth has come from discussions at the DPI-Forestry Office, Brisbane, and at the Gympie Research Centre. There was a good level of consensus on wood yields and stand increments. These are presented with some confidence.

Given the declining condition of the forests (Section 5), wood yields during the past decade have been low – around 20 m^3 ha^{-1} for a single harvest operation in the Blackbutt forest, 10 m^3 ha^{-1} for the Mixed Hardwoods forest, and 6 m^3 ha^{-1} for the (coastal) Spotted Gum forest. This latter yield is close to the limit for economic harvesting. Yields were somewhat greater during the earlier time period (1945 to 1980) when larger-boled trees were still available for harvest.

The yield of non-sawlog material as a proportion of total harvest volume during the 1990s is discussed in Section 4.1. These data have been used to estimate the amount of non-sawlog material removed from the forest for this decade. It is assumed that there was a smaller proportion of non-sawlog material in earlier decades. This is accepted to be 15 per cent.

The mean annual (merchantable) volume increments are also low, estimated to be 1.5 to 3.0 m^3 ha^{-1} for the Blackbutt forest, 0.3 to 0.5 m^3 ha^{-1} for the Mixed Hardwoods forest, and 0.2 m^3 ha^{-1} for the Spotted Gum Type. Understandably, the cutting cycle (the time between successive harvests) was estimated to be as long as 40 years for the Spotted Gum Type.

Cypress Pine forest. Yields were estimated to average 10 m^3 ha^{-1}, and MAI, 0.3 m^3 ha^{-1} in the 'Eastern Cypress' forests. Logging in the largely untapped 'Western Cypress' forest should yield 15 m^3 ha^{-1} if industry accept the challenge to utilise the resource. The associated Western Hardwoods yield 2 to 4 m^3 ha^{-1}, with a mean annual increment of 0.2 m^3 ha^{-1} $yr^{-1.}$

All harvest and residue data are presented in the data tables as air-dry tonnes.

Post-logging fuel-reduction burning

As in NSW, there are no relevant and readily available burning records. It was difficult to gain a good appreciation of the extent to which post-harvest fuel reduction burning has in fact been applied. Nevertheless, advice suggested that post-harvest fire was fairly widely used in the hardwood forests, though there was a general insistence that such burns were mild, and based on burning of heads of felled trees. Estimates of the percentage area burned and 'burning efficiency' are based on procedures described in the NSW State Report. It is assumed that mild slash reduction burns were carried out on 60 per cent of coupes, and 50 per cent of a coupe area was burnt. It is further assumed that on the area burnt 60 per cent of fine fuels were consumed in a mild burn, and 40 per cent of coarse woody debris fuels.

Fire has probably not been deliberately used in the Cypress Pine forests, though this remains a matter of debate.

Logging residues

The problem of estimating the weight of logging slash in selectively harvested forest has been addressed in the NSW State Report. Queensland estimates are similarly based on the sawlog-pulpwood-logging residue relationships for forests in north-east NSW subject to single tree selection and patch cutting, and for high quality moist, and low quality dry forest, respectively (from Snowdon *et. al.*, 2000).

SECTION 7

Plantations: Historical Development of Silvicultural Practices

Peter Snowdon

Ryde James

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES CONTINUED

LIST OF TABLES CONTINUED

PLANTATIONS: HISTORICAL DEVELOPMENT OF SILVICULTURAL PRACTICES

SUMMARY

The establishment and management of the Australian conifers and eucalypt plantation estate between 1945 and 2000 is described. During this period the area increase was 900,000 ha and 500,000 ha for conifers and eucalypts, respectively. Detailed descriptions are given for key plantation regions, and the effects of site conversion, growth rates, silviculture and harvesting on carbon balance are discussed.

1. INTRODUCTION

In 2000 Australia had approximately 1.48 Mha of plantation, consisting predominantly (65 per cent) (Table 1) of coniferous species. Five per cent is reported as farm forestry and 95 per cent as industrial plantations.

The primary aim of plantation forestry is to ensure the commercial efficiency of wood production while ensuring forests are managed on an ecologically sustainable basis in accordance with the National Forestry Policy Statement (Commonwealth of Australia, 1992) by following the framework of criteria and indicators as developed by the Montreal Process Working Group (Santiago Declaration, 1995). The latter is achieved by ensuring that management operations adhere to principles laid down in various Codes of Practice (e.g. State Forests of NSW, 1995, 1997, 1999). There are two main management strategies. Pulpwood regimes are commonly established at a high stocking rate, are usually not thinned during the rotation, and are clearfelled usually between 10 and 20 years of age depending on species and product specifications. Sawlog regimes are subject to repeated thinning designed to optimise the distribution of log size

Table 1. Total area (ha) under hardwood and softwood plantations in 2005 (Parsons *et. al.,* 2006).

State/Territory	Hardwoods	Softwoods	Other categories	Total
Western Australia	270,813	104,480	2,305	377,598
Northern Australia	14,090	2,239	0	16,329
South Australia	42,341	124,163	457	166,962
Queensland	37,496	186,633	2,108	225,637
New South Wales	55,196	273.606	2,821	331,623
Australian Capital Territory	0	9,500	0	9,500
Victoria	164,724	218,412	1,463	384,599
Tasmania	155,500	71,600	100	227,200
Australia	710,161	990,034	9,255	1,799,450
Proportion of total	**42.6%**	**56.9%**	**0.5%**	

classes and to achieve desirable wood properties. Thinnings may be used as pulpwood or other wood products. The rotation period for softwood sawlog plantations has been steadily declining and is currently about 30 years.

2. GROWTH OF THE PLANTATION ESTATE

The rate and timing of the expansion of the plantation estate denotes periods of probable (i.e. past event) carbon loss due to conversion practices prior to 1985 and to a large extent sets the timing for future management events, particularly harvesting, when carbon is removed from the site in products. Some residual carbon contained in harvest residues or soil components may be lost, depending upon the options taken to manage residues between crop cycles.

Limited resources of softwoods in native forests of Australia and nearby trading partners promoted the establishment of the first plantations of exotic conifers for timber production in an attempt to regulate the supply of softwoods and to provide an alternative to imported supplies. Expansion of the plantation estate was slow at first and dependent on many factors, such as the need for trial plantations as indicators of the most appropriate sites, development of research results to overcome poor growth on nutrient-deficient sites, the need to provide unemployment relief during the Great Depression, and on lack of manpower during World War II. South Australia (SA) received a grant from the United Kingdom to plant 2000 ha yr^{-1} a year from 1926 to 1936 in order to create migrant employment (Resource Assessment Commission, 1992). This gave SA the largest plantation estate until the 1960s. In 1966 the Federal Government

Figure 1. Expansion of Australian plantation estate between 1950 and 2000.

entered into an agreement with the States to finance, by means of long-term loans, the establishment and maintenance of plantation areas in excess of a pre-determined base rate (Horne, 1988). Funding continued until 1977, when environmental concern brought about its demise. Thereafter a reduced rate of planting was implemented in NSW and elsewhere (Horne, 1988; Resource Assessment Commission, 1992). Only small areas of hardwoods were planted until 1990. Since then there has been a rapid expansion of planting rate, with particular attention to producing pulpwood.

Data derived from Annual Reports of the Forestry and Timber Bureau (1950-1975) and Forest Resources and Forest Products Statistics published by The Australian Bureau of Agricultural and Resource Economics have been used to illustrate the expansion of Australian softwood and hardwood plantations (Figure 1). Some of the fluctuations are due to changes in methods of accounting.

3. THE SOIL RESOURCE

The properties of soils used on which plantations are established determines the initial soil carbon content, affects the resilience of soil carbon to change, and through chemical fertility and moisture storage characteristics, (to a large extent) controls the rate of carbon sequestration by the plantation.

Although a few plantations of softwoods and hardwoods were established in the 1800s, the full awareness of the need for plantation grown trees was not realised in many States until the 1920s. By that time the choice of land was limited because the more fertile land with moderate slopes had already been taken for agricultural use. There was a common belief that pines could be grown successfully on poor soils. Consequently, soil quality often received scant attention when planting sites were selected. There was also a desire to bring 'waste lands' into profitable use (Horne, 1988). Consequently, plantations were established on waste crown land, abandoned farmland and on poor quality native forest sites. Often these were on poor soils derived from sandstone or coastal sands. Many of the early plantings were failures and sometimes the plantations were abandoned. It was subsequently shown that most of these failed plantations were severely deficient in nutrients such as phosphorus and/or zinc (Ludbrook, 1942; Young, 1940; 1948; Stoate, 1950). The realisation of these limitations promoted the increased establishment of plantations on more fertile native forest sites.

For example, in NSW it was realised before World War II that there was not sufficient unallocated crown land or State Forest in appropriate localities for coniferous plantations (Horne, 1988). An active land acquisition programme commenced about 1960, usually by voluntary sale rather than by resumption. Planting was concentrated on the better-watered and more fertile highland sites rather than the impoverished coastal soils that had first been planted.

Increasing public resistance to conversion of native forest to plantations led to increased purchase of farming land. In the case of improved pasture, there were sometimes adverse effects of high nitrogen availability on tree form. As a consequence of these historic factors, the Australian plantation estate consists of a wide range of soil types that have had a variety of prior land uses.

3.1 TECHNICAL SOIL CLASSIFICATION

Following recommendations from the Australian Forest Nutrition Workshop held in Canberra during 1981, a working party was established to examine current soil classifications and to recommend one suitable for Radiata Pine (*Pinus radiata*) plantations. None of the broader classifications investigated at that time met the plantation forestry requirement of stated class attributes, so it was decided to develop a technical classification specifically for *P. radiata* plantations (Turner *et. al.*, 1990). A field manual was prepared in order to facilitate operational testing of the classification (Turvey, 1987).

The classification was developed in order to allow stratification of forestry areas into uniform units for scheduling wood production and soil-based silvicultural management; to provide a basis for the extrapolation of research results within and between forest areas; and to allow a systematic accumulation of soil information related to yield and other data on a computer compatible data base. The soil attributes which comprise the classification include parent rock, texture profile, depth to and type of impeding layer, texture, condition, degree of weathering of surface soil, and nature and colour of the subsoil. The nine soil attribute classes were subdivided further into a total of 67 classes. Soil attributes were selected on an *a priori* basis for their importance in affecting the performance of soil-based silvicultural activities (Turner *et. al.*, 1990). Such activities include those which directly affect wood production and management of the crop through site preparation, fertiliser and herbicide application, thinning and harvesting the crop. Turvey *et. al.*, *(*1990) examined the suitability of the classification as a basis from which to estimate the yield of wood from *P. radiata* plantations. Data were collected from trees and soil profiles on 181 sites in NSW, SA, Victoria and Tasmania. All but one of the attributes (texture profile) of the Technical Classification were significantly related to wood volume as single factors at the 5 per cent level of significance. In combination the soil attributes explained 75 per cent of the variation in wood volume across the sites.

The primary level of Parent Rock Code (PRC) in the Technical Soil Classification system classifies geological material by reference to its soil-forming characteristics. This offers a useful broadscale stratification of forest site because it discriminates discrete and meaningful soil chemical regimes that can be related to productivity. The occurrence of nutrient deficiencies, responsiveness to fertilisation and variations in plantation productivity can be broadly related to the geological substrate and variations in soil development. This provides a framework for extrapolation of research findings to broadacre forestry on a site-specific basis.

It is also feasible for the soil technical classification to be used as an approximate guide to soil carbon content and potential rates of carbon sequestration by new plantations. However, variation of soil properties within a rock code is

Table 2. Total areas of Australian State and private plantations in 1970 and 1990 according to Parent Rock Classes (Turner and Lambert, 1991).

Parent Rock Class (PRC)	PRC Code	Plantation at 1970	Added 1970 -1990	Plantation at 1990
Sandstones	02	7,105	11,375	18,480
Sands, shallow	022	77,220	81,210	158,430
Sands, deep	022	61,635	43,210	104,845
Sesquioxide	03	5,735	14,900	20,635
Argillaceous	05	147,920	204,650	352,570
Micaceous–chloritic	06	940	860	1,800
Feldspathic–quartzose	08	10,345	19,865	30,210
Feldspathic–micaceous	09	47,550	98,120	145,670
Ferro–magnesium	11	65,485	9,850	75,335
Total		**423,935**	**570,040**	**993,975**

Table 3. Soil chemical characteristics of some Australian forest soils according to Parent Rock Classes (Turner *et. al.*, 2001).

Parent Rock Class	Code	Organic carbon[A] (%)	Total phosphorus (ppm)
Sandstones	02	0.3 – 4.1	90 – 300
Silicious sands	022	0.8 – 1.7	31 – 83
Sesquioxide	03	2.8	112 – 278
Calcareous	04	2.2 – 5.1	53 – 97
Argillaceous	05	1.5 – 5.1	100 – 380
Felspathic–quartzose, medium grained	07	2.1 – 12.7	64 – 613
Feldspathic–quartzose, fine grained	08	1.6 – 3.4	105 – 290
Feldspathic–micaceous	09	5.8 – 7.4	249 – 418
Ferro–magnesium	11	9.2 – 12.7	1,040

[A] Factor of 1/1.72 used to convert organic matter to organic carbon (Baldock and Skjemstad, 1999).

also very considerable (Table 3). The distribution of Australian plantations across different parent rock classes defined by the Soil Technical Classification has been estimated for 1970 and 1990 (Turner and Lambert, 1991). A summary of these data is given in Table 2, while Table 3 gives some of the organic carbon and total phosphorus levels of those groups. Both properties can vary over 30-fold between soils.

Requirements for fertiliser amendments vary according to soil factors, particularly the soil parent material. Nutrient problems associated with particular soils can be derived from general principles and experimentation (e.g. Turner and Lambert, 1986). Thus, soils with less than 150 ppm total phosphorus (Table 3) would be expected to give substantial growth responses to the application of phosphate fertiliser. Deficiencies of potassium, zinc, copper and manganese occur most commonly on siliceous sands. Boron deficiency tends to occur on soils derived from igneous rocks.

4. MANAGEMENT PRACTICES IN PLANTATIONS

4.1 SITE CONVERSION

Conversion of native forest to plantation

Virtually all plantations have been established by conversion of native forest either directly or indirectly after a farming phase. The quantity of biomass involved in clearing eucalypt forest can be gauged from estimates of standing biomass (Table 4). On average about 81 per cent of the biomass is contained in the stem. Tropical and sub-tropical rainforests can contain 190 t C ha^{-1} (Turner and Lambert, 1996). In the poorest quality forests in Australia there may be little or no recovery of harvestable material. Even in better quality forests, only a small proportion of the woody components is usually harvested and the remaining debris (70 to 80 per cent of standing biomass) is left on the site. Harwood and Jackson (1975) estimated that the amount of C in logging slash was 315 t ha^{-1} in a mixed eucalypt forest with rainforest understorey in Tasmania. Jones (1978) recorded that on average about 250 t C ha^{-1} was present as fuels in 14 slash disposal fires in Western Australian Karri forest.

Table 4. Above-ground biomass of Australian eucalypt forests.

Species	Age	Basal area (m^2 ha^{-1})	Stocking Stems (ha^{-1})	Stem biomass (t ha^{-1})	Stand biomass above ground (t ha^{-1})	Source
E. diversicolor	37	26		183.8	225	Hingston *et. al.*,1979
E. diversicolor		37.5		207.9	284	Hingston *et. al.*,1979
E. dives	30–45	16			71.4	Lambert, 1979
E. marginata		68.8			264.5	Hingston *et. al.*, 1980
E. muellerana		30.1	123	195.6	325.4	Stewart *et. al.*, 1979
E. muellerana		22			175.8	Turner *et. al.*, 1992
E. muellerana		54.3			669.8	Turner *et. al.*, 1992
E. muellerana		24.8			211.3	Turner *et. al.*, 1992
E. obliqua	43.7	49.52	914	185.3	242.3	Attiwill, 1979
E. obliqua	50.7	57.6	865	227.8	298	Attiwill, 1979
E. obliqua	60.7	62.67	655	263.4	344.2	Attiwill, 1979
E. obliqua	66.2	64.81	568	282.5	370.7	Attiwill,1979
E. obliqua	70–80	53		338	401	Baker and Atiwill, 1985
E. obliqua	80–90	48.6		183	255	Baker and Atiwill, 1985
E. obliqua	38	65.8	920	344.3	372.5	Feller, 1980
E. pauciflora					117.7	Keith *et. al.*, 1997
E. pilularis		68			865.1	Applegate, 1982
E. regnans	38	49.8	650	558.4	623.8	Feller, 1980
E. rossii	30–45	10.2			62.1	Lambert, 1979
E. signata				58.5	103.6	Westman and Rogers, 1977
E.sieberi		24.2			212.8	Turner *et. al.*, 1992
E.sieberi		26.8			238.2	Turner *et. al.*, 1992
E.sieberi		39.7			358.3	Turner *et. al.*, 1992
E.sieberi		40.6			374.5	Turner *et. al.*, 1992
Average					**299**	

These values are probably towards the higher end of the range of slash left on the site following clearfell harvest of wet eucalypt forests. In most cases fire would have been used in some form to remove debris from the site after clearfelling (Gould and Cheney, 2007). At first, broadcast burning was applied to the material where it had fallen but from the late 1950s, when heavy machinery became available and when it was realised that a site clear of large woody debris would aid future silvicultural and harvesting operations, it became common to heap debris into windrows or mounds prior to burning. The consumption of slash in hot burns is variable but may be typically up to 50 per cent of the available fuel (Raison and Squire, 2007). Such hot fires may also lead to some loss of soil carbon. Thus, fires after clearing native forest may release approximately 25-75 t C ha^{-1}. When windrows were burnt the degree of combustion was often more complete than for the broadcast burns.

Fire would have led to the loss of carbon and nitrogen to the atmosphere. Other losses would occur, particularly in association with erosion due to wind and water. Considerable redistribution of nutrients (especially P) within the site would have occurred if the debris was stacked into heaps or windrows prior to burning. This would include topsoil inadvertently redistributed during the clearing process. Differences between methods used for site conversion can affect subsequent rates of plantation growth and carbon fixation. Sometimes effects on plantation growth are small (Hall and Carter, 1980) but large differences can occur (e.g. on old ash beds).

Conversion of Grassland to Plantation

Australia's grasslands include various temperate, natural grasslands, savanna, and those derived from clearing and conversion of woodlands or forests. Productivity of grasslands varies between climatic zones. In the temperate zone there is usually a marked seasonal pattern of productivity due to the influences of temperature and, particularly, drought. Productivity also depends on grass species composition, occurrence of clovers, fertiliser history and grazing or harvesting practices. Sown pastures can be 2.5 times as productive as native grazing lands.

Standing biomass can vary considerably but is always low when compared with that in an established forest. For example, the yield of a *Paspalum notatum* pasture in southern Queensland varied from 0.2 t C ha^{-1} to 1.7 t C ha^{-1} in winter and summer respectively (Wilson *et. al.*, 1990). In a nearby pasture of *Setaria sphacelata*, biomass was about 3.3 t C ha^{-1} (Cameron *et. al.*, 1989) during summer while pasture roots amounted to 3.0 t C ha^{-1} (Eastham and Rose, 1990). Losses of biomass C from the pasture sites during conversion to plantations would be small. Pastures are often heavily grazed until immediately before planting. Grass was first controlled by scalping or cultivating planting lines but application of herbicides is now included in site preparation. Studies of changes in soil C following plantation establishment on pasture sites have been reviewed by Polglase *et. al., (*2000).

4.2 MANAGEMENT BETWEEN ROTATIONS

Carbon and nutrient losses occur when forest produce is removed from the site. There is a great potential for further loss from harvesting debris or soil before the subsequent rotations are established. Thinning and harvesting operations leave a substantial amount of slash on the site. As slash is an important source of nutrients and organic matter released through decomposition, judicious management of slash would promote the long-term productivity of a site through its role in the

Table 5. Estimates of slash retained after clearfelling *P. radiata* stands.

Age yr	Stocking (stems ha^{-1})	Basal area (m^2 ha^{-1})	Woody material (t ha^{-1})	Foliage (t ha^{-1})	Cones (t ha^{-1})	Total slash (t ha^{-1})	Forest floor (t ha^{-1})	Reference
28	unthinned	–	59.6	9.7	0	69.3	10.2	Flinn *et. al.*,1979
29	360	56.5	79.3	8.2	9.3	96.8	32.6	Madgwick and Webber, 1987
34	962	76.7	162.0	25	0	187.0	16	Balneaves *et. al.*,1991
37	162	33.9	38.6[A]	11.8	1.9	52.3	32.1	Smedhurst and Nambier, 1990

[A] Material larger than 10 cm diameter removed.

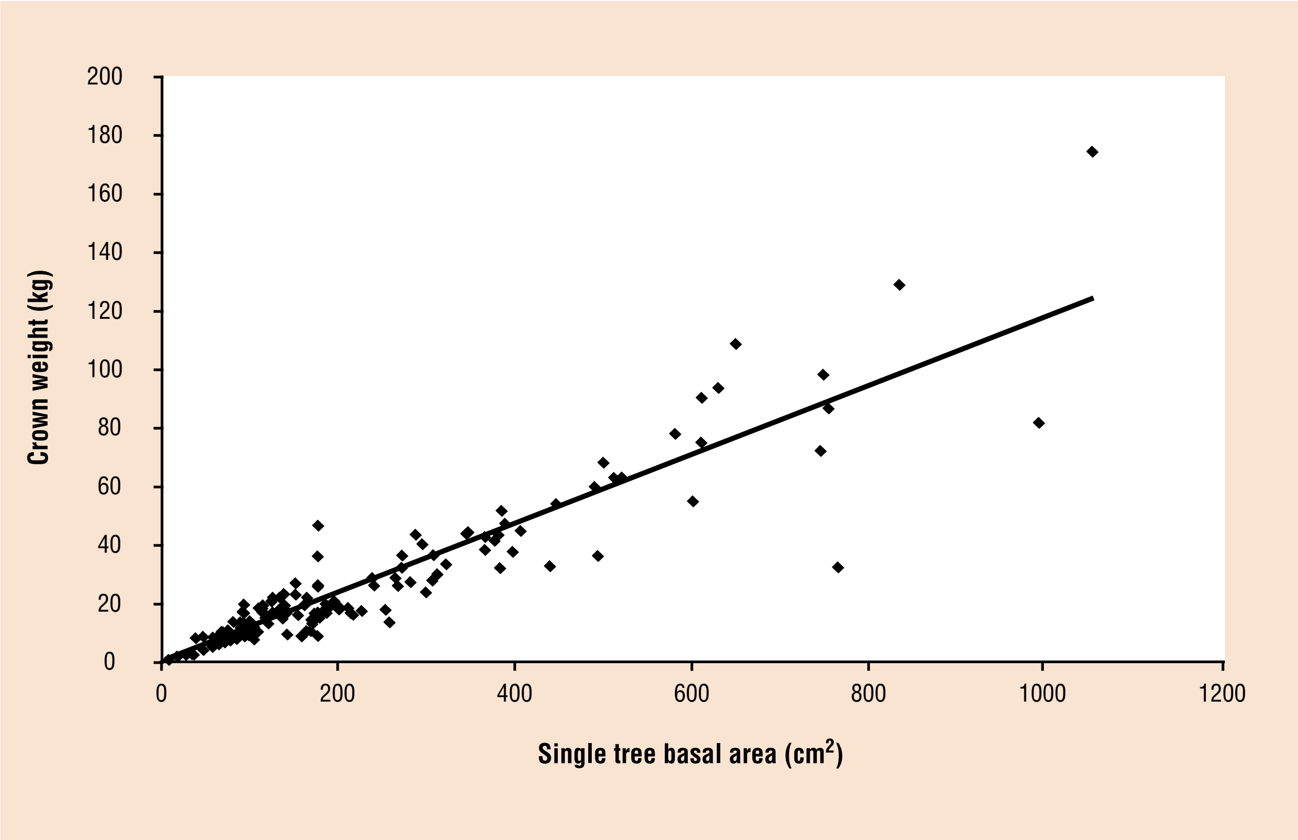

Figure 2. Relationship between crown weight and stem basal area in young *Pinus radiata*.

maintenance of soil fertility. However, slash can also be a hazard as a source of fuel increasing fire risk; as a source of infection and insects irruptions; and by increasing risk of injury in manual operations.

Amounts of residual slash when pine plantations are harvested usually range from 50 to 150 t ha^{-1}. Several examples for Radiata Pine are given in Table 5. Madgwick and Webber (1987) estimated logging residue of stem material to be 15 per cent of the stem and bark removed. The amounts of harvesting residue in Hoop Pine (*Araucaria cunninghamii*) plantations following clearfelling of first rotation plantations has been estimated at 206 t ha^{-1} (Constantini *et. al.*, 1997).

The amounts of various components estimated from stand-based biomass studies can be used to make alternate estimates. For example, Figure 2 illustrates the relationship between average crown (branches, foliage and cones) weight and average single tree basal area for 140 stands of *P. radiata* (Snowdon, unpublished data). Crown weight (CW kg) can be estimated from mean basal area (MBA cm^2) by the formula:

CW = 0.1191 MBA (s.e. = 10.6)

A better estimate can be obtained by including stand age (yr) and its interaction with mean basal area:

CW = 1.45 + 0.1726 MBA – 0.775 Age – 0.002462 Age*MBA (s.e. = 8.0)

The main management options for slash include:

- Broadcast burning of slash after redistribution on the site;
- Windrowing without burning;
- Windrowing followed by burning;
- Slash retention on the site by partial incorporation into the soil (e.g. Chopper rolling); and
- Slash retention with spot cultivation.

The option taken will depend upon the amount and type of slash and the requirement of site preparation for subsequent seedling establishment. There have been major changes in the management of harvested slash (or thinning slash) in plantations. The practice of burning of slash has been reduced to special situations (probably 10 per cent of the harvested area). Slash retention on the site by partial incorporation into the soil (e.g. chopper rolling) is becoming increasingly common and a preferred practice in pine plantations. The principal exceptions occur when very old stands which generate large quantities of logging slash are clearfelled, or, in pre-1970s stands established on native forest sites treated with a pre-planting broadcast burn which has left a legacy of hardwood residue which impedes vehicular access. In these cases the coarse debris is heaped and then burnt.

Flinn *et. al.*, (1979) estimated that the slash burn consumed 84 per cent of the 79.6 t ha^{-1} of harvest residues. However, this option results in the loss of nutrients and soil organic matter. Organic C in podzolised sands is highly dynamic and sensitive to management operations that influence organic C inputs, decomposition or both. Weeds help to maintain organic C reserves after clearfelling, particularly where logging residues have been burnt. Retention of above-ground logging residues also helps to maintain soil organic C reserves. Most harvesting and site preparation operations result in the loss of some of the labile carbon pool. Residue retention and weeds can buffer this pool during the period before significant litter input from the new crop occurs, at which time the pool is replenished. Long-term reductions in soil C occur when there are losses from the recalcitrant pool of soil C. This can result from scalping the site or the use of high intensity fires.

On low fertility soils, retention of slash after thinning or clearfelling plantations can give positive growth responses to the subsequent stand (Hopmans *et. al.*, 1993; Carlyle, 1995). Such improvements are not universal. Smethurst and Nambiar (1990) found no growth difference from *P. radiata* 3 years after planting on areas where slash was either retained or removed. Alternatively, heavy windrowing and heaping of slash prior to planting can decrease the growth of *P. radiata* on the scalped areas (between windrows and heaps) by up to 67 per cent compared with the growth on windrowed or heaped areas, and 28 per cent compared to non-scalped control (Dyck *et. al.*, 1989). It is likely that this unevenness reduces total productivity of the plantation stand.

Site Preparation

A variety of site preparation practices (e.g. complete cultivation, rotary hoeing, ripping, mounding, draining, spot cultivation) have been used prior to plantation establishment depending on soil conditions, topography, and many other local conditions. The available methods are often constrained by the methods used to manage logging slash and residual stumps on the site.

Cultivation, ripping and mound formation all result in the redistribution of nutrients on the site. Although nutrients may be conserved on the site as a whole, localised differences in quantity and concentrations of soil nutrients can lead to differences in tree growth rates. Lack of uniformity within the stand can contribute to lower productivity. Site preparation can result in a degree of weed control that can lead to better and more rapid establishment. Soil disturbance can

Table 6. Summary of changes in *P. radiata* planting stock and spacings utilised by APM Forests (McCarthy and Lieshout, 1991).

Period	Genetic material	Spacing (m)	Stocking (stems ha^{-1})
1960s	Routine seedlings	2.1 x 2.1	2200
1970s	Routine seedlings	3.0 x 1.9	1750
1980s	Orchard seedlings	3.6 x 2.0	1400
1987	Elite cuttings	3.6 x 2.8	1000

promote mineralisation and subsequent losses of soil carbon and increased risks of nutrient losses due to leaching. These can be important on sites where nutrient reserves are already low and can potentially result in decreased stand growth. While the long-term effects of some soil disturbance practices may be small, others, such as the formation of large mounds or drains may persist across crop cycles.

4.3 PLANTING

Most pine plantations are established or re-established by planting. This gives the opportunity for utilising genetically improved planting stock, specified spacing between trees (e.g. Table 6) and optimum control of operations such as ripping, fertilisation and weed control required for successful re-establishment. Seedling stock is commonly used but clonal material (usually cuttings) is attaining increasing importance. Stands established with cuttings are more uniform in growth and have desirable properties, such as small branch size. However, there is no evidence that their biological productivity is greater. For example, Spencer (1987) found that growth rates and total volume production by seedlings and cuttings from a 36-year-old *P. radiata* plantation were similar but the cuttings had better commercial productivity in terms of sawn recovery and yield of veneer. This was attributable to superior stem and tree form.

Genetic Material

Selection of species for particular sites is usually based on their ability to produce good growth and form for the particular circumstances of soil and climate. Thus in Western Australia (WA) and SA, Maritime pine (*P. pinaster*) is generally planted on sites considered too poor for *P. radiata*. In Queensland Slash Pine (*P. elliottii*) and Loblolly pine (*P. taeda*) were used successfully in early plantings. By the mid-1960s Hondurus Caribbean pine (*P. caribaea var. hondurensis*) became the major species in tropical areas (Ryan, 1990). Now it is the major species planted throughout the State. Testing continues with other species and hybrids. Choice of eucalypt species for plantations is also based on matching species performance to soil and climatic factors. With most of the successful plantation species there is a continuing program of genetic improvement based on selection of better seed sources, breeding for improved performance, and selection of superior individuals for the production of clonal material (e.g. Table 6).

Differences in carbon sequestration between species and between provenances within species can be quite large but less productive species or provenances are usually excluded from the plantation programme. Breeding is primarily concerned with improving the quantity, quality and merchantability of timber products. However, the potential for greater production may be constrained

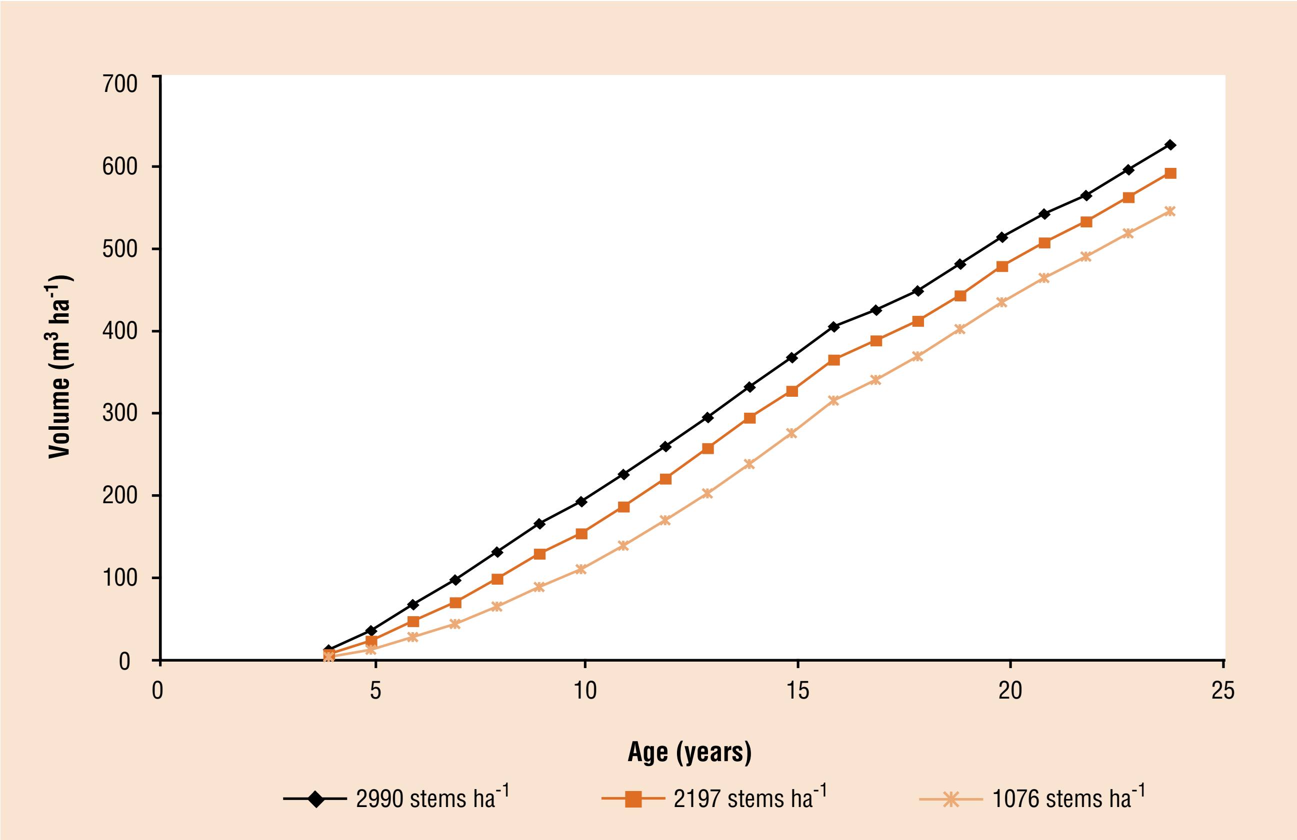

Figure 3. Effect of stocking on volume growth of *Pinus radiata*.

by soil, climatic or influence of silvicultural options, while the potential for greater merchantability will be influenced by the availability of markets and other considerations such as tree form or branchiness.

Stocking

Initial stocking rates in commercial plantations are chosen on the basis of planned thinning practices and end uses for the final crop trees. Row spacing when replanting plantations is often constrained by the presence of stumps from the previous rotation but variation in stocking can be achieved by varying spacing within rows. There is a tendency to space rows wider apart than in the past and to increase the number of trees in rows. This minimises establishment costs but increasing distance between rows can lead to larger branch sizes and subsequent problems with harvesting and processing.

In young stands the rate of biomass production is proportional to the number of stems. The effect of initial stocking on volume production is illustrated in Figure 3 (data from M. Benson, CSIRO Forestry and Forest Products 1990). Initially, the rate of production is directly proportional to the number of stems. This continues until the site is fully occupied, after which time production is constrained by site factors, so that identical rates of increase are obtained irrespective of stocking. In commercial plantations the compromise between establishment costs and requirements of the final product leads to a stocking rate of about 1,000 stems ha^{-1}.

Natural Regeneration

It is common for naturally regenerated seedlings to become established in pine plantations, particularly after heavy thinning has opened the canopy.

The degree of stocking and vigour achieved by natural regeneration is dependent on many factors including species, stand age, thinning history, degree of forest floor disturbance, site fertility and the nature of any competing understorey species. At the end of the rotation the natural regeneration understorey is of uneven age and uneven size, unevenly distributed spatially, and of uncertain genetic quality. During clearfelling operations much of the regeneration becomes damaged. Damaged stems are unsuitable for crop trees in the subsequent rotation and are more subject to invasion by various pests and diseases. Although the use of natural regeneration existing at the time of clearfelling for establishing the subsequent rotation ensures maximum conservation of nutrients and carbon, this option is now rarely chosen because it increases the difficulty of subsequent management operations and negates the opportunity to exploit advances made by tree breeding. Sometimes pre-clearfell natural regeneration is destroyed, commonly by fire, and the subsequent, more or less even-aged natural regeneration is used for the next rotation. In this case poorly stocked areas would need to be filled by supplementary planting and overstocked areas would need to be non-commercially thinned or spaced in order to maximise commercial productivity. Depending on the timing of these operations, it is common that the attainment of commercial production from naturally regenerated stands will be delayed by several years in comparison to stands that have been artificially regenerated (e.g. Whyte, 1973; Snowdon, 2000).

Natural regeneration may not be an option if there is not an adequate seed source. Poor seed production is likely to occur with fast growing species used in short rotations.

Coppice

With some species of eucalypts subsequent rotations can be established by using coppice from the previous crop. There is some evidence that productivity of some species may be reduced after several series of cuttings, and stocking may be reduced by stump death (Evans, 1999). A major disadvantage of using coppice for timber production is that each clump must be thinned to retain, usually, one select stem. Another disadvantage is that utilisation of genetically improved stock is delayed until the coppice stools are replaced.

4.4 CULTURAL PRACTICES

Fertiliser application

There are several circumstances under which application of fertilisers can be used to improve plantation growth:

1. To correct recognised nutrient deficiencies that would otherwise result in economically unacceptable low growth rates, or high levels of deformity or mortality. This is often best achieved when the stand is young and before the stand becomes irreparably damaged.
2. To assist successful plantation establishment, usually by application of fertiliser close to individual trees within a few months of planting, thereby ensuring a ready supply of nutrients to actively growing seedlings.
3. To boost growth in established stands by broadcast application of fertiliser. This is often done before canopy closure on deficient sites which have received spot applications at establishment or on marginal sites where there are no visible signs of deficiency but where there are other indications (e.g. low foliar nutrient concentrations) that nutrients are potentially limiting growth.
4. To hasten recovery from nutrient stress (and hence lowered growth rates) imposed by crown removal during thinning or pruning operations.

The first three practices are widespread and the economic benefits are well understood. However, application of fertiliser in conjunction with thinning operations has been employed only on a limited scale (see below). Fertiliser practice in Australian plantations has been subjected to many reviews (Crane, 1979; Nielsen, 1982; Turner, 1983; Birk, 1994).

Many older Australian plantations were established on infertile soils deficient in phosphorus. Many of these plantations were considered failures because productivity was often less than 6 m^3 ha^{-1} yr^{-1}. Growth rates could be increased by 5 to 12 m^3 ha^{-1} yr^{-1} by application of moderate rates of phosphate fertiliser. On many soils such treatment can rehabilitate sites to the extent that growth in the subsequent rotation may not require further treatment with phosphorus (Waring and Snowdon, 1976; Ballard, 1978; Gentle *et. al.*, 1986). Spot application of phosphate fertiliser is often insufficient to prevent deficiency recurring later in the life of the plantation (Flinn and Aeberli, 1982; Snowdon and Waring, 1990) so one or more broadcast applications of fertiliser applied pre- or post- canopy closure may be needed.

Except in Queensland, where routine application of phosphate fertiliser began in the 1950s (Simpson and Grant, 1991), little attention was paid to application of fertilisers to plantations prior to 1970. However, by 1980 applications were being made to about 24,000 ha annually, more than half being in Queensland and South Australia (Turner, 1983). During the 1980s, fertiliser usage in NSW increased four-fold (Knott and Turner, 1990). Although knowledge about phosphorus deficiency was well known there are still considerable areas that were not, or were insufficiently, treated during the first rotation. Assuming that a large proportion of plantations that existed in 1970 and that required significant additional P had not been treated, nor had they been treated since, about 15 per cent of the 1990 plantation estate would still require remidial P treatment. This is in addition to any fertiliser treatment used to ensure good plantation establishment. In the worst case of no fertiliser treatment, potential productivity on poor sites would have been reduced to one third or less of optimum (Turner, 1984). The majority of these stands would have been harvested and replanted during the 1990s. It is assumed that most of these stands have been treated with sufficient phosphate fertiliser in the new rotation to correct the problem.

Currently, major forest owners tend to use similar fertiliser regimes in second rotation sites as those used on first rotation sites on similar soils (Birk, 1994). There is considerable scope to refine fertiliser practices for second rotation sites, particularly since many of these have previously received fertiliser. Most commercial operations are likely to be using best current practice. However, it is particularly important that previously untreated areas of phosphorus deficiency be identified and treated.

Weed and Pest Control

Historically, woody weeds developing after planting former native forest sites were mechanically removed using hand tools and later with power-assisted tools or by cultivation (Boomsma, 1982). Selective phenoxy acid herbicides became readily available in the mid-1960s and became increasingly important for the control of eucalypt, acacia and other woody weeds in conifer plantations until the early 1980s, when aerial application in particular declined in response to controversy over their use. Scalping or cultivation were traditionally used to control pasture growth prior to planting. In the 1960s herbicides became increasingly important for control of pasture species both before and after planting. Vegetation management practices in Australian and New Zealand softwood plantations have been reviewed by Turvey (1984) and Richardson (1993).

By far the most important forest pathogen which established during the period 1971–95 was *Dothistroma septospora*, the cause of *Dothistroma* needle blight (Dudzinski *et. al.*, 1996). The first recorded outbreak of the disease in Australia was in a NSW Forestry Commission experimental plot of *P. radiata* near Gloucester, NSW in 1975. The disease has spread to Queensland, ACT, Victoria and Tasmania but is not recorded for SA, WA or the NT. In Victoria and NSW the pathogen is now widely established and disease has been periodically severe. The disease is considered to be significant when 25 per cent of the tree crown is defoliated.

In severely affected regions defoliation can be 80 per cent or more. Spray programs are not usually initiated until disease levels reach a 25 per cent threshold. It has been estimated that basal area increment loss at age 20 due to repetitive attacks of disease may be 20 per cent of potential growth.

Australia was free of poplar rust diseases until 1972 and 1973 when two separate species of rust spread quickly through eastern Australia (Dudzinski *et. al.*, 1996). The rusts cause serious to severe premature defoliation in late summer and can result in loss of growth increment. Occurrence of these diseases were important in halting the expansion of poplar plantations.

Australia ranks among the most quarantine conscious countries in the world. Nevertheless, many species of exotic forest/forest product insect pests have been accidentally introduced and have established in Australia since European settlement (Dudzinski *et. al.*, 1996). In the 1950s the introduction of the Sirex Wasp (*Sirex noctilio*) proved most damaging to commercial plantations of exotic *Pinus spp*. It is now widespread in several states. *Sirex* can be especially damaging during periods of protracted drought in unthinned plantations of intermediate age and was responsible for 1.75 million tree deaths in the Green Triangle region of south-eastern SA and south-western Victoria in 1987. Adequate control involves:

1. Maintaining an optimal thinning regime to maintain vigour;
2. Monitoring *Sirex* populations;
3. Introducing biological control agents at appropriate times and levels; and
4. Evaluating distribution and population levels of control agents (Haugen, 1990).

Eucalypt plantations are particularly vulnerable to pests and diseases because of the abundance of populations of causative agents in native ecosystems. Significant pathogens and pests vary markedly between sites while susceptibility to attack varies both between and within the Symphyomytus, Monocalyptus and Corymbia groupings (Simpson *et. al.*, 1997). At present there is insufficient information available on growth rates, crop values, pest and pathogen impacts, and costs of pest and disease management strategies to engage in integrated pest management programs.

Pruning

Pruning trees on plantation edges is often carried out in order to reduce fire risk and susceptibility to pathogens such as *Dothistroma.* Pruning of selected trees is sometimes carried out periodically to reduce the presence of knots in the final product. Pruning brings forward the time when foliage and branch material is deposited on the forest floor. The quantity of prunings will depend on pruning intensity and on the proportion of the stand that is pruned. Forest (1969) estimated that pruning *P. radiata* to 3 m at 7 years of age removed 6.27 kg branch wood and 3.05 kg foliage per tree. There is commonly little effect on stand growth unless the degree of pruning is excessive. Pruning is an important factor in determining the potential products created from the harvested material.

Thinning

Thinning and pruning operations are carried out primarily to improve the quality the final crop in stands managed under a sawlog regime. The manager's capacity to meet the requirements for an ideal regime is often constrained by financial considerations, particularly the current market for thinned trees and the perceived market for the final crop. Until the end of the 1960s there was a strong 'South Australian' influence on thinning practices (Kerruish and Shepherd, 1982). The main aims were that:

1. Every thinning is expected to produce a commercial yield;
2. The site is to be used to full production capacity all of the time;

3. The plantations are to be held in wind-stable condition; and
4. An average final crop tree of 50-60 cm DBHOB was expected in a rotation of 50 years (Lewis *et. al.*, 1976).

Thus, in sawlog regimes with conifers, commercial thinning commonly commences at about 10 to 15 years of age and is repeated in 5 to 6 year cycles. In overstocked stands there is a loss of diameter growth and wind-firmness while in under-stocked stands there may be undue limb development and a heightened risk of wind damage. Within a reasonably wide range of stocking, moderate thinning does not affect total productivity (Horne and Robinson, 1988).

In both Tasmania and WA silvicultural regimes have diverged markedly from the more conventional approach used in South Australia (Kerruish and Shepherd, 1982). Pre-commercial thinning is practiced by removing up to half the stems from a stand at age 6 to 7 years. This is combined with a carefully managed pruning programme to 6 m. There is, at most, one commercial thinning before clearfelling at 25-30 years. There is a substantial loss in production of smaller size classes but final harvest can be advanced by 10 or more years. Silvicultural policies in the other States have tended to be more opportunistic in the sense that management strategies have been modified periodically to respond to the exigencies of the time.

Many of the early Radiata Pine plantations were not thinned or were not thinned on schedule because of the lack of markets for thinned material. Lewis (1987) estimated that 25 to 33 per cent of pre-1956 stands of better site qualities had remained unthinned for more than their first 20 years and that many of them had suffered from protracted thinning intervals as well. Marginal site quality stands in this age segment variously awaited clearfelling or had been converted to useful stands by later-age thinning. Areas of very poor site quality were awaiting clearing for rehabilitation as second rotation plantations established using improved methods.

In the 1956-1965 age segment Lewis (1987) estimated that between 33 and 50 per cent of the better areas were unlikely to have been first thinned before age 20 and as a consequence had high proportions of small wood. There tended to be less marginal site quality stands in this age segment because of policies relating to purchase of better land and the use of fertilisers for early remedy of nutrient deficiencies. In NSW the productivity of private plantings was about 60 per cent of State Forest plantings on comparable land.

Table 7. Average thinning slash produced for each *P. radiata* tree removed (kg) (Burrows, 1980).

Age	Thinning type	Needles	Branches	Stem wood	Total
5	Non–commercial	3.7	5.5	42.1	51.3
11	Non–commercial	8.4	9.8	102.0	120.2
11	Commercial	8.4	9.8	21.8	40.0

The post-1965 segment had the advantage of increasing use of improved planting stock, competition control and fertiliser technology (Lewis, 1987). This resulted in greater proportions of higher site quality, fully-stocked, evenly-grown, close-spaced stands. However, the rapid increase in planting rates carried a high potential for thinning backlogs and the same undue proportions of smallwood sizes and sub-optimal proportions of better sawlog sizes, as characterised the older age segments.

Slash resulting from early thinning has been estimated for *P. radiata* in Western Australia (Burrows, 1980). The older stands would have been about 17 m tall. Thinning was based on the removal of subdominant and co-dominant trees. Slash consisted of stems with diameters generally less than 14 cm. About 79 per cent of the stem material was harvested. The total weight can be calculated by multiplying average weight (Table 7) by the number of stems removed.

Data from Madgwick *et. al., (*1977) indicate that the average weight of trees thinned from an 8-year-old Radiata Pine stand (Height (H) = 11 m, Basal area (BA) = 29.4 m^2 ha^{-1}) near Rotorua NZ would be about 36.3 kg. At Puriki, NZ the average weight of trees thinned at 6 years (H=8.4 m, BA=34.7 m^2 ha^{-1}), 7 years (H=8.2 m, BA = 34.9 m^2 ha^{-1}) and 8 years of age (H= 9.1 m, BA= 38.9 m^2 ha^{-1}) were 34.7, 34.9 and 38.9 kg respectively (Beets and Pollock, 1987).

Williams (1977) estimated that there were 22 to 27 t ha^{-1} of fine and coarse (>6 mm diameter) ground fuels under unthinned 12-year-old *P. radiata* stands in north-eastern Victoria. From 76 per cent to 80 per cent of the stems were merchantable to a 10 cm DBHOB. After thinning, residues were increased by 19 to 26 t ha^{-1}. Carlyle (1995) estimated that an average of 41.3 kg of slash per tree removed after commercial thinning of a 10-year-old *P. radiata* stand (BA = 36.2 m^2 ha^{-1}) at Mt. Gambier. The equations for predicting crown weight for individual trees of Radiata Pine given above can be used to estimate the crown component of thinnings.

Application of Fertiliser at Time of Thinning

Later age application of fertiliser to hasten growth recovery after thinning is now a standard practice. The additional growth due to application of fertiliser can amount to 5-15 m^3 ha^{-1} yr^{-1} for four to five years after thinning (Snowdon 1995). Often the responses are much less than this. For example, responses obtained in field operations may be 15 to 40 per cent less than those obtained in experimental conditions (Drielsma *et. al.*, 1990). Responses may be obtained from applications of phosphorus or nitrogen made singly or may sometimes only be obtained when both are applied. In order to obtain maximum benefit from the technique a site specific treatment approach must be adopted in which areas for treatment are stratified according to site and stand factors (Turner and Knott, 1991).

Post-thinning fertiliser application is commonly viewed as a tool for increasing future wood production, but it can also be used to justify heavier than normal thinning to meet immediate demands for timber (Turner and Knott, 1991). Use of later age fertilisation in combination with thinning is slowly being put into practice. For example, in NSW only about 2,500 ha were treated during the period 1983 to 1989 (Knott and Turner, 1990). In recent years, increasing areas are being treated in SA.

Fire Management – controlled Burning

Considerable attention is placed on protection of the plantation estate from loss by wildfire. Normally a proportion of the estate's land base will be excluded from plantation operations to form firebreaks. Controlled burning is usually practiced in adjacent native forest or grassland to reduce flammable vegetation and litter and thus further reduce the risk of fire in the plantation. Controlled burning is not commonly used to reduce fire hazard within Radiata Pine plantations, however, hazardous material such as pruning or thinning slash may be removed from the edges of stands and burnt at roadsides or in firebreaks.

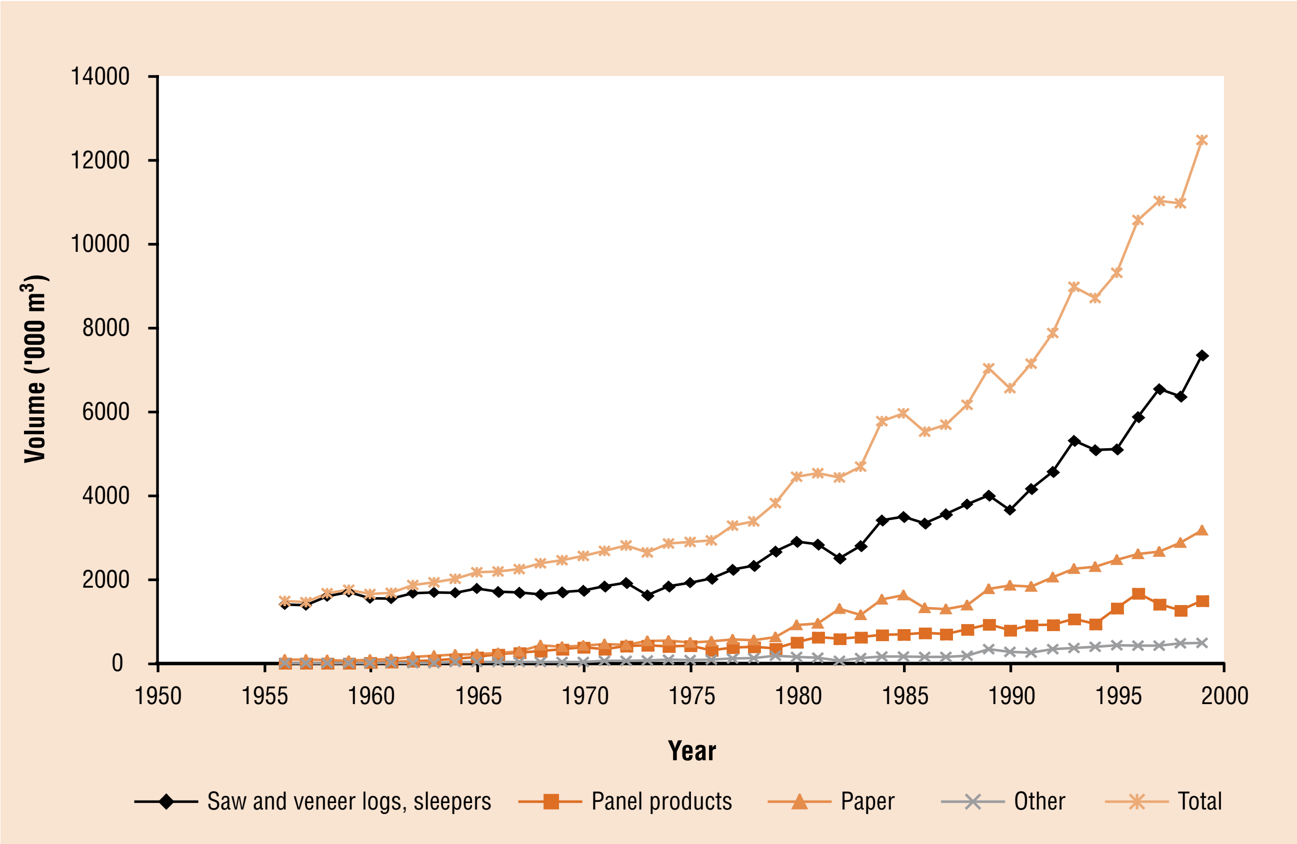

Figure 4. Roundwood removals from softwood plantations and its use for various forest products.

Queensland is the only State where controlled burning is used as a regular practice within tropical and sub-tropical pine plantations. A 3-year study on the growth and nutrition of 13-year Slash Pine stands found that soil organic C in the surface soil (0-2.5 cm) decreases significantly as a result of repeated fuel reduction burning (Hunt and Simpson, 1985). Such concerns about long-term fertility changes have led to the current practice of burning most plantations no more than twice during a rotation (Francis and Shea, 1987).

4.5 FINAL HARVEST

Initially there were few markets for small wood so most softwood production was for large size logs for sawn wood or veneer (Figure 4). By the end of the century, products from larger logs accounted for only about 60 per cent of total output. In the past, clearfelling of pine stands was often in the range 40 to 50 years of age. It is now more common for stands to be clearfelled at around 30 years of age. In the interim many sawmills re-tooled to suit the optimum sawing of smaller log sizes. As a consequence, it has now become more difficult to market large-size logs. It is also difficult to market wood from minor species whose wood properties do not suit local mills and whose products are unknown in the marketplace. Because the hardwood plantation resource is on average very young, roundwood removals are still very low; amounting to only 839,000 m^3 in 1999-2000.

Changes in genetic stock, improved stand management, and increased mechanisation of harvesting operations has lead to the expectation that a higher proportion of forest biomass is harvested than was previously achieved. This is not necessarily the case because the proportion of merchantable material removed at harvest will depend on the availability of markets and on the

Table 8. Mean annual volume increment MAI, (m^3 ha^{-1} yr^{-1}) for wood production for Australian plantations.

Region No.	Region	Species	Age (yr)	MAI
1	WA	*P. radiata*	30	20.7
		P. pinaster	40	10.0
		E. globulus	10	25.0
2	Tasmania	*P. radiata*	30	20.0
		E. nitens	20	15.0
3/4	SA andVic	*P. radiata*	30	20.8
5	Central Vic	*P. radiata*	35	12.4
6	Murray	*P. radiata*	30	15.0
7	Gippsland	*P. radiata*	30	20.0
8	Bombala	*Eucalyptus*	30	22.0
8/9/10/11	NSW	*P. radiata*	30	15.7
12	NSW	Sthn. pine	30	15.2
		Eucalyptus	45	9.1
13/14	QLD	Southern pines	30	9.0
		Hoop Pine	50	13.4
SA	SA Site Quality I	*P. radiata*	30	33.4
	SA Site Quality II	*P. radiata*	30	29.7
	SA Site Quality III	*P. radiata*	30	26.1
	SA Site Quality IV	*P. radiata*	30	22.2
	SA Site Quality V	*P.radiata*	30	17.8
	SA Site Quality VI	*P. radiata*	30	13.3
	SA Site Quality VII	*P. radiata*	30	8.9
NSW	Mullions Range NSW	*P. radiata*	48	8.5
	Lidsdale NSW	*P. radiata*	47	9.0
	Sunny Corner NSW	*P. radiata*	45	15.1
	Gurnang NSW	*P. radiata*	45	15.0
	Jenolan NSW	*P. radiata*	46	16.3
	Canobolas NSW	*P. radiata*	33	15.8
	Bondi NSW	*P. radiata*	46	15.7
	Nalbaugh NSW	*P. radiata*	50	16.3
	Buccleugh NSW	*P. radiata*	46	16.3
	Batlow NSW	*P. radiata*	48	18.6
	Mullions Range NSW	*P. radiata*	49	12.6
Victoria	APM Forests	*P. radiata*	30	26.0

marginal costs associated with harvesting smaller piece sizes. For example, provided there were markets for small sized logs, very high recovery rates were often achieved when manual methods were used for harvesting. With mechanised methods the degree of recovery can be constrained if the need to remove large branches is perceived to unduly increase marginal costs. There may also be a market preference for pulpwood from first rather than later thinning operations so that recovery in the latter will be reduced. In the final felling of the largest plantation stands, where individual stem dimensions exceed machine capability, mechanised felling and processing at stump is sometimes replaced by manual methods. Manual methods are also used where there is a need to remove large stem material to ensure efficient chopper rolling of harvesting residues before establishment of the next crop.

The common feature of all of the above systems is the removal of most branch and top material at the stump. Collection of this material for energy production will require modifications to current systems. Recently, a new system based on integrated delimbing/debarking/chipping has been introduced to NSW forests and elsewhere for harvesting of small sized thinnings. The technology has been in widespread use overseas for about a decade. Traditionally, chipping is undertaken at the processing plant, with raw material transported in log form. In these new operations, chipping is undertaken at the roadside in the forest. A large portable chipper unit that also incorporates a flail delimbing/debarking in-feed unit is located at the roadside edge of compartments to be harvested (usually a *P. radiata* plantation). Whole stems are transported to the delimber/debarker/chipper for processing into waiting chip vans. These systems usually recover a greater proportion of stem wood.

5. EVALUATION OF THE EFFECTS OF MANAGEMENT ON THE CARBON BUDGET

5.1 SEQUESTRATION

Growth Rates

Growth rates for plantations are often expressed as mean annual increment (MAI) in wood volume production. Usually this is evaluated over the full rotation length because annual growth rates vary with stage of stand development and, to a lesser extent, climatic factors. Plantation growth rates vary with species, site conditions and silvicultural management regimes. Table 8 reports growth rates for several plantation species grown in different regions within Australia (Turner and James, 1997), for different site qualities in South Australia (Lewis *et. al.*, 1976) and for several districts in NSW (Forestry Commission of NSW, 1981; 1984a; 1984b; 1987).

Table 9 illustrates the manner in which various silvicultural treatments can affect growth rates. Since silvicultural treatments change over time, it is expected that growth rates on similar sites will also change over time. Thus Whiteman *et. al.*, (1993)

Table 9. Mean annual increment for volume (m^3 ha^{-1}) for *P. radiata* according to site productivity and establishment practice (Turner, 1984).

Treatment	Unimproved nutrition status		
	Low	Moderate	High
Plant only	5	14	18
Plant + fertiliser	14	15	–
Plant + fertiliser + plough/weed control	15.5 [A]	17	24
Site Potential (Inferred from Ash bed growth)	17	19	–

[A] with later age fertilization.

found that the MAI (11 years) of *P. radiata* stands established in the period 1975-1982 was on average 51 per cent greater than stands established during 1950-1971. The degree of change depended on soil type with stands on fertile gradational clay loams increasing by 31 per cent, stands on duplex soils by 46 per cent, and stands on infertile sands by 76 per cent.

An important consequence of changes in silvicultural management is that the shape of the plantation growth curve can change. Growth curves are constructed from measurements taken from yield plots. With conifers the data usually cover a period of 30 years or more. Thus, growth and yield curves developed from data obtained from these older stands may be representative of silvicultural treatment no longer used in current management practice. To this extent the application of existing growth curves (e.g. Lewis *et. al.*, 1976; Turner and James, 2001) to estimate the growth of stands after application of new management techniques are likely to give misleading results.

Type 1 and Type 2 Responses

This dilemma can be partially resolved by considering how stands respond to different management options. There are two basic patterns of response in volume increment to silvicultural treatment. These have been defined as Type 1 and Type 2 responses (Snowdon and Waring 1981, 1984; Snowdon, 2001). Type 1 responses are characterised by a temporary increase in growth rate that reduces the time needed for the stand to reach a given stage of maturity or stand development (e.g. as indicated by a given stand basal area or a specified mean dominant height). Thereafter, the treated and non-treated stands follow parallel growth trajectories with a constant separation in time. In stands treated at or soon after establishment, peak current annual increment (CAI) in volume will be of about the same magnitude but will occur earlier in responding stands. Type 1 responses are analogous to the concept of a 'decrease in environmental resistance' (Switzer, 1978; Boardman and Simpson, 1981); the proposal that fertilisers are generally of benefit to the trees rather than the site (Miller 1981); and the concepts of 'biotic enhancement' and 'cultural enhancement' proposed by Burger (1994). Type 1 responses are obtained with treatments that have little or no sustained effects on soil or site properties. Examples include application of starter fertiliser at planting on fertile sites, weed control, and application of N-fertiliser after thinning or pruning. Mason (1996) has discussed the assumptions necessary in order for a treatment to produce a pure Type 1 response.

Type 2 responses are characterised by a sustained change in stand productivity, particularly as measured by volume increment at its peak or culmination. Growth responses for volume tend to increase with time so that the yield curves for treated and non-treated stands become divergent. In stands treated at or soon after establishment, peak volume CAI will increase and will occur earlier in responding stands. When a Type 2 response occurs after treatment in an older plantation there may be a second peak in CAI. Type 2 responses typically occur when the treatment has a large and sustained effect on site properties. They are broadly analogous to an increase in site carrying capacity (Switzer, 1978; Boardman and Simpson, 1981) which is the asymptotic value of total stand production or to 'abiotic enhancement' (Burger 1994). Type 2 responses typically occur when the capacity for the site to supply a limiting nutrient is enhanced and the improvement in nutrient-supplying capacity is sustained in the long term. For example, a moderate application of phosphorus fertiliser to a P-deficient site can rehabilitate sites to the extent that growth in the subsequent rotation will not require further treatment with phosphorus (Waring and Snowdon, 1976; Ballard, 1978; Gentle *et. al.*, 1986).

Table 10. Age for *P. radiata* to obtain 170 m^3 ha^{-1} according to site productivity and establishment practice (Turner, 1984).

Treatment	Unimproved nutrition status		
	Low	Moderate	High
Plant only	>30	15	12
Plant + fertiliser	15	13.5	–
Plant + fertiliser + plough/weed control	14[A]	12	10
Site Potential (From Ash bed growth)	13	11	–

[A] with later age fertilization.

Responses to Differences in Genetic Material

While tree breeding can lead to substantial gains in commercial productivity, it is also important to know whether genetic improvement is characterised by Type 1 or Type 2 responses. Unfortunately, there are few experiments where long-term comparisons of different genetic material (either within or between species) have been made under stand conditions (as opposed to single tree or row plots), and which have sufficient measurements to characterise the nature of the growth response. Growth multipliers are sometimes calculated from data from such experiments for inclusion in growth models (e.g. Nance and Wells, 1981; Carson *et. al.*, 1999). In effect, such analysis implies a simple scaling of the growth curve, which in turn implies a Type 2 response. Usually insufficient data are published to allow alternate analyses to be made (e.g. Snowdon, 2001).

Under plantation conditions, differences between genotypes are first expressed by their exploitative capacity to capture growing space by fast early growth. On highly fertile, well watered sites it is conceivable that the capacity for faster growth by some genotypes could continue to be expressed throughout the useful life of the plantation. This would be considered a Type 2 response. Under Australian conditions it is more usual for pine plantation growth to become constrained by the availability of water or nutrients. Differences between breeds or genotypes within species in the relative efficiency with which they utilise limited resources are probably small and difficult to measure in terms of stand growth. Consequently, under these circumstances, the differences between genotypes could be regarded as a Type 1 response.

Responses to Establishment Practices

Growth responses obtained to differences in establishment practice can usually be regarded as Type 1 responses. It is likely that the time needed to attain maximum response will vary amongst different classes of treatment (i.e. site preparation, weed control, starter fertiliser). Complexities will also arise regarding different rates of treatment and the presence of interactions between treatments. As a consequence it may be difficult to assess the amount by which the stage of stand development has been enhanced. On moderately productive sites in Australia it takes 15 years for *P. radiata* to obtain 170 m^3 ha^{-1}. Turner (1984) has estimated that ploughing in combination with weed control and a spot application of NP-fertiliser to stimulate growth immediately after planting can reduce the time taken to achieve this volume by three years (Table 10). On high productivity sites the gain is only two years. Lesser gains are obtained particularly when weed control is not included in the treatment combination. These estimates provide reasonable estimates of the degree of stand advancement that can be achieved but the age when peak response is achieved is unknown. Snowdon (2001) found that large responses to total weed control during the first three years of plantation establishment took about 12 years to develop fully.

Table 11. Mean current annual basal area increment of untreated *P. radiata* stands, growth response and stand advancement due to application of N-fertiliser evaluated five years after treatment for various trials.

Location	Foliar N (%)	Age (yr)	Initial BA (m^2 ha^{-1})	Mean CAI (m^2 ha^{-1})	Response (m^2 ha^{-1})	Advance (yr)	Reference
Basal area Response							
Santoft, NZ	0.60	11	11.9	1.92	5.40	2.00	Hunter and Hoy, (1983)
Eyrewell, NZ	–	7	4.8	3.62	4.70	1.03	Mead *et. al.*, (1984)
Pierces Ck., ACT, Aust.	1.13	15	27.7	3.57	1.54	0.45	Snowdon, (2001)
Nelson (N143), NZ	1.15	11	6.9	2.87	2.83 *	0.89	Mead and Gadgil, (1978)
Tumut (B), NSW, Aust.	1.17	15	26.0	1.89	2.09 *	0.85	Snowdon *et. al.*, (1995)
Belanglo (B), NSW, Aust.	1.29	18	25.4	2.20	2.40	1.04	Snowdon and Waring, (1990)
Tumut (A), NSW, Aust.	1.49	16	19.2	2.00	1.50	0.94	Snowdon *et. al.*, (1995)
Mt. Gambier (EM99) Aust.	1.50	12	20.6	2.73	2.88	1.09	Carlyle, 1995†
Vulcan, NSW, Aust.	1.55	24	25.0	1.97	2.17 *	0.90	Turner *et. al.*, (1992)
Vulcan, NSW, Aust.	1.55	24	20.0	1.95	0.83 *	0.39	Turner *et. al.*, (1992)
Volume Response			**Initial volume (m^3 ha^{-1})**	**Mean CAI (m^3 ha^{-1})**	**Response (m^3 ha^{-1})**		
Tokoroa, NZ	–	14	212	46.8	65	1.18	Woollons and Will, 1975
Tokoroa, NZ	–	14	151	37.6	37	0.80	Woollons and Will, 1975
Tumut (A), NSW, Aust.	1.49	16	187	29.8	27 *	0.75	Snowdon *et. al.*, 1995

† Clive Carlyle, CSIRO Forestry and Forest Products, *pers comm.*, 1995.
* Estimated by extrapolation or interpolation.

Responses to Later Age Fertilization

In the case of application of N-fertiliser at the time of thinning, there is evidence that the major component of the Type 1 response is achieved about five years after treatment (Woollons and Will, 1975; Hunter and Hoy, 1983; Mead *et. al.*, 1984; Hunter *et. al.*, 1986; Snowdon and Waring, 1990; Turner and Knott, 1991; Snowdon *et. al.*, 1995). Data were chosen from field trials which had a measure of initial stand basal area (or volume) and at least one measurement taken four, five or six years after treatment. If no direct measurement was available at five years, the best available data were used to estimate the five-year measurement by linear interpolation or extrapolation. These estimates were then used to calculate the five-year growth response.

The time advantage due to the Type 1 response was obtained by using the best available data to estimate the age at which the treated stand achieved the basal area obtained by the untreated stand five years after treatment.

Examination of a number of trials indicated that the average advance in stage of stand development five years after treatment was about one year (Table 11). The magnitude of response at five years is closely related to the annual growth rate in the untreated stands. In one trial the gain was two years but foliar analysis indicates that it had been severely deficient in nitrogen before treatment. At Vulcan, NSW and Tokoroa, NZ both absolute response and degree of stand advancement were reduced in the more heavily thinned stands. Both measures of response were also low at the Biology of Forest Growth (BFG) site near Canberra, ACT but there is no evidence to suggest why this occurred. Care needs to be taken in applying this method of estimation to ascertain that there are no interacting factors, such as degree of thinning or response to other nutrients (particularly phosphorus), which could bias the parameter estimates.

Changes in Soil Carbon

Polglase *et. al., (*2000) have recently reviewed the effects of reforestation and afforestation on changes in soil carbon. Data from published and unpublished sources were highly variable, indicating that predicting change on a specific site is very difficult. When averaged, the following trends were evident:

1. There was a general trend for soil carbon to change with plantation age;
2. Changes in the surface 10 cm layer of soil occurred most rapidly during the first 10 years after afforestation, achieving an average rate of loss of –140 kg C ha^{-1} yr^{-1} or 0.15 per cent yr^{-1} change in the initial amount of soil carbon;
3. There was little change in soil carbon within the 0-30 cm layer during the first 10 years but it increased over 19 years at an average of 2,630 kg C ha^{-1} yr^{-1} or 0.36 per cent of the initial content;
4. Although it is generally believed that soil disturbance such as ploughing, ripping or mounding accelerate decomposition of organic matter, there were no clear effects of site disturbance on soil carbon;
5. Former pasture generally has a high carbon content in the 0-30 cm layer that can be lost at an average rate of 97.5 kg C ha^{-1} yr^{-1} during the first 10 years;
6. Former cropland generally consists of stable humus resistant to further loss, so soil carbon should slowly accumulate at an average rate of 14.2 kg C ha^{-1} yr^{-1};
7. Climate significantly affects change in soil carbon after afforestation;
8. Soils with high clay content have a relatively high potential for accumulation of soil carbon; and
9. Differences in site management, including selection of species, weed control, fertiliser application and use of fire for fuel reduction can influence soil carbon.

6. DISCUSSION

6.1 SITE CONVERSION

Conifer plantations increased from about 100,000 ha at the end of World War II to about 1,000,000 ha at the end of the century. Eucalypts and other hardwood species were initially a minor part of the plantation estate but rapidly increased from about 100,000 ha in 1990 to about 500,000 ha in 2000 (Figure 1). The total area of softwood plantations has not varied much since 1990, so it can be assumed that the total rate of C-fixation will stabilise in the near future unless there is a change in area devoted to softwood plantations. The area of hardwood plantation is still increasing so it is unknown if or when total C-fixation by this portion of the plantation estate will stabilise.

Until the mid-1960s most new areas for softwood plantation were derived from native forest or scrublands. Thereafter an enlarging proportion was established on pastoral or agricultural land that often contained a variable amount of woodland or other woody vegetation. By the mid-1980s, clearing of native forests for the establishment of plantations had substantially ceased. Some of the early hardwood plantations were established after clearing native forest. However during the rapid expansion of the 1990s, most hardwood plantations were established on farmland. These changes in land use result in changes in the capacity to store carbon. From the available data on previous land use, in the year 2000 about 53 per cent of the plantation estate has been established on agricultural land, 21 per cent on former native forest land and 20 per cent are later age rotations on prior plantation land (Wood *et. al.*, 2001).

The aboveground biomass of native forests and woodlands converted to plantations probably lies in the range 50 to 300 t ha^{-1} (Table 4; see also Commonwealth of Australia, 1997). Pastures carry up to 3 t ha^{-1} of forage depending on seasonal conditions (Cheney *et. al.*, 1980) but scattered trees could raise the amount of carbon stored to 50 t ha^{-1}. The average (across age classes and species) aboveground biomass of plantations has been estimated to be 244 t ha^{-1} (Commonwealth of Australia, 1997). This estimate was made on Australia's maturing plantation estate and should not be considered to be a stable value. Different species and broadly different management regimes (e.g. sawlog, pulp) need to be considered separately because each combination will have its own typical average biomass density which will not stabilise until the age classes within the combination are approximately evenly distributed. On average, conversion of native forests, woodlands and pastures to plantations, has resulted in an increase in aboveground biomass density of those lands.

During conversion of native forests for plantation forestry some wood was salvaged as sawn wood, fencing materials or firewood, but the major proportion was burnt, releasing CO_2 and other gases to the atmosphere and converting some of the wood to resistant charcoal. Broadcast burning was carried out until the mid-1960s on most sites. While leaf and twig material may be totally consumed in broadcast burns, decreasing amounts of woody material are consumed as piece size increases so that only about 25 per cent of the larger (>20 cm diameter) logs are burnt (e.g. Cheney *et. al.*, 1980). Windrowing and heaping became the favoured practices for preparing sites for burning because more complete burning could be obtained, burning operations were safer, and the site was thereafter more accessible for machine operations. Cheney *et. al., (*1980) estimate that 50 to 100 t ha^{-1} of biomass is consumed when native forest or woodland is cleared for plantation establishment or agriculture. Total loss of carbon through burning probably peaked during the 1970s and then declined as an increasing proportion of new plantings were made on agricultural land.

From the 1970s a rapidly increasing proportion of softwood establishment was on second or later rotation sites. Slash from the harvesting operation is often in the range 50 to 150 t ha^{-1} (Table 5). Broadcast burning or windrow burning was commonly practiced between rotations in the early years. These ractices were associated with loss of fertility and decline in growth. By the mid-1980s retention of logging slash was seen as desirable so a variety of practices (e.g. chopper rolling) were developed to break the slash into smaller pieces and incorporate it into the soil. Alternatively, the new crop was often planted in lines cleared through the slash. Only small areas of eucalypt plantation have so far entered their second or subsequent rotations, but slash conserving methods are now commonly used for site preparation. When burning was practiced carbon would have been lost immediately to the atmosphere and some would have been retained as charcoal. With slash retention, loss of carbon to the atmosphere via decomposition is a gradual process, with some carbon being transferred to soil organic matter.

6.2 GROWTH RATES

In even aged stands, such as plantations or native forests regenerating after substantial disturbance such as wildfire or clearfelling, growth rates are at first rapid during establishment and juvenile stages (e.g. 4-6 tC ha^{-1} yr^{-1} for medium dense eucalypt forest). As the stands mature or become senescent growth rates drop to very low levels (<0.5 tC ha^{-1}) (NGGI 1999). Most of the native forests converted for plantation development were of lower quality, in terms of merchantable products were relatively mature with low growth rates, and were not considered suitable for timber production. Carbon fixation of grasslands is intermediate in value but because turnover is high there is negligible net accumulation of biomass.

The maximum mean annual increment (MAI) for volume culminates at about 30 years for fast growing softwoods (e.g. Lewis *et. al.*, 1976). Maximum stem growth rates in individual stands can vary from 9 to 33 $m^3 ha^{-1} yr^{-1}$ of harvestable stemwood according to site quality. This is equivalent to 3.3 to 11.9 $tC ha^{-1} yr^{-1}$ total increment in the aboveground biomass. For the plantation estate as a whole the average rate of sequestration will depend on the distribution of stands across various site qualities and the age class distribution within site qualities. The average age of Australian softwood plantations in 1990 was 15 years (calculated from age distribution given by the National Forest Inventory, 1997). By assuming an estate wide maximum MAI of 22.2 $m^3 ha^{-1} yr^{-1}$ (SQ IV), the corresponding MAI at 15 years would be 18 $m^3 ha^{-1} yr^{-1}$ which indicates an average of 6.5 $tC ha^{-1} yr^{-1}$ increment in the total aboveground biomass. This is consistent with estimates given by Kirschbaum (2000). By 2000 the average age of softwood plantations had increased to 18.2 years (based on Wood *et. al.*, 2001) corresponding to an increase to 7.1 $tC ha^{-1} yr^{-1}$ total increment in the total aboveground biomass. Hollinger *et. al.*, (1993) estimated that the average sequestration into total biomass (including roots) of New Zealand plantations in 1988 was 6.4 $tC ha^{-1} yr^{-1}$.

Changes in silvicultural and other practices over the past 50 years have influenced both peak current annual increment (CAI) achieved by plantations and the age at which this is achieved. Improved site selection has been coupled with improved soil management. While many early plantations were established on phosphorus deficient sites these have now for the most part been rehabilitated, often resulting in a doubling of peak CAI. Drainage of wet sites has also led to marked increases in productivity. Large changes in peak CAI have a substantial effect on MAI and thus the average sequestration rate of the plantation estate will have increased.

Other practices such as improved weed control and improved genetic stock have reduced the time required to achieve peak CAI but do not affect peak CAI. The effect of these treatments is to slightly increase MAI and average sequestration rates. Rotation length has also been shortened since the 1950s so that harvesting now takes place closer to the time of peak MAI. This has the effect of slightly increasing average MAI for the plantation estate. Better monitoring of forest conditions has enabled silvicultural operations to be carried out on time and in an effective manner. Similarly, effective monitoring and appropriate responses have minimised losses to insect pests, diseases and fire.

6.3 HARVESTING

Harvesting of softwoods has increased over the period (Figure 4). Since harvesting lags behind establishment, softwood biomass production should continue to increase for about another 20 years. Further increases will then depend on resumption of planting new land or improvement in silvicultural and other practices. Average annual roundwood removals from softwood plantations are currently about 2.5 $tC ha^{-1} yr^{-1}$. This is comparable to an estimate of 2.7 $tC ha^{-1} yr^{-1}$ for New Zealand plantations (Hollinger *et. al.*, 1993). Extraction of roundwood from hardwood plantations averages only 0.4 $tC ha^{-1} yr^{-1}$ because of their comparatively young age. Production rates will rise rapidly in the near future.

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9. APPENDICES

9.1 APPENDIX 1

HISTORICAL DEVELOPMENT OF SILVICULTURAL PRACTICES.

There have been many and varied changes in silvicultural practice since 1945. The approach used here is to document:

1. The general history of forestry on a State by State basis using a variety of information sources which document or may assist in interpreting changes that have taken place; and
2. Specific details of stated policies for silvicultural management at particular times.

Both sets of information are generally given in tabular format. This information forms the primary source for the tabulated changes in management practices required of this consultancy (see Appendix 2).

Table 12. Significant events and changes in the silviculture of pines in South Australia.

Year	Significant events or changes in silvicultural practice
1883	Woods and Forests Department established with sole emphasis on plantations as the principal forest resource.
Pre-1926	Sites completely cleared of scrub then ploughed before planting.
Post-1926	Native forest felled, broadcast burned then planted in pre–pitted holes.
1931	Sawmill opened Mt. Burr (Brown, 1976).
1935	Permanent sample plots established to determine trends of growth with age, site and spacing. Thinning studies commenced.
1936	Clearfelling followed by second rotation cropping commenced.
1936-37	First aerial photographic survey of forests.
1940	Sawmill opened Nangwarry (Brown, 1976).
1940	Routine spraying in South–east region to correct zinc deficiency commenced.
1941	Cellulose Australia Ltd. Pulp and paper mill started at Snuggery utilised small logs from thinnings. www.forestry.sa.gov.au/history.htm
1941	Soil and topographic survey of the South–east region completed with aim of establishing a relationship between soils and forest site quality.
1947	Stocking rate 1680 to 2200 stems ha^{-1} (Lewis, 1957).
1948	Sawmill opened Mt. Gambier (Brown, 1976).
1948	Routine application of ortho–superphosphate (OSP) begun in Adelaide Hills forests on lateritic podsolic soils.
1950	N.W. Jolly Provisional Thinning Schedule introduced.
	3000 ha 20–24 year old pine burnt at Penola.
1956	First fourth thinning in 1922 plantation (Lewis, 1957).
1957	Production of particle board from small logs commences. www.forestry.sa.gov.au/history.htm
1958	First production seed orchards established.
1959	Opening of third State–owned sawmill at Mt. Gambier enables full utilisation of plantations.
1960	Comprehensive silvicultural guidelines made available to managers on seedling culture, control of woody regrowth with herbicides, and application of zinc and OSP fertilisers to plantations.
	Routine phosphate application restricted to low site–class sites with wet–site moisture status (Boardman,1974). First Thinned–Stand Yield Table produced (Lewis *et. al.*, 1976)

Table 12. Significant events and changes in the silviculture of pines in South Australia.

Year	Significant events or changes in silvicultural practice
1963	First version of Optimum Thinning Range introduced (Lewis *et. al.*, 1976).
1964	Acknowledgement of second rotation decline of about 25 per cent in yields from replanted plantations in the South–east region. About 85 per cent of second rotation stands across all site classes affected. Systematic use of 1080 poison begun.
Mid-60s	Forest Reserve becoming fully planted with additional planting land dependent on purchase of more or less cleared land reverting from agriculture.
1966	Defects in seedling production and inadequacies in ground preparation, vermin control, transplant handling, planting technique and adequacy of residual weed control identified as deficiencies contributing to poor survival and reduction in yields at first thinning.
1976	Introduction of Maximum Growth Sequence (MGS; Woods, 1976) combining cultivation with application of herbicides and fertilisers during the first five years of plantation established as general practice in the South–east region.
1979	Caroline fire destroys 3,000 ha of 2 to 19 year old pine.
1979-80	Chopper roll trial at Penola.
1980	First observations of *Sirex noctilo* wood wasp and Ips grandicollis bark beetle in South east region. Program developed for release of parasitoids for Sirex.
1981	Fertiliser regime revised for Central Region on basis analogous to that used in the South East region. Post canopy closure (7–12 years) and post 1st thinning (18–25 years) applications on low site quality stands.
1982	FM3 fertiliser replaced with FM4 in 10 to 14 year old stands. Introduction of trash rolling in second rotation site preparation.
1983	February 16. 16,814 ha of South–east plantations destroyed by Ash Wednesday fire plus 2,920 ha in the Adelaide Hills.
1984	Site–specific modification of MGS in interests of economy and efficiency in use of staff, funds and materials. MGS eliminated from sites better than first rotation SQIV as determined from growth plots (1 per 20 ha). Applications only after weeds controlled. Increased emphasis on post–thinning fertilisation particularly in stands younger than 25 years. Commenced pre–commercial thinning to 1,200 stems ha^{-1} when green level reaches 2 m plus some non–commercial thinning of stands suitable for commercial thinning.
1985	Revision of fertiliser practice with written guidelines to consolidate shift in emphasis from post–establishment to post–thinning application. Post–planting applications only when 95–100 per cent weed control obtained.
1988	Forest Manual No. 2 published including a critical path chart for determination of site–specific practices for re–afforestation of second and subsequent rotations.
1989	90 per cent completion of Ash Wednesday burn replanting or preparation for planting.
1990	Joint venture programme for planting eucalypts begins with pulp and paper manufacturer Kimberly–Clark Australia. www.forestry.sa.gov.au/hard.htm
1993	Sawmills separated to become Forwood Products. Forestry activities now managed by Primary Industries South Australia (PISA).
1996	Second joint venture programme, the Green Triangle Treefarm Project, for planting eucalypts begins. www.forestry.sa.gov.au/hard.htm
1997	ForestrySA formed under Department of Administrative and Information Services (DAIS). www.forestry.sa.gov.au/history.htm
1999	Total harvesting of eucalypts in first joint venture project begins. www.forestry.sa.gov.au/hard.htm
2001	South Australian Forestry Corporation begins trading as ForestrySA. www.forestry.sa.gov.au/history.htm

South Australia

Pinus radiata and other pines

The history of changes in silviculture of *Pinus radiata* grown in SA to the mid-1980s has been reviewed by Boardman (1988). This review and data from Annual Reports of the Woods and Forests Department and Primary Industries SA forms the basis of the summary in Table 12. Material from other sources is referenced separately.

Details of silvicultural practices used in the 1950s are shown in Table 13.

By 1970 there had been little change other than types of plough used in site preparation from native forest sites (Stewart, 1971). Problems with land availability had led to increased planting of pasture. Ploughing promoted the growth of grasses so planting lines were scalped to 60 cm width with increasing use of chemical weed control, particularly where topography prohibited the use of mechanical equipment. In 1976 the Maximum Growth Sequence (MGS) of establishment practice designed for *P. radiata* grown on marginal sandy sites in the South-eastern Region was introduced (Woods 1976). Brief details are given in Table 14.

By 1987 site-specific prescriptions had been produced for South Australian Radiata Pine plantations (Table 15).

Eucalypts

The majority of *E. globulus* plantations in the South-east region and SW Victoria have been established since 1997. Most since 1998 have been by Prospectus Companies. Establishment practices are summarised in Table 16.

Table 13. Establishment and management practice for *P. radiata* in South Australia (Lewis, 1957).

Handfelling of scattered trees on ex–pasture land and chain pulling of indigenous forest.		
Broadcast burning or more usually heaping or windrowing followed by burning.		
Various forms of cultivation including ploughing and deep ripping.		
Open rooted planting in slits (or pits on non–cultivated land).		
Spray with 2 1/2% zinc sulphate on zinc deficient sites.		
Superphosphate application on poor sites.		
Removal of coppice and pulling of woody weeds as required.		
Low pruning for better visibility and more effective fire fighting inside stands.		
Thinning	**Mean Dominant Height (m)**	**Residual stocking (stems ha^{-1})**
1st	19	860 – 990
2nd	25	680 – 800
3rd	29	500 – 620
4th	33	370 – 500
In early years first and second thinnings tended to be made 5 to 8 years later and 125 to 250 trees heavier. Stockings are within bays between access rows. Thinning from below.		
Average thinning yields to top diameter under bark of 10 cm were approximately:		
1st	33 m^3 ha^{-1}	
2nd	28 m^3 ha^{-1}	
3rd	33 m^3 ha^{-1}	
Rotation age taken as at least 40 years and possibly 50 years.		

Table 14. Optimum establishment sequence for *P. radiata* on marginal sandy sites.

Phase	Treatment
Pre-planting	Three disc–ploughing operations during the two year period prior to planting to kill bracken and sclerophyllous weeds, to aid breakdown of organic debris, and to conserve moisture.
Planting	Disc cultivation one month prior to planting. Strip application of weedicide to kill annuals and to maintain weed–free zone for 12 months. Plant sturdy stock with high nutrient content.
Post-planting	Apply starter fertiliser at one month. Re–apply fertiliser at 10 months. Repeat weedicide application at 11 months. Apply fertiliser at 14 and 22 months. Apply weedicide to inter–row strip at 23 months. Apply fertiliser at 26, 38 and 50 months.

Table 15. Site-specific prescriptions for *P. radiata* plantation establishment (Archer *et. al.*, 1987).

South-eastern Region
Plantations established on fertile soils (terra rossa and volcanic soils) or improved pasture do not receive fertiliser in first five years after planting.
Second rotation sites with former rotation better than SQ V not fertilised until early assessment with growth plots.
Plantations established on infertile soils (or if former rotation was SQ IV or below) treated with FSM which is similar to FM4 augmented with extra phosphate.
Fertiliser not applied until 85 per cent of competing weeds controlled.
Competition control applied during first two years of after establishment.
Adelaide Hills
NP fertiliser applied as high analysis formula with NPK at 18:20:0 or 20:10:0.
Criteria for application similar to South–eastern region.
Northern Region
Limited use of superphosphate at establishment on soils derived from quartose rocks.

Table 16. Establishment and management of *E. globulus* plantations (David Fife, CSIRO Forestry and Forest Products, *pers. comm.*, 2001)

All sites established on ex–farmland after soil survey for hardpans etc.
Pre–ripping spray of sorrel or bracken.
Rip to as much as 1.2 m depth and mound with rows 4 m apart.
Knockdown weedicide over mound one month before planting.
Plant at 2.0 to 2.5 m spacing in rows (1,000–1,250 stems ha^{-1}).
No fertiliser at planting. Apply fertiliser at 2 to 3 years of age.
Follow up weed control particularly in bays between rows at one year.
No thinning or pruning.
Expected rotation 10–12 years. Contracts usually for 21 years to allow for two rotations.

New South Wales

Pines

The 247,000 ha of softwood plantations in New South Wales are dominated by *P. radiata*. In the north east border areas there are about 13,000 ha dominated by Slash Pine (*P. elliottii*) with small areas of Hoop (*Araucaria cunninghamii*) and Bunya Pine (*A. bidwillii*) (Anon., 2000). Significant events and changes in the silviculture of pine and eucalypt plantations in NSW are summarised in Table 17. Details have been gleaned from annual reports of the Forestry Commission of NSW and State Forests of NSW (SFNSW). Information from other sources are cited separately.

Establishment and maintenance techniques used in the 1950s and 1960s are detailed in Tables 18 and 19 respectively.

Limited markets for small-sized softwood produce severely affected the initiation and frequency of thinning in early stands. Prescriptions for these

Table 17. Significant events or changes in the silviculture of pines in New South Wales.

Year	Significant events or changes in silvicultural practice
1914	First commercial plantation of *P. radiata* initiated at Tuncurry.
1916	Creation of Forestry Commission of NSW.
1926-35	Planting concentrated in Oberon and Wagga/Batlow regions.
1935	Planting ceases except for Prison Afforestation Camps (Grant, 1989).
1946	Funds for planting resumed (Grant, 1989).
1960	Particle board factory opened at Oberon using thinnings from Central Tablelands (Grant, 1989).
~1960	Land acquisition program begins. This includes some grassland sites.
1964	Peeling of Radiata Pine logs for plywood begins in Wagga Wagga (Grant, 1989).
1967	Particle board factory opened at Tumut using thinnings from Southern Highlands (Grant, 1989).
1969-70	Windrow clearing with ploughing introduced in Tumut district as opposed to broadcast clearing and burning (Hall and Carter, 1980).
1978	Plan to establish 3,000 ha of southern pines on grassland in the Border Ranges district (Drielsma *et. al.*, 1990).
1980/81	Pulp and paper mill opened at Albury using pulpwood from Southern Tablelands NSW and north–eastern Victoria (Grant, 1989).
1981/82	Medium density fibreboard plant completed at Wagga Wagga utilising pulpwood from the Southern Highlands (Grant, 1989).
1985	Pre–commercial thinning no longer practiced in Tumut district (Carter, 1987).
1988	Medium density fibreboard plant completed at Wagga Wagga utilising pulpwood from the Central Tablelands (Grant, 1989).
1992	State Forests of NSW formed.

Table 18. Establishment and maintenance techniques for Radiata Pine plantations in New South Wales (Anon., 1957a).

Forest sites cleared and burnt. Pre–pitting in autumn prior to planting.
Grassland sites ploughed before bar planting.
Establishment by slit planting usually at 1,680 stems ha^{-1} but 2,200 stems ha^{-1} on better sites.
Coppice and competing scrub growth brushed in 1st and 3rd years after planting.
Low pruning to 3m when trees reach about 7 m at 7 to 8 years. Select *P. elliottii* pruned to 7 m.
Commercial thinning of poorer stems at 15 to 16 years.

Table 19. Features of plantation practice in plantations near Tumut (Muir, 1965).

Roading carried out two years before planting to allow for proper consolidation of road formation. This allows for salvage logging of native forest, and lessens risk of road damage due to storm water during the period between burning and re–vegetation.	
Clearing by D6 capacity tractors on slopes less than 16–18 degrees. Removal of tree stumps reduces subsequent costs of scrubbing eucalypt coppice.	
Burning in late January or early February.	
Planting from end of May until August.	
After introduction of Myxomatosis, temporary fencing discontinued in favour of baiting rabbit populations with 1080 poison.	
Two scrubbing treatments in successive autumns after planting.	
Ground pruning about 3 m at 7 to 8 years of age when trees are 10 to 12 m tall.	
Thinning schedule (stems ha^{-1}):	
14 years	1,360 to 750
20 years	750 to 500
25 years	500 to 300
35 years	300 to 200
40 years	200 to 150
45 years	clearfell
Mean annual increment of 18 m^3 ha^{-1} yr^{-1} expected at clearfell.	

Table 20. Prescribed operations and management for Radiata Pine plantations on the Boyd Plateau (Forestry Commission of NSW, 1973).

Merchantable stems felled and sold.
Pushing or pulling of trees by bulldozer then heaping in windrows about 60 m apart. Ploughing between windrows. Limited areas of broadcast felling with chainsaws. Burning of debris.
Rabbit control with 1080 poison and temporary fencing.
Planting by hand or machine at 1,250 to 1,500 stems ha^{-1}.
Woody regrowth removed by treatment with hand tools.
First thinning expected at about age 13 years and subsequently at 5 to 6 year intervals.
Clearfell and replant at about 45 years.

thinnings were initially in terms of reduction in stocking but subsequent research resulted in general acceptance of a basal area criterion (Gentle *et. al.*, 1962). First commercial thinnings reduced basal area to 21-23 m^2 ha^{-1} at 13 to 16 years of age. Subsequent thinnings were designed to reduce basal area to 23-27 m^2 ha^{-1} when the stands had achieved about 37 m^2 ha^{-1}. Hall and Carter (1979) reported that thinning practice had not changed markedly for a number of years, although there was a trend to earlier and heavier thinning Maximum basal area was restricted to 34-37 m^2 ha^{-1} with thinnings at least 5 years apart. In the absence of markets for small wood a schedule with higher residual basal areas was used. By the late 1980s thinning schedules had been refined but were still based on basal area rather than stocking (Horne, 1988).

Stewart (1971) assessed that 5 per cent of new forest sites were prepared on grassland, while on native forest sites 17 per cent were broadcast felled by chainsaw and 54 per cent by tractor while the final 24 per cent was windrowed. Until 1968 all ex-forest sites were broadcast burnt. The windrow and plough technique was introduced on the Oberon plateau in 1968. In 1970 the 10,000 ha annual programme was concentrated in Tumut, Bathurst, Bombala, Nundle and Nowendoc districts. Ploughing was to 20 cm depth. On grassland sites mechanical scalping was used with chemical weed control on steeper slopes. Methods used for establishment and maintenance of pine plantations in the early 1970s are summarised in Table 20.

Hall and Carter (1979) reported that there had been no major changes in the techniques used for converting eucalypt forest to plantation. Windrow clearing, single ploughing and planting by hand or machine were still standard practice. Some regions were using herbicides on native grass competition where ploughing was impossible or had failed to provide sufficient control. Follow up manual or herbicide control of eucalypt and wattle regrowth was often required. On second rotation sites debris was flattened and burnt before hand planting. On improved pasture, planting lines were ripped and herbicide applied to one metre wide strips in early spring after planting. Pruning of 25 to 40 per cent of the stands was justified on protection grounds.

Strategies for establishment and maintenance of first and second rotation stands in the 1980s are given in Tables 21 and 22 respectively.

Eucalypts

Prior to 1994, 24,400 ha of eucalypt plantations had been established on the north coast of New South Wales (Bruskin, 1999; Anon., 2000). These were dominated by Flooded Gum (*E. grandis*) and Blackbutt (*E. pilularis*). Most were planted in the 1960s and 1970s. Ex-pasture sites were scalped before planting (Pryor and Clarke, 1964).

The area includes 14,000 ha established by Australian Paper Manufacturers (APM) for pulpwood and subsequently purchased by SFNSW in 1994. Early methods of establishment were probably similar to those used by APM in Gippsland (see below). On average sites in the Coffs Harbour region average growth rate is about 10 m^3 ha^{-1} yr^{-1}.

A major plantation establishment program began in 1993/94, the government setting a target of 2000 ha in the first year, rising to 10,000 ha by the third and successive years (Lacey, 1997). The new programme was focused on the north coast, primarily on pasture or lightly timbered grazing land. The aim was to develop the plantations on private land under joint venture arrangements. Experience with planting eucalypts was minimal so establishment practices were largely based on experience gained with eucalypt planting elsewhere in Australia (Lacey, 1997). The major species in 1999, in order of planted area, were: Dunn's White Gum (*E. dunnii*), Spotted Gum (*Corymbia variegata*), Blackbutt (*E pilularis*) and Flooded Gum (*E. grandis*). Details of plantation establishment and management are given in Table 23.

MAI in the recent plantations exceeds that of the pre-1994 plantations. Plantations have been ranked into three productivity classes expressed as total stand growth for commercial and roundwood production (Anon., 2000):

Low productivity: 15 m^3 ha^{-1} yr^{-1}

Medium productivity: 18 m^3 ha^{-1} yr^{-1}

High productivity: 22 m^3 ha^{-1} yr^{-1}.

Victoria

Pines

State Forests

The main coniferous species grown in Victoria is *P. radiata*. The history of changes in its silviculture in Victoria to the mid-1980s has been reviewed by Lavery (1988). This review and data from Annual

Table 21. Strategy for silvicultural management of young plantations on agricultural land in the Tumut district (Carter, 1987).

Clear remaining timber if necessary.
Graze heavily until time of planting to reduce grass competition.
Blade plough to 45 cm width on 3 m centres.
Plant at 2.5 m spacing (~ 1300 stems ha^{-1}) by machine where possible.
Spray with atrazine at 8 kg ha^{-1}. Respray in second year if pasture growth heavy.
Re–introduce grazing stock at age 3 to 4 years.
Prune at 6 to 7 years.
First thin at 13 to 15 years for pulpwood.

Table 22. Strategy for silvicultural management of young second rotation plantations in the Tumut district (Carter, 1987).

Stack and burn larger debris in windrows. Smaller branches, needles and litter retained in place as far as possible.
Blade plough to 45 cm width between stump rows.
Plant at 2.5 m spacing (~ 1,300 stems ha^{-1}) by hand.
Fertilise with 150 g of 'Starter 15' per tree.
Spray with atrazine at 8 kg ha^{-1}.
Prune at 6 to 7 years.
First thin at 13 to 15 years for pulpwood.

Table 23. Methods for eucalypt plantation establishment and maintenance (Bruskin, 1999).

Sites cleared and rip mounded or rip cultivated with rows 4 m apart.
Knockdown and residual herbicide applied before planting. Some broadcast spraying is carried out but the majority is in 2 m wide strips.
Container grown stock planted initially at 833 stems ha^{-1}, but this has been increased to 1,000–1,250 stems ha^{-1}.
50g subsurface application of di–ammonium phosphate made within a month of planting.
Planting applications of herbicide are made if required when the trees reach 2 m height. Cattle are grazed to reduce weeds and lower the fire hazard.
Pruning is carried out in selected stands. Current practice is for a single variable lift up to 4 m to maximise clearwood on the butt log.
Based on growth model projections, an early commercial thinning for fibre and small mill logs between 7 and 10 years is indicated.
A second commercial thinning between 15 and 25 years is proposed.
Clearfell between 25 and 35 years is proposed.

Reports of the Forests Commission of Victoria forms the basis of the summary in Table 24. Material from other sources is referenced separately.

Early methods used for the establishment and maintenance of *P. radiata* plantations are summarised in Table 25.

From the end of World War II until the 1960s case logs were in heavy demand. Many plantations (e.g. Castlemaine) were established for this purpose. Consequently, selected plantations were thinned for both case logs and pulpwood. First thinning was often delayed until 20+ years of age (David Flinn, *pers. comm.*, 2001).

Table 24. Significant events and changes in the silviculture of pine plantations in Victoria.

Year	Significant events or changes in silvicultural practice
1872	Macedon Forest Nursery established.
1910-30	14,000 ha established but about 10,000 ha fail, particularly on coastal sands.
1918	Forests Commission established.
1930-39	Extension of plantings in central and northeast regions.
1940	Beginning of second rotation crops at Bright.
1945	Plantings in South Gippsland commence.
1947	Plantings in Rennick commence.
1953-54	Increased demand for pulpwood allows thinning of plantations.
1954-55	Studies on effects of non–commercial thinning commenced.
1961	Expanded program of plantation development initiated.
1962	APM Forests commence thinning 12–year–old plantations (Mann, 1990).
1965-66	Heavy anchor chain drawn by a pair of crawler tractors now firmly established as the most efficient method of clearing native forest. Supply commenced to a particleboard factory at Mt. Gambier enabling commercial thinning near State border.
1966	Plantation area estimated as 29,200 ha for Forests Commission plantings and 36,300 ha of private plantations (Simpfendorfer, 1967).
1970	Improved seed available from Departmental seed orchards.
1974-75	Large softwood sawmill opened in Ovens Valley.
1975-76	Construction of sawmill to utilise logs from Latrobe Valley plantations completed.
1976	Thinning practice in State plantations. Reduce stocking from ~1,600 to 700 stems ha^{-1} at 12 to 14 years when stand top height 17 to 20 m. Aim to produce 50 m^3 ha^{-1} pulpwood and round timbers. Two or three subsequent thinning at 5 to 7 year intervals to reduce stocking to 200 stems ha^{-1}. Nominal rotation of 35 years. Thinning in APM Forests plantations. Similar to above but commences at 9 years on good sites with subsequent thinning at 3 to 5 year intervals (Wright and Opie, 1976). Gippsland Woodmill sawlog intake begins (Mann, 1990).
1981-82	New industrial complexes opened at Albury–Wodonga and Mytleford.
1983-84	Community pressure intensifies for phasing out of clearing native forest for plantation establishment.
1985	Moratorium on aerial application of herbicide introduced in December.
1985-86	Establishment of Department of Conservation, Forests and Lands.
1987	Conversion of native forest to plantation phased out completely.
1988	One–off exemption to Departmental moratorium on aerial herbicide application to enable adequate control on a backlog of sites.
1988-89	Difficulties in meeting land purchase targets for plantation establishment on cleared agricultural land. New plantation share–farming scheme commenced. State Plantations Impact Study in response to mounting opposition to land purchase for plantations.
1989	Northeast. Re–establishment by broadcast burn and hand plant with seedlings. No cultivation or weed control. Selective spot fertiliser application of superphosphate and/or boron. Woody weed control from 2 or 3 years as necessary (Squire, 1983; Borschmann, 1995).
1989	Code of Forest Practices introduced which controls the establishment of plantations on public and private property. Chopper–roller purchased for use in northeast and southwest as an alternative to burning residues. Large scale trial (250 ha) of granular herbicide for control of eucalypt and acacia regrowth.

Table 24. Significant events and changes in the silviculture of pine plantations in Victoria.

Year	Significant events or changes in plantation forestry
1992	Department of Conservation and Environment formed.
1993	Department of Conservation and Natural Resources, and Victorian Plantations Corporation formed.
1994	Northeast. Chopper roll slopes <20° and slash load <100 t ha^{-1}. Broadcast woody weed control, rip planting line, hand plant high fertility select cuttings, apply residual strip weed control (Borschmann, 1995).
1998	The VPC, its staff and perpetual leasehold over VPC managed public land consisting of 166,400ha, the majority of it Radiata Pine, was bought by Hancock Victorian Plantations, which is 60 per cent owned by US Hancock Timber Resources Group and 40 per cent by Australian super funds UniSuper, National Australia Asset Management and Australian Pension (Peacock, 2001).
2001	In August, paper company Paperlinx sold its Australian Paper Plantations for $152 million to Hancock, in a bid to free up cash and increase its balance sheet flexibility (Peacock, 2001).

Table 25. Establishment and maintenance techniques for Radiata Pine plantations in Victoria (Anon., 1957b).

Prior clearing and burning as required.
General cultivation not practiced. Planting into planting pits. If topography permits rotary hoe to 60 cm width and plant in slits. 1680 stems ha^{-1}. Areas not fenced.
Brushing (weed control) by hand to 60 cm radius once or twice around each tree.
Pruning to 2m as a fire protection measure when lower limbs are dead and 75 per cent of trees exceed 7m. Follow up pruning to 7 m of 370 stems ha^{-1}.
Early first thinning to 1000–1100 stems ha^{-1} at 4 to 5 years. Previously thinnings were commenced at 10 to 14 years and repeated at 4 to 5 year intervals.

Table 26. Second rotation establishment using slash retention at Rennick in 1984 (Geary *et. al.*, 1987).

Year 1	
Summer - autumn	Treat under–stand natural regeneration >30 cm height with a rotary slasher.
Spring	Treat under–stand natural regeneration >50 cm height with a low intensity prescribed fire.
Spring - summer	Hand–clean surviving regeneration if warranted.
Spring - summer	Clearfell stand.
Year 2	
Summer - autumn	Spread edge–tree residues.
Autumn	Macerate logging residues with rotary slasher or chopper–roller.
Winter	Hand–plant second rotation crop.
Winter - spring	Apply chemical weed control.
Year 3	
Winter - summer	Hand–clean natural regeneration surviving or germinating subsequent to second rotation establishment if warranted.

By 1970 broadcast felling and burning were rapidly being replaced by windrowing or heaping for a range of reasons including reduced fire risk (windrow burning is safer than broadcast burning), to facilitate access for cultural treatments (e.g. ground-based herbicide application), and access for harvesting. Ploughing, primarily for controlling woody weeds, particularly eucalypts, had become common practice where topography and ground conditions permitted. APM Forests were creating windrows followed by ridge ploughing for control of suckers and germinants (Stewart, 1971).

The general practice for establishing second rotation sites was to broadcast or windrow (preferred) burn slash. If woody weeds were a problem the sites were ploughed. Hand planting with mattocks was practiced. A limited amount of spot weed control was used when grass was a problem. On known phosphorus deficient sites spot applications of superphosphate (170 g per tree) were made from the mid-1970s. This was followed by broadcast application of superphosphate (800 kg ha^{-1}) at 4 years (David Flinn, *pers. comm.*, 2001). By the 1980s considerable attention had been given to establishing second rotation stands (Table 26).

By 1988 most new plantation sites were on ex-pasture sites with herbaceous weeds, however, woody weeds were a problem on second rotation sites. Pasture sites were ripped to 60 cm, or ripped and mounded on wet sites.

Weed control was in strips 1.2 m wide. Cuttings were planted when available. No fertiliser was applied unless trace elements (e.g. copper, zinc) was required (David Flinn, *pers. comm.*, 2001).

Grand Ridge Plantations Pty. Ltd.

APM Forests Pty Ltd (later known as AMCOR Plantations (1996) and Australian Paper Plantations (1998) are now owned by Grand Ridge Plantations Pty Ltd. They currently manage about 35,000 ha of pine plantations. APM Forests began planting pines in Gippsland in 1950 (Brown, 1976). Early methods in use are recorded in Table 27.

Considerable modifications to these procedures were made during next 35 years (Table 28).

Recent developments in pine silviculture are shown in Table 29.

Eucalypts

Grand Ridge Plantations Pty. Ltd.

Grand Ridge Plantations Pty Ltd. currently manages about 15,000 ha of eucalypt plantations. APM Forests commenced planting eucalypts in the Strzelecki project in 1960, with planting rates averaging 200 ha per year during the 1960s and 500 ha per year in 1970s (Mann, 1990). Details of recent establishment and maintenance techniques are recorded in Table 30.

Table 27. Pine planting operations of APM Forests at Longford (Chandler, 1953).

Tea–tree and scrub cleared with a fluted steel roller.
Lightly timbered areas cleared with anchor chain between two tractors.
Heavily timbered land cleared two tractors connected by wire cable to a 2.7 diameter hollow steel ball (Hi–Ball method).
Timber heaped into windrows about 100 m apart and later burnt.
Complete cultivation with 8 furrow Majestic plough.
Rabbits exterminated by fencing, dogs, ferrets, poison and traps.
Seedlings planted with Lowther planting machine at 2.1 by 2.1 m spacing (2,270 stems ha^{-1})

Table 28. Schedule of introduction of new genetic stock and silvicultural treatments by APM Forests (Whiteman *et. al.*, 1993).

Planting Year	Genetic stock and silvicultural treatment
Up to 1971	Predominantly unimproved seed with some seed production area seed. All areas were cultivated using conventional agricultural offset disc and ridging ploughs. No chemical weed control at planting. Seedlings machine planted. 22 kg ha^{-1} elemental P at planting (as superphosphate). Chopper roll, slash or spray woody weeds with phenoxy herbicides.
1972	'Rome' bedding harrow forestry plough introduced.
1973	Simazine 4.5 kg ha^{-1} active ingredient (ai)+ Amitrol 1.0 kg ha^{-1} ai at planting.
1974	All planting with genetically improved 1.0 generation orchard seed. Heavy chopper roller introduced for second rotation site preparation. Hand planting second rotation sites.
1975-78	Limited areas mainly on sands and duplex soils established with 'intensive silviculture' as follows: – Simazine 4.5 kg ha^{-1} ai + Amitrol 1.0 kg ha^{-1} ai at planting – 60 kg ha^{-1} elemental P at planting (as Super or Double super phosphate) – Simazine 4.5 kg ha^{-1} ai + Amitrol 1.0 kg ha^{-1} ai at 9 months – 83, 38 & 45 kg ha^{-1} elemental N P & K respectively applied at 9 months (500 kg ha^{-1} Pivot 900)
1976	Planting with culled 1.0 generation orchard seed commences.
1978	Hexazinone at 3 to 4 kg ha^{-1} ai at planting only introduced replacing 1 or 2 applications of Simazine and Amitrol. Contouring of all planting sites to retain moisture.
1979	Fertilising with 60 kg ha^{-1} elemental P plus 96 and 6 kg ha^{-1} elemental K and Cu respectively depending on soil type (replaces previous fertiliser practice).
1980-82	Planting with 1.0 orchard seed after second culling. Use of phenoxy herbicides suspended in 1980.
1981	Marsdan heavy chopper–rollers introduced for second rotation site preparation. Winged ripper introduced for cultivation of heavy textured soils, on moderate to steep terrain.
1985	New establishment fertiliser prescriptions introduced as follows: At planting 50 kg ha^{-1} elemental P plus 50 kg ha^{-1} and 6 kg ha^{-1} elemental P and Cu respectively depending on soil type. Dependent on soil type, further fertilising with NPK at age 5 and/or first thinning.
1986	Planting with cuttings commences. Wide–tyred skidders introduced as prime mover for second rotation establishment.

Table 29. Establishment and silviculture of pines by Australian Paper Plantations (Hescock *et. al.,* 1999).

Pre-1998	Second rotation sites chopper–rolled with offset double B–8 Marsden roller pulled by a D–8 bulldozer.
1998+	Second rotation sites on flat sites chopper–rolled with two passes of a large single Marsden roller behind a rubber tyred skidder.
Pre-1998	Pre–plant weed control applied mainly in strips when applied.
1998+	Broad acre aerial application of pre–planting herbicide. All plantations have been established with cuttings from 1988. From 1995 stocking rates were increased from their lowest level of 1,000 stems ha^{-1}, reaching 1,500 stems ha^{-1} in 1999.
Pre-1998	Post–planting application of herbicides in strips.
1998+	Broad acre aerial application of post–planting herbicide.
Pre-1998	NPK fertiliser applied in a strip 4–8 weeks after planting.
1998+	One third of fertiliser applied by hand to individual trees shortly after planting and remainder is applied in a 1 m wide strip along the tree row at age 1 year.

Table 30. Establishment and maintenance of eucalypt plantations by APM Forests (Jenkin, 1990).

E. regnans planted on sheltered, frost–free sites with good soils, >900 mm rainfall, usually above 400 m elevation.
E. nitens planted on similar but more frost–prone sites.
E. globulus planted on drier 700–900 mm rainfall sites and on steeper slopes where full site preparation is impossible.
On agricultural land, derelict buildings removed, scrub is bladed off but healthy trees retained. On sites previously planted with *P. radiata* harvesting residues are retained and incorporated by chopper roller. A second chopper rolling is applied after fallow.
Flat, recently cleared sites broadcast ploughed to kill woody regeneration. Clay loam or compacted soils ripped to 0.7–1.0 m with winged ripper. Ripped pasture sites rotary hoed to break clods. Sands and waterlogged sites ridged. Drainage as required. Steep sites pit–planted in 30 x 30 cm scalped areas.
Pre–planting herbicide depending on target species. With machine access a 2 m strip is sprayed over planting lines. On steep sites 1 m diameter spot spraying is practiced.
Poisoning of rabbits and wallabies with 1080. Warren ripping and fencing. Removal of domestic stock.
Seedlings raised in peat jiffypots till 0.2–0.3 m tall then hand planted at 1,000 stems ha^{-1} (3.3 x 3.0 or 3.6 x 2.8 m) late May to late August when soil moist. Wider between row spacing on flat sites where machine access is desirable.
Granular NPK fertiliser applied at 100 g per tree. On steep sites 21 g pills applied.
Inter–row chopper rollers used on moderate slopes to control weeds. Pasture sites rotary hoed in 1.3–1.6 m strips between sprayed strips during first summer to reduce water competition.
Thinning seen as a strategic option while expanding the plantation estate. Current operations consist of third row out–row plus removal of suppressed individuals. All thinnings machines based with mechanical de–barking. No pruning carried out.
E. regnans rotations expected to be in excess of 30 years with thinning yielding 30 m^3 ha^{-1} yr^{-1} on better sites. Early *E. globulus* plantations with MAI of 10 m^3 ha^{-1} yr^{-1} at 18 years.

Table 31. Establishment and silviculture of eucalypt plantations by Australian Paper Plantations (Hescock *et. al.,* 1999).

	Excavators used to heap debris on second rotation sites traditionally cleared with bulldozers.
	Steep sites traditionally ripped with winged ripper with small disc crowders now mounded with a Savannah plough provided site is relatively clear of debris.
	Flatter sites mounded with Savannah plough.
	Ex–pasture sites mounded then rotary hoed to reduce air pockets.
	Broad acre application of pre–planting herbicide using either a skidder or a helicopter.
	Early (May–June) planting of potted seedlings.
	Sub–surface application of 200 g per tree of NPK fertiliser in two slits by hand.
	Browsing controlled by repellents and limited shooting.
Pre-1996	Little post planting weed control.
1996+	Separate herbicide treatments applied to inter–row and treeline 12 months after planting.
	Poorly growing sites (usually pit–planted areas) re–fertilised at 1 year.
	Trees routinely fertilised from the air at 2 years.

The current focus for eucalypt establishment is to achieve rapid early growth with near weed-free conditions for the first 2 years after planting and to protect seedlings from grazing damage (Table 31).

State Forests in Gippsland

Significant areas of eucalypt plantations were established in the Gippsland area by the Forests Commission. The main species were Shining Gum (*E. nitens)* and Mountain Ash (*E. regnans)*. Methods of establishment were similar to those used by A.P.M. (David Flinn, *pers. comm.*, 2001).

State Forests in Southwest Victoria

Details of methods used for planting eucalypts in southwest Victoria are similar to those used in joint venture plantations in southeast SA (see above).

Western Australia

Exotic pines

The major softwood species planted in WA are *P. radiata* and *P. pinaster* (Maritime pine). Significant events and major changes in the silviculture of pines in WA are shown in Table 32. The principal sources of information for this Table were the annual reports

Table 32. Major changes in the silviculture of pines in Western Australia.

Year	Significant events or changes in silvicultural practice
1908	Pine planting commences at Ludlow (Stoate, 1947).
1933	Research Programme commenced (Stoate, 1947).
1944	First Departmental sawmill to operate on wood from Departmental plantations built (Stoate, 1947).
1948-9	Loan funds become available to recommence pine planting.
1955	Policy revised to concentrate on *P. radiata* (Harris, 1955).
1956	Pine Plantation Working plan sets goal at 81,000 ha and planting rate of 810 ha per annum.
1957	Site quality assessment initiated based on S.A. model.
1964	*P. pinaster* seed orchard established at Joondalup.
1965	*P. radiata* seed orchard established at Chandlers Farm.
1967	In association with *Softwoods Forestry Agreement Act*, plantation target set at 97,100 ha with planting rate of 2,400 ha per annum.
1969/70	Widespread drought in SW of State.
1970s	Silviculture 70 adopted. Initial stocking (*P. radiata* 1704 stems ha^{-1}, *P. pinaster* 1988 stems ha^{-1}) reduced to 740 stems ha^{-1} at 5 and 6 years respectively. Reduction of *P. radiata* to 200 stems ha^{-1} at age 11 years and *P. pinaster* to 247 stems ha^{-1} at 14 years (Butcher and Havel, 1976). Rotation length reduced from 40 to 30 years for *P. radiata* and from 60 to 40 years for *P. pinaster*.
1975	Planting of Donnybrook Sunkland proposed.
1978	In April cyclone Alby causes wind damage in 884 ha of plantation and a further 339 ha of associated fire damage.
1984	Department of Conservation and Land Management formed.
1988/89	Drought in Blackwood Valley and windthrow in the Sunklands.
1998	Plan to extend plantations of maritime pine (1,250 stems ha^{-1}) used to control salinity in Collie River catchment to 3000 ha by 2001 (CALM Media Release 00136, 4/8/98).
1999	In January 1999, an agreement signed with British Petroleum (BP) marking the beginning of the first pilot study in Australia to examine the potential for planting tree crops as carbon sinks to offset greenhouse gas emissions (www.fpc.wa.gov.au/plantations_in_wa.html).
2000	The Forest Products Commission (FPC) established in November (www.fpc.wa.gov.au/about.html).

from the Woods and Forests Department and more recently the Department of Conservation and Land Management. Other sources are cited separately.

Methods used to establish and maintain exotic pine plantations in the 1950s are shown in Table 33.

Little change in practice occurred during the next seven years (Anon. 1964).

Pinus pinaster

Methods used for the establishment and maintenance of Maritime pine in the late 1960s and 1970s are detailed in Tables 34 and 35 respectively.

Table 33. Exotic pine establishment in Western Australia (Anon., 1957c).

Prior to clearing the area is protected from fire for a minimum of three years to facilitate an effective final burn. All merchantable logs and economic firewood removed from the area and the scrub knocked flat to dry. After 12 months the area is burnt in winter or early spring.
Thorough ploughing to 25 cm. On the coastal plain, furrow lining at right angles to original ploughing is carried out.
Hand or machine planting at 1330 to 1680 stems ha^{-1} for *P. radiata* or 2200 stems ha^{-1} for *P. pinaster*.
Where required superphosphate applied at 60 g per tree and zinc sulphate spray applied.
Low prune all stands when labour and funds are available. In Radiata Pine, high prune of select trees where finances and labour permit.
P. pinaster. All stands of Fair Average Quality (FAQ) and above:
At height 12 m thin to 750–875 stems ha^{-1};
At height 18 m thin to 500–625 stems ha^{-1};
At height 24 m thin to 210–375 stems ha^{-1}.
P. radiata. All stands of Fair Average Quality and above:
At height 18 m thin to 750–875 stems ha^{-1};
At height 24 m thin to 500–625 stems ha^{-1};
At height 30 m thin to 375–500 stems ha^{-1};
At height 36 m thin to 250–375 stems ha^{-1};
At height 42 m thin to 200 stems ha^{-1}.

Table 34. Establishment and management of *P. pinaster* on Swan Coastal Plain (Van Noort, 1968).

Clear sparse forest and scrub from coastal dune complex.
Site allowed to lie fallow for at least one summer. Firewood operators remove larger timber.
Clearing burn followed by rake, stack and burn.
Plough to 20 cm to control scrub competition.
Furrow lining two months prior to planting. A broad V–shaped furrow about 90 cm wide and 15 cm deep is formed so that water is directed into planting line. Newly germinated weeds thereby removed from planting line.
Machine planting at 2.4 x 1.8 m (2,240 stems ha^{-1}).
Fertilise with superphosphate (85 g per tree) a few weeks after planting and zinc oxide as required. Re–apply superphosphate at 500 kg ha^{-1} at 7 years.
Scrub control by inter–row cultivation at 12 to 18 months and at three years if necessary.

Table 35. Silviculture 70 and Silviculture 78 for *P. pinaster* (McKinnel, 1979).

Age	Silviculture 70	Silviculture 78
0	Plant 1,100 stems ha^{-1}.	Plant 625 stems ha^{-1}.
3		Thin to waste to 300 stems ha^{-1}.
5-6	Thin to waste to 750 stems ha^{-1}. Low prune to 2.1 m.	Low prune to 2.1 m.
8	High prune 125 stems ha^{-1} to 4.5 m.	High prune all trees to 4.5 m.
10		High prune 100 stems ha^{-1} to 6 m.
14	Thin for pulpwood to 250 stems ha^{-1}.	
20		Thin to 100 stems ha^{-1}.
25	Thin to 125 stems ha^{-1}.	
30-40	Clearfell.	Clearfell.

Table 36. Silviculture 70 and Silviculture 74 for *P. radiata* (McKinnel 1979).

Age	Silviculture 70	Silviculture 74
0	Plant 1,600 stems ha^{-1}.	Plant 1,100 stems ha^{-1}.
5	Thin to waste to 750 stems ha^{-1}. Prune all trees to 2.1 m.	Thin to waste to 750 stems ha^{-1}. Prune all trees to 2.1 m.
7	High prune 200 stems ha^{-1} to 4.5 m.	High prune 125 stems ha^{-1} to 4.5 m.
11	Thin for pulpwood to 200 stems ha^{-1}.	Thin for pulpwood to 250 stems ha^{-1}.
18		Thin for sawlogs to 125 stems ha^{-1}.
30	Clearfell.	Clearfell.

Pinus radiata

Methods used for managing *P. radiata* during the 1970s and 1980s are given in Tables 36 and 37 respectively.

Modified silviculture was practiced on steep country (McKinnel, 1979).

Plans were being made for clover establishment a year prior to planting.

Eucalypts

Brown mallet (*E. astringens*) sown to form plantations from 1924 for the production of tanbark (Stoate, 1947). The main emphasis on using plantation grown eucalypts for wood products did not begin until the 1980s. Methods used for establishment and maintenance of plantations are given in Tables 38 and 39.

Table 37. Establishment and maintenance of *P. radiata* in the Donnybrook Sunkland (Keene and Kelers, 1980).

Bulldozer clearing of the area follows thorough utilisation of native Jarrah (*E. marginata*) and Marri (*E. diversicolor*) forest.
Area thoroughly ploughed to 20 cm to reduce competition from scrub.
Mounds 3.5 m apart and 0.2 to 0.3 m high formed to shed surface water.
Machine planting on mounds, 3.5 x 2.5 m (1150 stems ha^{-1}).
Initial fertiliser with Agras No 1. (N:P:S = 18:18:16) at 100g per tree at planting.
Foliar spray of trace elements during following spring.
At 3 years scrub control, culling to 750 stems ha^{-1}, re–fertilise with Agras No 1.
At 5 years low prune 750 stems ha^{-1}.
At 6 years reapply trace elements.
At 7 years high prune 250 stems ha^{-1} to 5 m.
At 8 years re–fertilise with Agras No 1.
At 9 years high prune 125 stems ha^{-1} to 7 m.
At 14 years re–fertilise with Agras No 1.

Table 38. Establishment and maintenance of eucalypt plantations by Bunnings Tree Farms (Jenkin, 1990).

E. globulus planted on sites with greater than 700 mm rainfall.
Scrub and residual trees cleared, heaped and burnt on ex–agricultural land.
Forest blocks harvested, residual trees pushed and then root raked (0.3 m depth) into windrows and burnt. Original technique of broadcast burning shown to be inadequate in earlier plantings.
Ex–bush sites broadcast ploughed to remove woody weeds.
Ex–pasture sites ripped to 0.5 m or, on poorly drained sites, ridged.
Ex–pasture sites with couch are first broadcast sprayed and fallowed. Planting lines sprayed prior to ripping or ridging.
Ex–bush sites fallowed then broadcast sprayed after weed regeneration.
Poisoning of rabbits with 1080. Removal of domestic stock.
Seedlings raised in peat jiffypots till 0.15–0.3 m tall then hand planted at 1,700 stems ha^{-1} (3.3 x 1.75 m) on high quality sites with good rainfall or 1,250 stems ha^{-1} on routine sites. Wider rows of 4 m spacing sometimes included for machine access. Planting from late May to late August when soil moist.
Application of 100 g per tree granular NPKZn fertiliser applied within one month after planting.
Sheep introduced to ex–pasture sites in autumn when trees 1.2 m tall.
On ex–bush sites inter–row disc cultivation followed by broadcast application of 180 kg ha^{-1} superphosphate.
Thinning and pruning trials only.
Rotation of 15 years yielding MAI of 20 m^3 ha^{-1} yr^{-1} expected on routine sites. On some sites a rotation of 10 years is planned with MAI of 40 m^3 ha^{-1} yr^{-1}.

Table 39. Establishment and maintenance of eucalypt plantations by CALM (Jenkin, 1990).

E. globulus planted on sites with greater than 600 mm rainfall.
Only ex–pasture sites established.
Sites ripped to 0.7 m or, on poorly drained sites, ridged.
Couch and kikuyu sites broadcast sprayed. After cultivation a 2 m strip is sprayed over the planting line.
Poisoning of rabbits and wallabies with 1080. Removal of domestic stock.
Seedlings raised in peat jiffypots till 0.2–0.3 m tall then hand planted at 1,667 stems ha^{-1} (3.0 x 2.0 m) on standard sites and 1,428 stems ha^{-1} (3.5 x 2.0 m) on coastal sites. Sites planted from late May to late August when soil moist.
On poor sites with less than 15 ppm residual phosphate, 50 g granular diammonium phosphate applied. On better sites 50 g granular NPK applied.
Application made two weeks after planting. On ex–pasture sites, sheep grazing is introduced a few months after planting. Later–age fertilisation is under consideration.
No thinning or pruning.
Rotation length varied according to productivity which ranges from 15 to 35 m^3 ha^{-1} yr^{-1}.

Six species of native mallee eucalypts are being developed as short rotation tree crops for drier zones of Western Australia's wheatbelt. Planting mallee eucalypts on farmland commenced in 1994, with the aim of building an initial resource as the basis of a new industry. More than 7,000 ha of mallees have been planted to date (www.fpc.wa.gov.au/plantations_in_wa.html).

Tasmania

Data from Annual Reports of the Tasmanian Forestry Commission and later Forestry Tasmania form the basis of the summary significant events and changes in silviculture of Radiata Pine and eucalypts in Tasmania (Table 40). Material from other sources is referenced separately.

Methods of establishment and maintenance of plantations of exotic trees used during the 1950s are given in Table 41.

By 1979 the clearwood and scantling regimes first suggested in 1970 for Radiata Pine had been approved for practice. Methods used for plantation establishment and maintenance in the 1990s are shown in Table 42.

Queensland

The current species grown in State owned plantations in Queensland is Honduras Caribbean Pine (*P. caribaea var. hondurensis*) 31 per cent, hybrids 16 per cent, Slash Pine (*P. elliottii*) 25 per cent, Loblolly pine (*P. taeda*) and other pines 2 per cent, Hoop Pine (*Araucaria cunninghamii*) and other native conifers 25 per cent, and hardwoods 1 per cent. Some private companies have been active in hardwood plantings in the drier regions of the State. In the past there have been some large private plantings of pines (e.g. 18,000 ha of Slash pine planted by APM during the 1970s) (John Simpson DPI Forestry *pers. comm.*, 2001). The history of forestry in Queensland has been reviewed by Holzworth and Hatcher (2000). This review and data from Annual Reports of the Queensland Department of Forestry and its successors the Queensland Forest Service and DPI Forestry forms the basis of the summary in Table 43. Material from other sources is referenced separately.

Pinus spp.

Methods used for management of southern pines during the 1950s, 1970s and 1980s are shown in Tables 44, 45 and 46 respectively. Methods used for establishment on pasture sites are given in Table 47.

Table 40. Major changes in the silviculture of *P. radiata* in Tasmania.

Year	Significant events or changes in silvicultural practice
1920	Forestry Department established (Felton and Farmer, 1990).
1920's	Field scale trials of Radiata Pine (Felton and Farmer, 1990).
1920's	Initial planting of pines at Strahan, Beaconsfield and Sister's Hills.
1930's	Initial planting of pines on fertile sites under derelict farmland in NE and NW Tasmania.
1940's	Selective pruning program introduced.
1947-49	Shortage of wire netting for control of vermin offset by use of larger planting stock combined with trapping and shooting of vermin.
1951	Thinning of 14 to 17 year old plantations in Warrentina Block begin (NE).
1952	Thinning begins at Stoodley Block (NW). Plan to establish seed orchards. Portions of Beaconsfield plantation treated with rock phosphate at 250 kg ha^{-1}.
1953	Thinning program suspended due to lost market for cases.
1954	Thinning program resumed.
1959	Sufficient seed harvested from plantations for all planting stock. Previously seed was obtained from New Zealand or South Australia.
1962	Plantation estate of 4,300 ha of Radiata Pine (Felton and Farmer, 1990).
1968	Chemical control of weeds prior to planting. Routine application of N and P fertiliser where required at planting. Cultivation introduced routinely, where needed.
1969	Chemical control of young eucalypt growth now standard practice with Tordon 20K replacing Tordon 50D because of greater selectivity.
1973	Aerial fertilising program commenced (WA Neilsen, Forestry Tasmania, *pers. comm.*, 2001).
1976	Base age for *P. radiata* Site Index changed from 15 to 20 years, with metrication. Commercial clearfelling expected to begin. Trials planned for aerial spraying of 2,4,5–T for control of wattle in plantations.
1977	'Clearwood' regime introduced (WA Neilsen, Forestry Tasmania, *pers. comm.* 2001).
1982	APPM decide to develop substantial eucalypt plantation resource in northern Tasmania (Whyte, 1990).
1984	Very heavy early thinning to 250 stems ha^{-1} at 4 years of age for all areas devoted to production of pruned trees.
1985	Strategic decision not to exceed 35,000 ha (Felton and Farmer, 1990).
1988	Large scale Eucalypt plantations commenced by Forestry Tasmania (W.A. Neilsen, Forestry Tasmania, *pers. comm.*, 2001).
1989	Development of minimum herbicide system of weed control (W.A. Neilsen, Forestry Tasmania, *pers. comm.*, 2001).
1990	Reversion to selective pruning regime with the retention of unpruned trees for an anticipated pulp market (W.A. Neilsen, Forestry Tasmania, *pers. comm.*, 2001).
1994	Forestry Tasmania formed.
1997	Sale of 50% of pine resource to GMO and Rayonier contracted to manage the resource (W.A. Neilsen, Forestry Tasmania, *pers. comm.*, 2001).

Table 41. Establishment and maintenance of exotic trees in Tasmania (Anon., 1957d).

All areas burnt in summer prior to planting. Some areas fenced. All areas poisoned for destruction of vermin.
No cultivation except by one private company using mechanical planters.
Slit planting of 1/0 stock in fenced plantations and 1/1 or 2/0 in unfenced plantations.
About 500 stems ha^{-1} pruned to 2.4 m when 5.1 m tall; 4.8 m when 7.5 m; and, 6.6 m when 10.5 m. Aim for final 375 stems ha^{-1} select stems.
First thinning at age 10 to 11 years to leave 625 stems ha^{-1} over 15 cm DBHOB. In stands over 12 years 850 stems ha^{-1} over 15 cm DBHOB retained.

Table 42. Establishment and maintenance of plantations in Tasmania (Neilsen, 1990).

Suitable planting sites indicated by eucalypts of moderate to great height (>34 m predominant height) or stands dominated by *E. obliqua* or wet forest species.
Native forest: Windrowing and heaping usually after broadcast burn. Heaps may be burnt. Second rotation pines: Debris may be reduced by burning. Debris may be pushed aside from planting lines and cultivation carried out at same time. Grass: Poa grass areas scalped.
Cultivation dependent on slope and erosion class. Ripping of heavy clay soils otherwise discing. Mound ploughing of low lying flat areas, poorly drained soils and infertile soils.
Broadcast or strip spraying pre–planting. Aerial and ground based spraying for control of eucalypt and acacia regrowth after planting pines.
Fencing, shooting, trapping or poisoning of vermin.
Eucalypt plantations and non–clearwood pines spaced 3 m between rows and 2.5 m within rows (1,333 stems ha^{-1}). Clearwood pine spaced 5 m between rows and 2.5 m within rows (800 stems ha^{-1}).
All plantation species responding to fertiliser are treated post–planting on fertile and infertile sites. On phosphate deficient sites aerial application of phosphate applied fertiliser at about five years to pines only.
Pine clearwood regime: Thin to waste and 250 stems ha^{-1} at 5 years. Prune to 2.1 m at 6 years; 4.3 m at 7 years and 6.4 m at 9 years. Clearfell at 24 years. **Pine knot control regime:** Thin to 300 stems ha^{-1} at 14 years. Clearfell at 28 years. **Eucalypt pulpwood regime:** Unthinned until DBHOB about 25 to 30 cm. **Eucalypt sawlog regime:** Thin to 200 stems ha^{-1} before first pruning (MDH 6 to 12 m). Prune to 6.4 m. Clearfell at mean DBHOB of 60 cm.

Table 43. Significant events and major changes in silviculture of exotic pines in Queensland.

Year	Significant events or changes in silvicultural practice
1900	Forestry Branch formed in Department of Public Lands (Holzworth and Hatcher, 2000).
1925	Pine planting commences (Simpson and Grant, 1991).
1933	Phosphorus deficiency identified (Simpson and Grant, 1991).
1935	Experimental thinning practices (Bevege, 1972).
1943	Initial stocking of Slash and Loblolly increased from 1680 to 2200 stems ha^{-1} (Jerym, 1968).
1945	Strong timber market with logs 13 cm DBHOB to 7.5 cm top diameter under bark (TDub). Stands thinned when 22.2 m^3 ha^{-1} became available in stems greater than 14.5 cm DBHOB in the 'other than select' (OTS) portion of the stand. These stands were about 10 years old and about 12 m tall (Jerym, 1968).
1948	First thinning prescription. In stands at 1680 stems ha^{-1}, merchantable OTS removed to give 800 to 950 stems ha^{-1}. In stands at 2200, all OTS greater than 14.5 cm DBHOB removed at age 12 years (Jerym, 1968).
1949	Initial stocking of Slash and Loblolly reduced from 2200 to 1680 stems ha^{-1} (Jerym, 1968).
1950s	All sites receive 50 kg P ha^{-1} as rock phosphate (Simpson and Grant, 1991).
1951	Thinning prescription relaxed to retain 850 stems ha^{-1} in 1680 stems ha^{-1} stands and 1100 stems ha^{-1} in 2200 stems ha^{-1} stands. Second thinning considered to take place five years after the first and aimed to reduce stands to 600 stems ha^{-1} (Jerym, 1968)
1952-53	Unmerchantable thinning from 1682 stems ha^{-1} to about 1000 stems ha^{-1} at age 4–5 years due to unfavourable markets (Bevege, 1972). Stands averaged about 2.7 m tall.
1957	Diameter limit for OTS increased to 17 cm and it was prescribed that at second thinning 1680 stems ha^{-1} stands be reduced to 400 stems ha^{-1} and 2200 stems ha^{-1} stands to 500 stems ha^{-1} (Jerym, 1968).
1958	Selection rate for high pruning reduced from 395 stems ha^{-1} to 296 stems ha^{-1}. Final crop of 296 stems ha^{-1} anticipated (Bevege, 1972). Unmerchantable thinning intensity increased to leave about 750 stems ha^{-1} at age 5 years (Jerym, 1968).
1959	Forestry Act promulgated (Holzworth and Hatcher, 2000).
1961	Unmerchantable thinning to 750 stems ha^{-1} ceased between Brisbane and Gympie (Jerym, 1968).
1962	Unmerchantable thinning to 988 stems ha^{-1} ceased due to advent of pulpwood market and tree breeding programme (Bevege 1972).
~1965	Initial stocking of Slash and Loblolly increased from 1680 to 1330 stems ha^{-1} (Jerym 1968).
1966	All unmerchantable thinning ceased within 130 km of Gympie (Jerym, 1968).
1967	Establishment of the Honduras Caribbean pine clonal seed orchard at Kennedy near Cardwell commenced. Establishment continued in stages carried out over several years (Yule, 1987). Large scale plantings of Slash pine on drained and line mounded swampy sites commenced. Line mounding was carried out by a twin disc plough drawn by a rubber tyred tractor to produce a mound 60 cm wide and 25 cm high (Yule, 1987). New Beerburrum nursery completed and first sowing carried out (Yule, 1987). Wet sites in the Tuan–Toolara complex previously considered to be unplantable were shown to be satisfactory after mounding and draining (Ryan, 1990).
1968	Proposed pulp thinning at age 12 to reduce stocking to 860 stems ha^{-1}. Second pulp thinning from below at age 17 to reduce stocking to 600 stems ha^{-1} with remaining stems greater than 19 cm DBHOB. Subsequent thinnings for sawlogs of stems greater than 21.5 cm DBHOB removing 4.6 m^2 ha^{-1} when 110 per cent of limiting basal area reached (Jerym, 1968). Large scale aerial pre–plant spraying trials carried out to control woody weeds in exotic pine plantations. Both pre–plant and post–plant aerial spraying operations were carried out in subsequent years until the Agricultural Chemicals, Distribution Act 1966 was applied in 1972 (Yule, 1987). Individual tree application of 20 kg N plus 20 kg P ha^{-1} fertiliser approved for swampy line mounded sites in sub–tropical lowland areas. Practice was applied to the 1970 planting and then abandoned (Yule, 1987).

Table 43. Significant events and major changes in silviculture of exotic pines in Queensland.

Year	Significant events or changes in silvicultural practice
1969	Machine planting trialled in exotic pine plantations at Tuan, becoming the predominant form of planting at major coastal sub–tropical centres by winter 1972 (Yule, 1987). Dipping of Slash Pine roots in clay slurry introduced (Yule, 1987). Inter–row spacing on line mounded sites changed to 3.0 m with trees planted at 2.4 m along mounds departing from 2.7 m x 2.7 m spacing (Yule, 1987). Overall ploughing of exotic pine sites trialled as a measure to control woody weeds and introduced on a large scale basis the following year (Yule, 1987). Twenty year old phosphate deficient Loblolly pine stands on red earths refertilised with 50 kg P per hectare (Yule, 1987). Large scale second rotation trial established at Beerwah. Trial results subsequently indicate no second rotation decline in productivity (Yule, 1987).
1970	Plantings extended from better–drained sites to include less fertile soils in areas of poor drainage (Simpson and Grant, 1991). Construction of 20 ha nursery at Toolara begins with first sowing carried out in 1972 (Yule, 1987).
1970s	Superphosphate applied at 60 kg P ha^{-1} (Simpson and Grant, 1991).
1971	Ripping with single tine to 60 cm introduced to soils shallow to clay, hardpan or to silty soils. Trials subsequently show no growth response to ripping up to a depth of 1 m and practice was abandoned in 1978 (Yule, 1987). Large scale aerial fertilising introduced to newly planted coastal sub–tropical plantations (Yule, 1987).
1972	Agricultural Chemicals Distribution Control Act applied, leading to the abandonment of aerial spraying with herbicides. In its place a second overall plough was carried out before planting and inter–row cultivation after planting to control woody weeds (Yule, 1987). Fertiliser prescription for exotic pines adjusted – Sub–tropical lowlands – 60 kg P ha^{-1} Caribbean Pine/tropical – 60 kg P ha^{-1} Areas<SI 30 m – P applied as superphosphate or triple superphosphate instead of rock phosphate (Yule, 1987). Introduction of selective pre–emergence herbicides chlorthal dimethyl and propazine to exotic pine nurseries (Yule, 1987).
1973	Large scale machine planting trials with open root Honduras Caribbean Pine stock carried out at Tuan gave a survival rate superior to hand planting (Yule, 1987). A spacing of 3.0 m between rows introduced on all sites to facilitate use of mechanised inter–row cultivation (Yule, 1987).
1974	Honduras Caribbean Pine seed collected at Kennedy yields first major collection of 55.6 kg of seed, sufficient to meet a significant part of Departmental needs at the time (Yule, 1987).
1975	Line mounded areas fertilised with N plus P in 1969–70 aerially refertilised with 40 kg P ha^{-1} bringing P level applied to 60 kg ha^{-1} (Yule, 1987). Fertilising of poorly drained humus podzol soils with Cu to correct malformation introduced (Yule, 1987). Inter–row spacing of 2.4 m between rows introduced at major sub–tropical regions to facilitate future out–row thinning (Yule, 1987).
1976	Introduction of tree shaker to Slash Pine seed orchard at Beerburrum. Subsequent trials showed that mechanical shaking was unsuited to other species, particularly Honduras Caribbean Pine (Yule, 1987). Large–scale plantings of Honduras Caribbean Pine commenced in Tuan–Toolara complex near Gympie (Ryan, 1990).
1977	Fertiliser regime depends on prior fertiliser history (Simpson and Grant, 1991). Aerial re–fertilising of 1800 ha of 10–year–old Slash Pine on poorly drained sites carried out (Yule, 1987). First major purchase of improved pasture grazing land for exotic pine establishment takes place at Toolara (Yule, 1987).
1978	First large scale planting at Wongi, north of Maryborough carried out in winter 1979 (Yule, 1987). Small areas of soil salinity detected in newly planted areas at Tuan (Yule, 1987). Major review of exotic pine spacing undertaken. 3 m x 3 m spacing adopted for all species except for Honduras Caribbean pine on good to average sites in the integrated Zone, where spacing of 3 m x 2.7 m was adopted and on inferior sites in Bundaberg area where 3 m x 3.3 m was adopted (Yule, 1987).
1980	Strip ploughing introduced at Kuranda as a measure to ameliorate soil erosion in high erosion hazard areas (Yule, 1987).
1980s	Increased planting of *P. caribaea* and hybrids (Birk, 1994).

Table 43. Significant events and major changes in silviculture of exotic pines in Queensland.

Year	Significant events or changes in silvicultural practice			
1981	Spacing of Honduras Caribbean Pine on average to good sites increased from 3 m x 2.7 m to 3 m x 3 m (Yule, 1987). New facilities for kiln drying, extraction and cleaning established at Beerwah (Yule, 1987). First sowing in new Ingham nursery carried out (Yule, 1987).			
1982	New spacings adopted for exotic pines: Sawlog zone – 3 m x 4.5 m or 3.5 m x 3.8 m Integrated zone – Slash Pine – 3 m x 4 m Honduras Caribbean Pine and hybrids – 3 m x 3 m (Yule, 1987) Prescriptions to add nitrogen fertiliser to podzols in southern plantings and poorly drained sites in central and northern regions. Low initial stocking (1,000 stems ha^{-1}) introduced with early precommercial thinning to 750 stems ha^{-1} at 3–years–of–age (Simpson and Grant, 1991).			
1983	Pre 1983, virtually all new sites developed from cleared native forest. Post 1983, sites developed for cattle grazing have been acquired for planting. Pre 1983, little or no fertiliser applied at planting on northern sites. Post 1983, fertilisers applied (Simpson and Grant,1991). Large–scale second rotation establishment commenced at Beerwah, 46.3 ha replanted following final crop logging (Yule, 1987).			
	Species	**Zone**	**Initial spacing (m)**	**Stocking per ha**
	Slash Pine	Integrated	5.0 x 2.4	838
	Honduras Caribbean Pine	Integrated	5.0 x 2.1	952
	Honduras Caribbean Pine	Sawlog	5.0 x 3.0	666
	Radiata Pine	Integrated	5.0 x 3.0	666
	Radiata Pine	Sawlog	5.0 x 3.0	666
1984	Sufficient seed of clonal seed orchard grade available for all Honduras Caribbean Pine sowings (Yule, 1987).			
1985	Interrow spacing narrowed from 5.0 m to 4.5 m to account for greater planting losses than expected to achieve survival rates of 750 in the integrated Zone and 500 in the Sawlog Zone (Yule, 1987).			
1987	High analysis fertilisers being used. Later age application of 40 kg P ha^{-1} to 25 per cent of Slash Pine plantations completed. (Simpson and Grant, 1991).			
1989	Queensland Forest Service formed within Queensland Department of Primary Industries (DPI) in December.			
1992	Later age application of 40 kg P ha^{-1} to Slash Pine plantations completed (Birk, 1994).			
1994	4,712 ha of plantation damaged in Queensland's worst plantation fire (BTL, 1995).			
1995	DPI Forestry established as a commercial entity within DPI in July.			
1996	1970 ha of privately owned plantations outside Caboolture purchased from APM (BTL, 1996).			

Table 44. Management of exotic trees in Queensland (Rogers, 1957).

Useful trees completely logged. Remaining vegetation brushed, felled and burnt when dry. Unburnt material stacked and burnt.
Seedlings established in 45 cm x 45 cm square chipped of grass. Grass protects seedlings from drying winter winds.
Brush and coppice tending for first 4 to 5 years.
Application of rock phosphate to areas with low total soil P analysis.
Pruning to 6.3 m of 400 stems ha^{-1} over period of three years. First pruning of 600 stems ha^{-1} when trees about 6 m tall.
Thinning of OTS stems greater than 14.5 cm DBHOB and equal and higher than nearby select tree removed to effective stocking of 850 stems ha^{-1}. Second thinning to 600 stems ha^{-1} at about age 20 years. Third thinning at 25 years to select only. Each thinning yields about 50 m^{3} ha^{-1}. Possibility that unmerchantable thinning of Slash Pine to 750 stems ha–1 will be introduced soon.

Table 45. Management of Caribbean Pine (Hawkins *et. al.*, 1972).

Routine plantings of *P. caribaea* largely restricted to ridge sites with well–drained soils deeper than 60 cm to clay and with original vegetation at least 15 m tall. *P. elliottii* considered to be better adapted to swamp sites.
Seed broadcast sown in nursery and seedlings transferred to metal tubes when about 7 cm high then lined out for summer out–planting.
All commercial trees removed and residual vegetation pushed, heaped and burnt during the year prior to planting. Swamp sites drained prior to clearing.
Ridge sites completely ploughed to 25 cm. Sections with shallow clay or hardpans are ripped to 70 cm. Swamp sites totally ploughed, ripped and mounded along planting lines to improve soil depth and local drainage.
Weed regrowth controlled with pre–planting herbicides applied with knapsacks or mist–blowers.
Planting of tubed stock after first reliable rains, normally between December and March. Spacing of 2.7 m x 2.4 m (1540 stems ha^{-1}) except for seed–orchard or grafted stock which is spaced at 2.7 m x 3.0 m (1230 stems ha^{-1}).
Areas below site index 30 broadcast fertilised with 290 kg ha^{-1} triple superphosphate.
Complete protection from fire practiced with large external and internal firebreaks.
Stands above site index 23 pruned. First pruning of 500 stems ha^{-1} to 2.4 m when predominant height reaches 9.1 m. second pruning one year later of 300 stems ha^{-1} and a final pruning to 6.4 m two years later. Prior to 1972 four pruning lifts were issued.
Pre–commercial thinning to 1,000 stems ha^{-1} on sites north of Bundaberg.
First commercial thinning when stand will yield 28 m^3 ha^{-1} at age 10–14 years depending on site index. Stocking reduced to 875 to 550 stems ha^{-1} depending on degree of pre–commercial thinning. Second thinning applied about 5 years later. Mean annual increment for merchantable volume range from 11.8 to 18.9 m^3 ha^{-1} yr^{-1} depending on site index.

Table 46. Exotic pine management in Queensland (Francis and Shea, 1987).

Native vegetation felled and heaped after logging merchantable trees. Debris burnt.
Cultivation, ripping plus mounding and/or drainage as necessary.
Knockdown and residual herbicides used to ensure 6 to 9 months of weed–free conditions to promote survival and rapid early growth.
Application of 60 kg P ha^{-1} at planting and other nutrients (e.g. Cu) as required.
Pre–commercial thinning at 3 to 4 years of age to achieve desired stocking of 750 stems ha^{-1} for integrated regime or 500 stems ha^{-1} for sawlog regime.
Slash Pine pruned if Site Index (SI = predominant height at 25 years of age) 24 m+ and Honduras Caribbean Pine at SI 26 m+. The best 300 stems ha^{-1} pruned to 5.4 m in two lifts at two year intervals when predominant height reaches 9.5 m.
Preferred first thinning utilises a fifth out–row plus selection thinning in bay for pruned stands or a third out–row in unpruned stands. Subsequent thinning on selection basis. Historically a large number of low intensity thinnings from above have been used to promote growth and dominance of pruned stems. The number of thinnings is being reduced and minimum thinning yields raised to 50 m^3 ha^{-1}.
Plantation prescribed burning restricted to twice per rotation.
Rotation length of 35 years for Slash Pine and 30 years for Honduras Caribbean Pine with expected MAI of 11 to 18 m^3 ha^{-1} depending on species and site.

Table 47. Exotic pine establishment on improved tropical pastures (Francis and Lewty, 1985).

Graze pastures until one week before herbicide treatment.
Strip cultivate 2.4 m width and 25 cm depth about six months prior to planting.
Spray with knockdown herbicide one week before planting.
Plant (winter).
Apply residual herbicide immediately after planting.
Maintain planting strip grass–free for six months using knockdown/residual herbicides.
Grazing may be re–introduced at about two years.

Table 48. Development of establishment and maintenance techniques for Hoop Pine.

1914	Trial plantings begin.
1920-21	First commercial plantations (~50 ha) established in Mary Valley, Atherton, and Fraser Island.
1949-50	Trials with herbicides begin.
1954-55	Work under way to produce a yield table.
1964	Seed orchard established in Imbil.
1967-68	Most Hoop Pine areas prepared by pushing scrub with dozers. Areas tended with pre–plant misting and post–plant knapsack applications of herbicide.
1969-70	First departures from traditional 2.7 m x 2.4 m spacing (1,540 stems ha^{-1}). Spacing up to 3 m x 3 m (1,110 stems ha^{-1}) where there was no prospect of a pulp market.
1971-72	Four–stage pruning reduced to three stages.
1974-75	Ground pruning with chainsaws begun. Third lift pruning abandoned and pruned height reduced to 5.2 m.
1976-77	First large scale planting of seed orchard stock. Operational power misting replaces knapsack spraying for pre–plant tending.
1978-79	Spacing of 3 m x 3 m adopted for genetically improved stock except on grassy, degraded areas subject to rat damage where traditional spacing maintained.
1979-80	Pruned height raised to 5.4 m and number of pruned stems increased from 300 to 400 stems ha^{-1}.
1980-81	Ground pruning of all stems adopted.
1980-81	Spacing of 3 m x 3 m adopted except in Gympie District. Pre–commercial thinning to 750 stems ha^{-1} introduced except in Gympie District. Herbicide and sown grassed regimes tried on a large scale. Power misting and splatter gun techniques developed for lantana control in established plantations. Residual herbicide successfully used in second rotation establishment.
1982-83	Spacing widened to 5 m x 2.4 m (833 stems ha^{-1}) but adjusted to 4 m x 3 m (833 stems ha^{-1}) on sites with high erosion hazard.
1982-83	Pre–commercial thinning to 750 stems ha^{-1} adopted in all districts.
1983-84	Sown grass crops and weed free bands or rings adopted in all new plantings.

Hoop Pine

Planting of Hoop Pine began in the 1920s. By 1963/64 the cut of plantation Hoop Pine exceeded that of natural grown Hoop Pine for first time (Holzworth and Hatcher, 2000). Hoop Pine sites are fertile, weed prolific and are on typically steep and broken terrain which limits access and potential for tractor working. The history of plantation development since the 1950s (Table 48) has been reviewed by Holzworth (1999).

Methods used for the establishment and maintenance of Hoop Pine plantations are described in Tables 49 and 50.

Eucalypts

Trial plantings of eucalypts began at Pomona near Gympie in 1950. Research into best methods to establish native hardwood plantations were under way in 1994 and there was a 10 year plan to expand the Pomona plantation in order to assess the commercial viability of eucalypt plantations for State and private investment (Pennington, 1994). The principal species used is Gympie Messmate (*E. cloeziana*).

Table 49. Techniques for establishment and maintenance of Hoop Pine plantations (Trist, 1949).

Planting confined to areas that have carried rainforest or scrubby forest.
Felling carried out from June to August. Material to 20 cm diameter stacked 3 to 6 m from clearing edge prior to burning in October.
Planting at 2.4 m in rows 2.7 m apart (1,500 stems ha^{-1}). Refilling carried out if survival less than 80 per cent. If deaths due to frost damage, refilling is with *P. patula.*
In the first year the area is covered as often as necessary by chipping, particularly for inkweed. In the second year all woody weeds and harmful softweeds are removed by grubbing. Specified weeds are not removed. After the second year and up to pruning all softweeds other than inkweed are left. Grass is chipped as necessary and woody weeds are grubbed. Vines are removed. After pruning selective tending is aimed at retaining useful scrub species and eliminating various specified weeds.
Pruning is aimed to produce 150 stems ha^{-1} of good form and vigour pruned to 6.3 m with a central knotty core of less than 15 cm.
Thinnings are directed at promoting the growth and preservation of dominance of trees selected for pruning.

Table 50. Establishment and maintenance of Hoop Pine plantations (Dale and Johnson 1987).

First rotation sites. Native forest logged and cleared. Debris pushed into windrows and burnt. Depending on season, oats (winter) or Japanese millet (spring) broadcast sown to stabilise exposed soil.
Second rotation sites. After harvesting, the understory scrub species are felled by hand. On slopes less than 12^{o} planting lines are pushed into debris with a V–blade. On steeper slopes debris is burnt under mild conditions. Cereal cover crops are planted to protect exposed soil.
Planting at 2.4 m within rows 5 m apart (833 stems ha^{-1}).
Young trees tended to maintain a ring of bare earth by using herbicides. Creeping pasture grasses sown in inter–row to stabilise soil and inhibit pioneer species. Chemical tending of undesirable species until time of first pruning at about age 10 years. Some mowing practiced on more level sites.
Pruning of selected 400 stems ha^{-1} in two lifts to 5.4 m.
In older stands with 850 stems ha^{-1}, stocking is reduced to 600 stems ha^{-1} at first thinning and to 400 stems ha^{-1} at second thinning. In younger stands stocking is reduced to 400 stems ha^{-1} at first thinning.
Clearfell at about 50 years of age.

Australian Capital Territory

Softwood planting began in the Canberra region in 1915, the principal species being *P. radiata*. By 1950, when the forest estate came under the control of the Forestry and Timber Bureau, about 6,380 ha had been planted. The estate was transferred to the Department of Interior in 1963, by which time plantings had increased to about 10,550 ha. During this period about 2,350 ha were pruned to 2.6 m, usually with two lifts of 1.3 m.

The standard method for site preparation and subsequent methods for establishment and maintenance during the 1950s are given in Tables 51 and 52 respectively. In 1950, 316 ha of plantation were destroyed by fire in the Stromlo working circle. This area was re-established with natural regeneration. From 1956 to 1963 non-commercial thinning was used to reduce stocking to the standard espacement of about 1680 stems ha^{-1}.

Table 51. Site preparation for softwood plantations in the Australian Capital Territory (Shoobridge, 1951).

If soil cultivation unnecessary or impracticable, clearing by cable between two tractors. Timber allowed to dry for at least 12 months then windrows burnt without further heaping. If country unsuitable for cultivation or country too steep or rough for recovery of firewood push or pull timber and heap into windrows for burning after drying. Salvage of fence timber and firewood one year prior to clearing. Push stumps and remaining trees into heaps and burn immediately.
On recently cleared forest land and slopes less than 12 degrees, rip to 45 cm with two tines at 90 cm spacing following contours as close as practicable. On open grasslands ripping carried out with five tines. Heavy dried–off grass burnt if necessary. Previously, mouldboard ploughs used to prepare planting lines in grassland.

Table 52. Establishment and management of pine plantations in the Australian Capital Territory (Anon., 1957e).

Areas cleared in early summer by pulling. After firewood removed the cleared forest is broadcast burned or stacked and burnt in windrows in the following autumn.
Ripping or ploughing prior to planting according to site.
Planting at 1,330 to 1,680 stems ha^{-1} (Prior to 1941 at 750 stems ha^{-1}).
Tending to remove native seedling and coppice growth.
Pruning to 2.4 m in two lifts. Selective pruning to 6 m.
Thinning from below at 15 years and then at three–year intervals.
Logs harvested to minimum 15 cm Top DUB then cordwood to 10 cm Top DUB.

Table 53. Plantation establishment for first rotation Radiata Pine in the Australian Capital Territory (Fernside, 1978).

Leasehold land withdrawn from agricultural leasehold for planting. Plans for 400 ha per year.
Seed orchard seed supplemented by seed from older stands.
Riplines to 30 cm backfilled with roller. Subsoil fertiliser (125–250 kg ha^{-1} of NPK 15:30:0 or 10:9:8) application in combination with ripping.
Rectangular spacing of 3.6 m x 2.4 m (1160 stems ha^{-1}) but anticipated move to 4.2 m x 2.1 m (1,330 stems ha^{-1}).
Thinning to 650 stems ha^{-1} before canopy closure.

Table 54. Standard regime for *P. radiata* in the Australian Capital Territory for 1983.

Age	Operation
0	Establishment including site preparation (including crushing regeneration and crosscutting slash on second rotation sites), planting and fertilising.
4	Scrubbing or releasing.
8	Non–commercial thinning to 650 stems ha^{-1} and pruning to 2.2 m for fire control and to reduce the cost for logging.
20	First commercial thinning to 360 stems ha^{-1} (Fifth row outrow plus selection, Sebire, 1987).
25	Second commercial thinning to 253 stems ha^{-1}.
30	Third commercial thinning to 172 stems ha^{-1}
35	Clearfelling

Table 55. Plantation establishment for first rotation of *P. radiata* in the Australian Capital Territory (Johnston, 1987).

Area predominantly cleared of remaining scattered native trees with retention of significant clumps. About 40 ha per annum.
Cultivation by deep ripping with single tine plough to achieve cultivated zone 1.5 m wide and 0.7 m deep.
Pre–plant application of herbicide from helicopter for weed free zone up to three growing seasons. Within water catchment broadcast or strip spraying planting rows practiced.
After planting 150 g Starter NP 20:20 applied to all plants.
In Cotter catchment follow up spot application of herbicide at age one year.

From 1970 new plantings were restricted to ex-pasture sites (Johnston, 1987). These were generally of a lower site quality than those used previously. Methods of establishment during the 1970s are recorded in Table 53.

In 1974 there was a considerable degree of wind damage. Second rotation was generally established by natural regeneration after rolling flatter areas to crush debris and provide a disturbed seed bed (Lea, 1984). Seedlings were thinned at about two years to 770 stems ha^{-1} and competing wattle and eucalypt growth removed.

J.R. Groom and Associates (1983) have reviewed plantation operations in the ACT. From 1978 most clearfelled areas were re-established by natural regeneration. This involved the loss of one or more growing seasons, arduous early manual thinning and sustained the use of unimproved growing stock. There was a tendency for thinning to be delayed with the aim of producing a commercially extractable yield, despite the fact that 78 per cent or more of the returns are produced at clearfelling.

The standard regime in 1983 is shown in Table 54. Mean annual increment for the 36 years (35 growing plus one year re-establishment) was estimated as 14.15 m^3 ha^{-1} yr^{-1} (J.R. Groom and Associates, 1983).

Sebire (1987) reported that the average rotation for sustained yield purposes was 35 years. The standard practice for second rotation consisted of chopper rolling followed by deep ripping. In areas where debris presented an unacceptable fire hazard it was heaped and burnt before ripping. Seed orchard material was used in all new plantings although increasing use was being made of cuttings. Chemical weed control and one or two applications of fertiliser were standard practice.

Table 56. Plantation establishment for second rotation sites in the Australian Capital Territory (Johnston, 1987).

Chopper roller used where possible to crush slash to enable deep ripping and pre–plant herbicide application. Heaping and burning prior to ripping where chopper rolling impracticable.
Areas over 18^o planted by hand or natural regeneration allowed to establish. Stocking 600 to 800 stems ha^{-1} depending on slope.

Table 57. Establishment and silviculture of Radiata Pine on dry sites in the Canberra region (Jamieson and Cooper, 1997).

Single drum roller to crush slash on slopes where conventional machine can operate.
Keyline ripping from gullies to ridges on a grade of 1:200 to optimise water conservation. Mounding combined with ripping to reduce costs. On first rotation sites mounds are rolled to break down grass clods. In second rotation a V rake is used to clear slash before mounding.
On steep country an excavator with a cultivator head produces a cultivated area 1.2 m wide and 650 mm deep with a 300 mm mound over the cultivated spot.
Broadcast spraying of weedicide before planting with post–planting broadcast, strip or spot spray.
On second rotation sites surviving natural regeneration is removed manually in the summer following planting and occasionally during the third year.
Stocking of 1,000 stems ha^{-1}.
Application of 150 g per tree NP fertiliser 4–8 weeks after planting. Boron applied on some sites 1.5 to 2.5 years after planting.
Pruning of 300–400 stems ha^{-1} to retain a green height of 4.0–4.5 m. A minimum of two lifts to a height of 5.1 m to ensure a saleable sawlog. Standard practice is three lifts to 6.3 m.
Non–commercial thinning at about 7 years to 600–650 stems ha^{-1} with remaining unpruned trees removed in a commercial thinning.
Later age fertiliser applied 5–7 years before clearfell depending on timing of final thinning.
Historically productivity has been about 8 m^3 ha^{-1} yr^{-1} on dry sites but is expected to achieve 16 m^3 ha^{-1} yr^{-1} with improved management.

Table 58. Silvicultural practice for exotic species plantations in the Northern Territory (Haines, 1987)

Low scrubland and low open woodland chosen as planting sites. Anticipated that it would be necessary to revert to clearing eucalypt forest within a few years.
Clearing 12 months prior to planting.
Stick raking and cultivation to remove and kill woody regrowth during summer. Further cultivation prior to planting.
Planting by machine. Prior mounding of planting lines discontinued. A 5 m x 3 m spacing (~ 667 stems ha^{-1}) regime adopted for sawlogs. Earlier a 3 m x 3 m regime had been used.
NPK fertiliser delivering 60 kg P ha^{-1} applied at planting.
Existing plantations to be handed over to Tiwi Land Council from 30 June 1987.

The standard regimes for first and second rotation sites during the 1980s are shown in Tables 55 and 56 respectively. Methods used in the 1990s are given in Table 57.

Calcium/sodium borate is now routinely applied at age one year.

Northern Territory

Plantation establishment of *Callitris intratropica* began in 1960-61 and continued for about 15 years (Haines 1987). Trial plantings of Honduras Caribbean Pine began in 1965 and since 1970 has been the primary species. The plantation project is now confined to Melville Island. In 1987 there were about 4,000 ha of plantations on Melville Island of which about 60 per cent was Honduras Caribbean Pine with a weighted average age of seven years (Haines, 1987). Annual establishment was about 250 ha yr^{-1} Silvicultural practices are summarised in Table 58.

9.2 APPENDIX 2

ASSUMPTIONS MADE DURING PREPARATION OF SPREADSHEET WORKBOOKS

Regional spreadsheet workbooks

The National Plantation Inventory recognises 15 regions within Australia, each of which may have several characteristic plantation species (National Forest Inventory, 1997). Turner and James (2001) have constructed 'indicative yield tables' for principal species grown in specific regions and combinations of these regions. The original intention was to produce spreadsheet workbooks for each of the species and groups used by Turner and James (2001). Several of the inventory regions cross State boundaries. There has been much convergence of plantation practices during the period but in the past there have been distinct differences in practice between States. Thus, it has been convenient here to merge inventory regions within States and to provide separate silvicultural regimes in some regions that are split by State boundaries. We present data for ten regional groups (Table 59) some of which partially overlap other groups. Seventeen spreadsheet workbooks are presented, there being separate workbooks for species and species groups within regions.

Spreadsheets

Each workbook contains three spreadsheets; one each for the cases where plantation has been established by:

- Conversion of native forest;
- Re-establishment on a former plantation site; or,
- Conversion of farmland.

Individual spreadsheets are left blank when particular combinations of prior land use and plantation species rarely occur within a region or group of regions, e.g. eucalypt plantations on sites converted from native forest.

The spreadsheets vary in the options for pre-planting site preparation. Conversion from native forest and former plantation both allow for the distinction between broadcast burning or windrowing or heaping of slash before burning. In the case of plantations extra options of chopper rolling or planting through the logging slash are given. The main pre-planting options when converting farmland to plantation involve the control of grasses and other vegetation by grazing or use of herbicides in spots, as strips or in broadcast applications.

Variations in cultivation prior to planting on all sites reflect the degree of soil disturbance. These include:

1. No disturbance or spot cultivation such as planting pits or, more recently, preparation with an excavator;
2. Strip cultivation such as drains, rips or mounds; and
3. Broadcast cultivation by plough or rotary hoe.

Only the most disturbed state is recorded (e.g. when broadcast ploughed sites are subsequently ripped or mounded, only the broadcast ploughing is recorded).

Similarly, three degrees of post-planting weed control are recorded on all site types:

1. Manual weed control including clearing around planted stock and control of some intervening vegetation using hand tools or manual sprayers;
2. Strip weed control using mowers, cultivators or machine mounted sprayers; and
3. Blanket applications of herbicide usually from aircraft.

If the sum of these operations is less than 100 per cent, the deficit indicates the percentage area on which weeds were not controlled. The need to repeat weed control treatments is not recorded.

The initial stocking of the plantation is recorded, as is the stocking remaining after each thinning. At the first thinning, the proportion of removals left as waste is recorded. The presence or absence of pruning is noted but no indication is given of the degree of pruning nor of the number of pruning lifts.

Some spreadsheets have been annotated with comments about specific practices.

Table 59. Details of workbook files describing changes in plantation practices from 1945 to 2000.

Region number	Region name	Species	File name
1	Western Australia	*Pinus radiata*	WAradiata.xls
		Pinus pinaster	WApinaster.xls
		Eucalyptus spp.	WAeucalypt.xls
2	Tasmania	*Pinus spp.*	TASpine.xls
		Eucalyptus spp.	TASeucalypt.xls
3/4	South Australia	*Pinus spp.*	SApine.xls
3	Green Triangle SA/Vic.	*Eucalyptus spp.*	SAVICeucalypt.xls
3/5/6	Victoria	*Pinus spp.*	VICpine.xls
7	Gippsland	*Pinus radiata*	APMpine.xls
		Eucalyptus spp.	VIC7eucalypt.xls
8/9/10/11/12	New South Wales	*Pinus spp.*	NSWpine.xls
12		*Eucalyptus spp.*	NSWeucalypt.xls
9	ACT	*Pinus spp.*	ACTpine.xls
13/14	Queensland	*Pinus spp.*	QLDpine.xls
		Araucaria sp.	QLDeucalypt.xls
		Eucalyptus spp.	QLDHoop.xls
15	Northern Territory	*Pinus spp.*	NTpine.xls

Data sources

The major sources of data are recorded in Appendix 1. These include itemised accounts of current practice at specified times, historical accounts of significant events which might impinge on silvicultural or harvesting practices, and records of changes in individual practices. As far as possible records of actual practice, as opposed to recommended practices which may not yet have been implemented have been used to develop the spreadsheets.

General assumptions

1. At any particular time the suite of management practices used by State plantation authorities for a particular crop type are similar for all State-owned or managed plantations within the specified region or regional group.
2. Within the specified region or regional group, privately owned plantations are managed in a similar manner to State owned plantations.
3. Within the specified region or regional group, post-establishment silvicultural practices (pruning, thinning etc.) in particular crop types are similar despite differences in prior land use (native forest, plantations, farmland).
4. It is assumed that little or no change in site preparation and establishment practice occurred between 1945 and the first reported statements of practice. The first statements were usually those presented to the 7th British Commonwealth Forestry Conference in 1957.
5. Only small areas of eucalypts were planted prior to 1990, so methods of management are generally ignored before that time. It is assumed that in particular regions site preparation methods would be similar to that used for softwoods.
6. Eucalypt plantations established from native forests are often small and scattered (e.g. Booth, 1984). They are generally ignored in the Tables because with remote sensing they will be indistinguishable from even-aged natural regeneration or enrichment plantings.

SECTION 8

Fire Management in Australian Forests

Jim Gould

Phil Cheney

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FIRE MANAGEMENT IN AUSTRALIAN FORESTS

SUMMARY

This review examines the changing nature of fire management and fire occurrence in Australia over the last 50 years.

There is a high level of uncertainty about the accuracy of most data for forest fires and inconsistency between States on the type of information recorded. There is little information on total fuel load and fuel consumption by forest type and fire type.

The available records show a slight decline in area burnt by wildfire, but these data may be confounded by a changing area base used for reporting. The area burnt by prescribed burning for fuel reduction and other forest management increased sharply after 1960, but is currently declining. The current trends are likely to continue. The consequence of this trend will be the probability of greater areas burnt by wildfire during extreme events in the future. The extensive wildfire in SE Australia during the summer of 2002-03, indicate the highly unpredictable nature of fire impacts on carbon balance of Australian forests.

Suppression of wildfire is a forestry fire management practice. The impact of fuel reduction burning and wildfire suppression is difficult to quantify but has contributed to the decline in the area burnt by wildfires on land managed by forestry agencies. The authors believe that, on a national scale, proactive fuel management can be successful in decreasing the area burnt by wildfire in Australia.

An accurate calculation of the impact of fire on carbon balance requires better field data (fuel combustion, areas burnt) as well as modelling. Fires need to be classified by vegetation type, burning conditions, and recent fire history, which determine fuel available for combustion. In addition to direct emissions of CO_2 and other greenhouse gases, fire also affects the nature of forest growth and thus rate of carbon uptake into biomass and soils.

Fire is a dominant factor in the natural regeneration of most eucalypt forests and, ecologically, these forests have co-evolved with fire. Climate change will affect both fire weather, forest growth and fuel dynamics, but the consequences for carbon budgets are poorly known. Fuel management using prescribed fire has an important role in protection of life, community assets, and a range of forest values, including carbon stocks. Active forest fire management could reduce both the area of forest burnt by wildfire, as well as the very high inter-annual variability in the area burnt.

1. INTRODUCTION

Australian forests are dominated by native species (mainly eucalypts and acacias) and cover 160 million ha (State of the Forests Report, 1998). The main forested regions are in the far north, the east coast, Tasmania and the southwest corner of Western Australia (WA). These forest areas of Australia, mainly composed of fire-dependent and fire-adapted species and ecosystems, have evolved in the presence of a fire regime driven originally by natural sources of fire ignition, by cultural practices of aboriginal people, and most recently by the European influence over the last two hundred years. The forests are a source of raw material for forest industry, and a source of many tangible and intangible products and services, including recreational and cultural opportunities for all Australians. In recognition of these values, forest fire protection efforts were established in the early 1900s, and have steadily developed to the point where Australian State public land management agencies are recognised as among the world's leaders in fire management.

Forest fire management in Australia is the responsibility of State and Territory governments. Fire management on public lands (e.g. State

Forests, National Parks, State Parks, Crown Lands) is the responsibility of the State agency charged with managing those areas. Fire suppression may be carried out by individual agencies or placed with one agency (e.g. in Victoria responsibility for suppression on all State lands is held by the Fire Management section of the Department of Sustainability and Environment). Fire management on private lands is carried out by volunteer bushfire brigades or industry brigades who are co-coordinated and supported by the State rural fire agencies. In recent years there has been an increase in the corporatisation of State-owned plantations and the fire management of these forests, along with new plantation forests established on private land, rests increasingly with the State rural fire authorities. This shift in fire responsibility has mainly occurred in South Australia (SA) and Victoria over the last 7-10 years.

Most of the States provide fire management directly as a government service, generally by the department(s) that manage lands, forests and other natural resources. Their fire management programs provide varying levels of planning, fuel management (i.e. prescribed burning), detection, pre-suppression and suppression operations. The level and type of activity in each category vary with each agency's natural resource polices, protection priorities, financial resources, and, in particular, the ecological and physiographical conditions of the forest itself. Consistent with the statutory obligations and policies of public management agencies, their fire management objectives include:

- Protection of people from bushfire.
- Protection of buildings and facilities from bushfire.
- Prevention of bushfires burning onto neighbouring property.
- Conservation of natural and cultural values including protection of:
    - Native plant and animal species, habitats and communities;
    - Soil and water resources;
    - Scenic and landscape values; and,
    - Aboriginal and european historic heritage.

All agencies deliver an organised detection program. Fire towers are the most common detection system, offering regular surveillance of high-value areas and community assets. The use of fixed-wing aircraft for detection has increased in the past 15 years.

Suppression strategies use a mix of resources from the land management agencies with support from rural bushfire authorities. Ground crews using fire appliances (fire tankers), heavy equipment (bulldozers), and hand tools are the backbone of the suppression system. Aircraft for aerial suppression have been used in Victoria for more than 30 years, and over the past decade other forest agencies have increasingly used this strategy.

Different suppression strategies are used by the agencies, based on the nature of the forest and fire regimes that they deal with and, to some extent, on the organisational philosophy. Some agencies, such as those in Victoria and WA, have relatively large full-time fire management organisations compared to those in other States.

All the State fire management agencies face a similar array of challenges in meeting their fire management objectives and the task is becoming increasingly difficult. As a government service, fire management has been subject to financial pressures, resulting in staff reductions and erosion of traditional levels of fire management resources. Resources are declining at a time when demands for protection by the general community are increasing. Concurrently, the demands for ecologically appropriate forest management practices and concerns about the long-term impacts of prescribed burning practices have led to the suggestion that, in some areas, fire is adversely affecting biodiversity and long-term sustainability of forest ecosystems.

These issues are overlain by debate about how fire can affect climate change, greenhouse gas balance at the landscape and national level, and whether those changes are being exacerbated by managed and/or wild fires.

This report is part of a review of change in forest management practices in Australia's forest estate since World War II. This report does not cover fire management on private forest land or public lands managed for conservation or other purposes. The area of public land used for forest production has changed during the period of the review but is estimated to be around 13 million ha in 1998 (Table 2).

The fire management practices that may have an impact on the forest carbon budget are:

- Fire suppression (i.e. the number and area burnt by wildfires)
- Prescribed burning for fuel reduction in native forests and conifer plantations
    - Firebreak burning
    - Top-disposal burning after selective logging
    - Broad-area burning
- Prescribed burning for habitat management (ecological burning)
- Prescribed burning (slash burning) for native forest regeneration which includes
    - Silvicultural burning beneath partially cut forest
    - Broadcast burning of clearfelled forest
    - Windrow or pile burning
- Prescribed burning for plantation establishment and re-establishment, including
    - Broadcast burning
    - Windrow burning

Each of these operations is carried out under different conditions that result in different levels of fire intensity and fuel consumption, so in addition to knowing the area burnt, it is also necessary to know:

- The amount of fuel potentially available;
- The proportion of potentially available fuel burnt;
- The fuel dynamics before and after the fire events.

In this report, estimates of these factors were made by using readily available unpublished data, published information and personal experience.

2. METHODOLOGY

This review evaluates the implications of past natural and human-induced fire on the greenhouse gas balance of Australia's forests. This review is based on the data summarised in Table 1.

There are no reliable fire statistics for fires on private forest land. Fires that occur on other public forest land (e.g. National Parks) may or may not have been included in the data depending on the fire management arrangements in each State and whether or not there are interagency protocols within the State for the management and reporting of forest fires.

The data were drawn mainly from State forestry agency annual reports. Such data include the number of fires, area of State forest burnt, the protected area and the area burnt by managed fires (i.e. prescribed fires for fuel reduction, regeneration or silvicultural management). See Appendix 1 for detailed fire statistics.

Each agency maintains fire statistics for its own purposes. There are no consistent conventions for reporting of fires or the areas burnt. During the 55-year review period there have been many changes to the procedures and criteria for reporting of fires and the areas for which statistics were

Table 1. Summary of the data reviewed to examine changes in management and impact of fire in State Forests since World War II.

Data	ACT	NSW	QLD	SA	TAS	VIC	WA	AUS
No. of fires & burnt area								
Annual Reports		√	√			√	√	
Direct from State agency		√		√	√			
State special reports		√				√		
CSIRO reports	√			√				√
Other sources					√			
Fuel Consumption								
Literature	√	√				√	√	
CSIRO data	√	√						
Fuel accumulation								
Literature	√	√	√			√	√	
CSIRO reports		√						

collected. National forest fire statistics were compiled by the Commonwealth Forestry and Timber Bureau between 1956 and 1970. These reports set several categories for fire reporting:

Area requiring protection: the area of forest land that the authority supplying fire statistics is responsible for protecting from fire;

Intensively-protected forest land: forest land covered by a detection system and on which actual fire suppression action will normally commence within two hours of a fire being reported to the local fire headquarters;

Extensively-protected forest land: forest land which may or may not be covered by a detection system but on which fire suppression action will be taken as access and availability or fire suppression crews permit;

Non-protected forest land: forest land on which fires are allowed to burn unattended for a considerable period or until they threaten more highly protected forest.

During this period (1956-1970) the area requiring protection, as specified by the 14 agencies providing statistics, ranged from 16.56 to 22.55 million ha whilst the intensively protected area category ranged from 7.52 to 10.79 million ha. These statistics were not maintained after the Forestry and Timber Bureau was dissolved and its functions transferred to the Commonwealth Department of Primary Industry.

Over the time period covered by this review the responsibilities of agencies managing forests have changed. In some States, areas have been transferred from State Forest to National Park, whilst in other States both State Forest and National Park agencies have been amalgamated and brought under a common fire management structure. The tenure of the land actually burnt has not always been recorded, so to maintain some consistency, fire statistics (when available) have been selected from those regions that are predominately State Forest (e.g. in WA only statistics for three southwest forest divisions of the Department of Conservation and Land Management (CALM) have been used).

Most agencies have published fire statistics in their annual reports, although in recent years there has been a change in the format and structure of the annual reports to more strategic reporting of their activities and fire statistics have been excluded. To supplement data from annual reports, each State agency forest fire management office was approached to obtain the data directly from its existing databases. Additional data required to complete the tables in Appendix 1 would have to be extracted from individual records of the forest management unit in question (i.e. forest compartment records, logging coupe records, plantation compartments, individual prescribed burning plans, etc.). The extraction of data at this detailed level was beyond the scope of this review.

3. AREA BURNT

3.1 WILDFIRES

It was difficult to draw firm conclusions about the trends in the number of wildfires and area of forest burnt from the data collected from State agency annual reports. The trends are confounded by inconsistencies in the data collection and reporting practices. Throughout the period of review, the area for which fire statistics were collected has changed, so there is no consistent fraction relative to the total State forest, let alone the total area (including conservation tenures) of forest.

In earlier years, areas burnt in remote locations were often unreported and the reporting criteria, methods, reliability and accuracy of all fire reports are open to question. Recent statistics include areas burnt on different land tenures (both public and private lands). Also, over this review period there have been many changes in the land tenure between State Forest, vacant crown land, National Parks and private ownership. These factors make it difficult to identify definitive trends in area burnt either by wildfires or prescribed fires.

Based on the data collated from annual reports and other sources maintained by State forestry agencies, it is estimated that, on average, approximately 213,000 ha of State Forests were burnt each year by wildfires (Table 2). The total area of forest burnt by wildfire on all public lands could well exceed 500,000 ha if wildfires in National Parks, conservation reserves and other public land were included. Table 2 gives the long-term average number of wild fire events in State Forests and average annual area burnt based on the tables in Appendix 1.

Table 2. Annual average number and area of bushfires in State Forest (multiple-use native forest) between 1945 and 2000.

State	Fire management agencies[a]	Area forest (Mha)†	Number of fires	Area burnt (ha)
Queensland	QLD DPI	4.0	135	44,400
New South Wales	NSW State Forests	3.1	195	60,500
ACT	ACT Forests [b]	0.015	15	160
Victoria	Dept. NRE	3.4	450	83,800
South Australia	SA Forestry [b]	0.03	10	4,500
Tasmania	Forestry Tasmania	1.3	149	8,790
Western Australia	Dept. CALM	1.6	250	10,700
Total		**13.4**	**1,204**	**212,850**

[a] Agencies with primary responsibility for forest fire management on public land.
[b] Pine plantation fires only.
† From State of the Forests Report (1998)

Figure 1 depicts the number of fires and the total areas burnt by wildfires in state forest between 1945 and 2000. The total number of fires and total area burnt during major fire seasons such as 1951/52, 1980/81 and 1982/83 that occur mainly in New South Wales (NSW), SA and Victoria, are much greater than reported in the forest agencies fire reports because there are no fire statistics collected for private forest land. An indication of the extent of burning in these severe seasons is given in occasional individual reports. Luke and McArthur (1978) estimated that over 4 million ha of land in the eastern and central regions of NSW were burnt in 1951/52 fire season. Also, during the 1982/83 fire season, which included the devastating Ash Wednesday fires of 16 February 1983, more than 756,000 ha burnt in Victoria and SA (See Table 3). Some 486,000 ha burnt in the fire protected area in Victoria and 21,000 ha of pine plantation burnt in SA. In major events like the 1961 Dwellingup fire in WA and the 1967 Hobart fires in Tasmania, there were large areas burnt outside the fire protected areas that are not included in the tables listed in Appendix 1.

The area of State Forests in NSW burnt during the 1993/94 fire season was low compared to the area burnt on National Park, other public land and private property. This was attributed to the effectiveness of fuel management and suppression activities on State Forest. These fires had a major impact on fire management practices in NSW over the past five years.

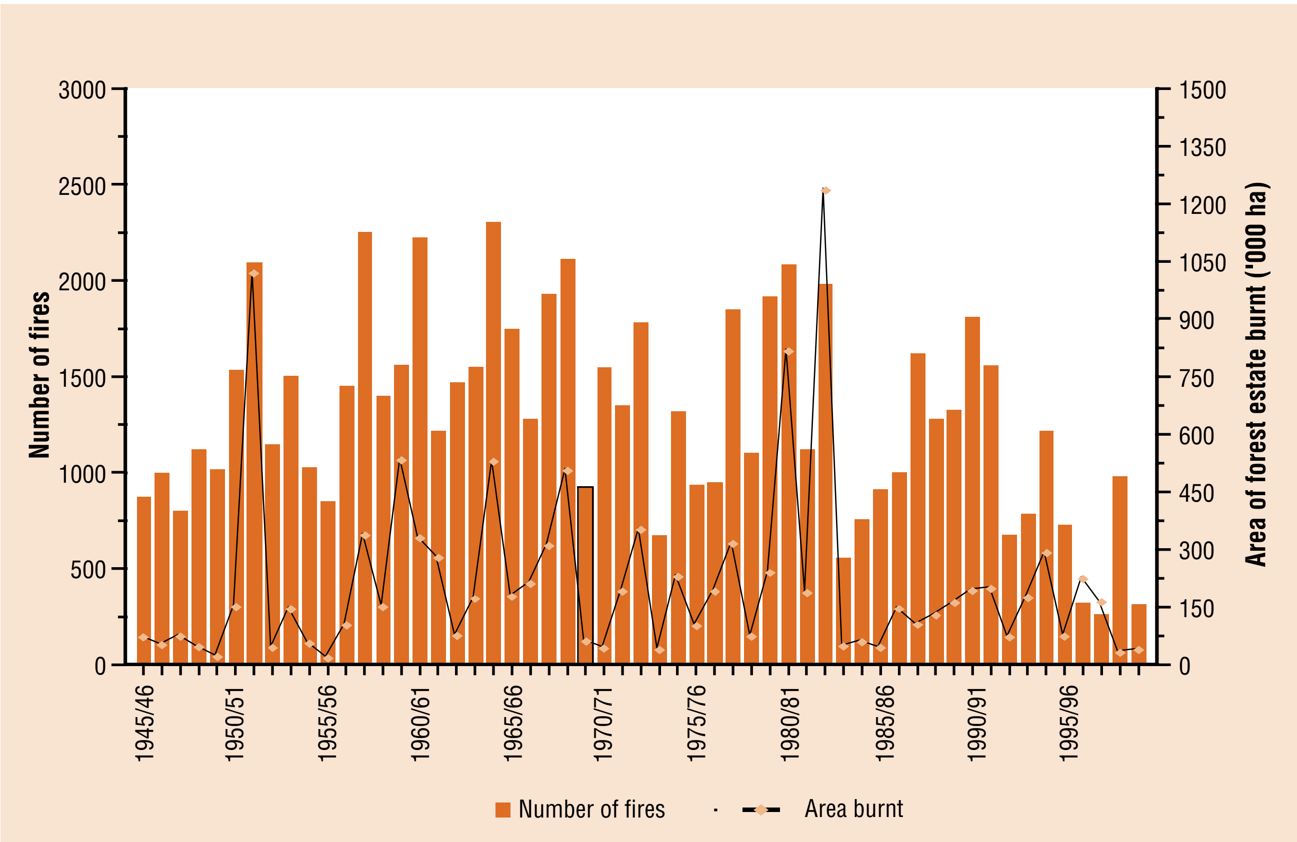

Figure 1. Number of fires (bars) and the area burnt (line) from 1945 to 2000 for State Forests.

Figure 2 shows that, despite much variation from year to year, there is a strong national downward trend in the number of wildfires, while there is little change in the total area burnt. However, the data probably underestimate the area burnt by wildfires early in the review period. The area base from which statistics were gathered was small and it is suspected that the areas burnt by fires in many areas were not always recorded. Thus, the trend in area burnt is probably downward, reflecting the downward trend in the number of fires.

Since the Ash Wednesday fires in 1983, the average annual area burnt (125,000 ha) and number of fires a season (950 fires) are well below the 55-year average. If the 1980/81 and 1982/83 fires were excluded from the long-term average there would have been a stronger downward trend in the total area burnt starting in the mid-1970s. The area burnt in 1980/81 and 1982/83 exceeds the long-term average because of the recurrence of two particularly severe weather events following a period of extended drought. There are several reasons for the reduction in area burnt and number of wildfires since 1983. Much of the heavy fuel accumulation had been reduced by the earlier introduction of broad-area fuel reduction burning and the fire management programs (i.e. detection, suppression) have improved.

Devastating wildfires (Table 3) have occurred in many parts of Australia and have burnt vast areas of native vegetation and often resulted in loss of life and property. There have been some improvements in fire management after most of these fire disasters.

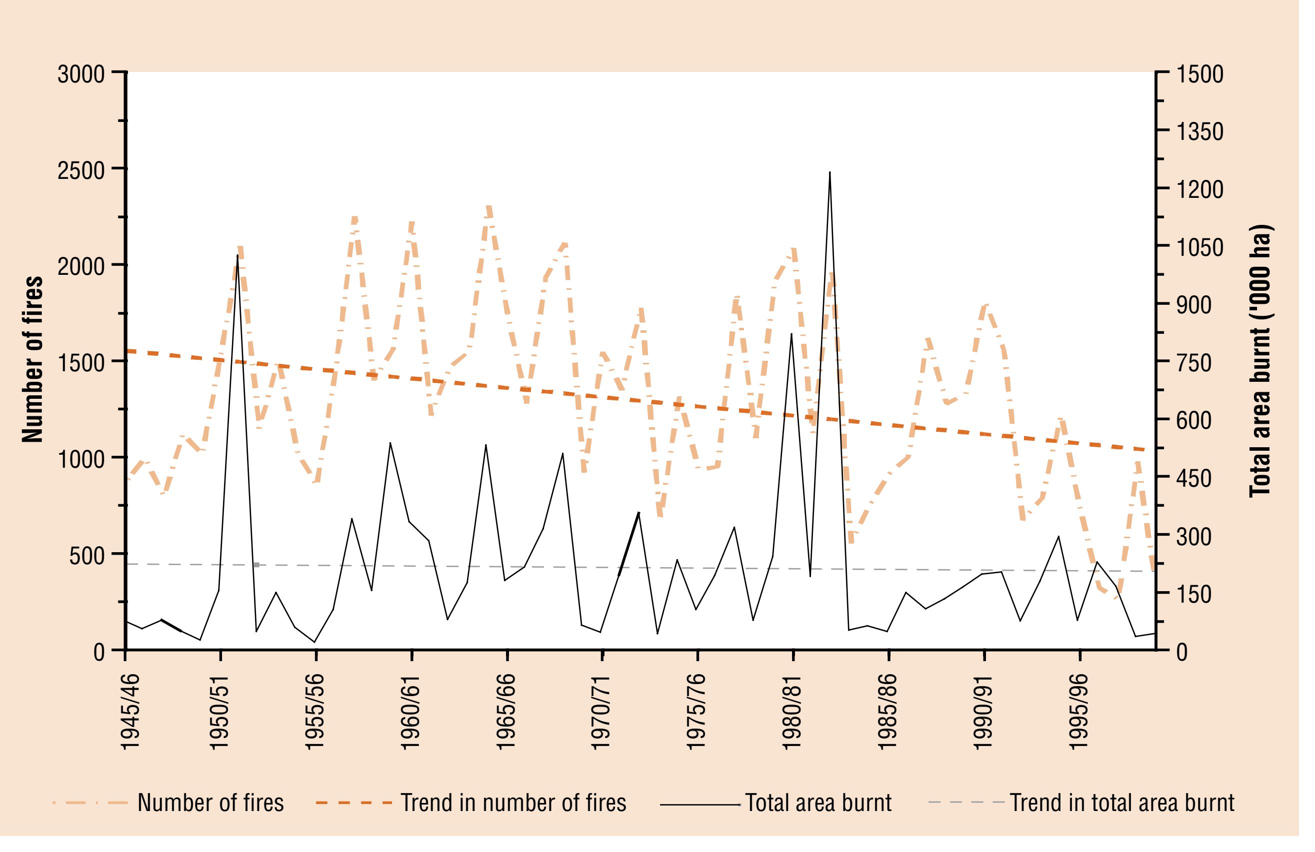

Figure 2. Trend in the number of wildfires and total area of State Forest between 1945 – 2000.

After the 1961 fires in WA there were major changes and improvements in prescribed burning in forest areas both on State Forests and other forested lands. After 1967, Tasmania developed a modern rural fires organisation that, together with the Forestry Commission and the Urban Fires Services, then covered the total area of the State (Cheney, 1976). After the Ash Wednesday fires in 1983 and the NSW Fires in 1994 there was more consultation with bushfire specialists from all government departments, community interest groups and local governments to produce and implement fuel management and fire protection plans. Also, the fire control agencies recognised and improved suppression resources and tactics to combat wildfires. They also recognise that no fire suppression system can halt the forward spread of a high-intensity fire burning in continuous heavy fuel load under the influence of extreme fire weather conditions.

Despite the improvement in fire control, planning, and prevention, if there are heavy fuels loads and ignition sources, devastating fires will break out under extreme fire danger and will burn out of control for many hours. Under these circumstances the magnitude of the bushfire disaster can only be reduced by hazard reduction and fire protection measures undertaken at a local level.

3.2 PRESCRIBED BURNING - NATIVE FORESTS

The damage caused by wildfire and the ability of suppression forces to control it is strongly linked to fire intensity, which is governed by fuel, weather and topography. Of these factors, only the fuel level can be manipulated, thus fuel management is the basis of wildfire prevention and control throughout much of Australia. This requires the periodic removal from part of the landscape of some of the surface litter and understorey vegetation. This can be achieved by manual, mechanical, or chemical methods or by the use of fire.

Studies conducted by McArthur (1962), Peet (1965), and others since the 1960s (Cheney *et. al.*, 1992) have provided the technology for fire to be used effectively to manage fuels. These studies enable the behaviour of fires that are lit under given conditions to be predicted. A range of operational procedures provides a high level of security against fire escape. Due to the improvements in techniques and the application of fire behaviour knowledge, prescribed burning has become a reliable fuel management tool. The only safe and effective way of reducing fuels over large areas is by low-intensity prescribed fires. In Australia, this is generally synonymous with broad-area fuel reduction. In most eucalypt forests, the aim of fuel-reduction programs is to keep the load of fine fuel (fuels less than 6 mm in diameter) on the forest floor to <10 t ha^{-1}. This will prevent the development of crown fires in medium to tall forest and will limit the rate of spread and

Table 3. Some devastating bushfires in Australia and their impact on lives and property.

Year	Location	Area burnt (ha)	Houses lost	Lives lost	Source
1939	Vic/NSW	>1,000,000	?	77	Luke and McArthur (1978)
1961	WA	506,000	?	None	Cheney (1976)
1967	Tasmania	264,000	1,718	62	Cheney (1976)
1983	Vic/SA	756,000	2,463	76	Keeves and Douglas (1983) Rawson *et. al., (*1983)
1994	NSW	800,000	230	4	Gill and Moore (1998)

damage done by wildfires in all but extreme fire conditions. The frequency of burning is determined by litter accumulation rates. Burning rotations are normally between 5 and 10 years.

Prescribed fire is also used in native forests to remove slash accumulations and to prepare a seedbed for the regeneration of native forest species and more recently to regenerate understorey species and manipulate vegetation to provide suitable habitat for native fauna. Although these operations also remove fuels, they are generally of higher intensity than burns used specifically for fuel reduction and the intensity prescribed is determined by the requirements for good regeneration.

In this review, it was only possible to separate the prescribed fires used to manage native forests into a few of the selected categories. Most State agency reports did not differentiate between the different types of management fires and these were often recorded only as prescribed fires. Where no data are available, qualitative comments on the practices have been made based on the experience of the authors.

Fuel Reduction Burning

Burning to protect townships and to stimulate grazing has been carried out since soon after European settlement. This was usually done every year and mostly applied to grassy woodlands in spring before the onset of the fire season and often to remove dead grass from the previous season's growth and stimulate fresh grass for grazing. Forest authorities generally believed that all fire would cause damage to the forest and that there was no way of reducing the impacts of severe forest fires burning in summer. Although there were some advocates of fuel reduction burning under the forest, particularly in WA, the principle of reducing fuels to reduce the damage from wildfire and to make fire suppression easier was not generally accepted until McArthur's work in the early-1960s.

Today, fuel reduction on public land in most States is prioritised to protect townships, settled areas, farms public assets and recreational areas as described in regional fire management plans. These plans include input from government department specialists, community interest groups, neighbouring landowners and local government and have been progressively developed since the 1970s. In general, burning to protect townships and high value assets is more frequent and more intensive than broad area fuel reduction and the areas involved are much smaller.

Firebreak Burning

Prior to World War II the forest protection policy tended to favour fire exclusion and attempts at fire prevention were confined to fire break construction, top disposal and 'burning-off', a crude form of fuel reduction burning often associated with illegal burning by graziers to stimulate grass growth and improve grazing in State forests. In the 1930s, the forestry agencies put a great deal of effort into construction of 'fire-breaks' by cutting down dead trees and understorey vegetation and laboriously burning the surface fuels to develop fuel-reduced firebreak strips (Luke and McArthur, 1978). Later, roads and tracks superseded these firebreaks and were used as access routes to burn long, narrow burnt breaks. In WA, a track parallel to the road was constructed and the area between burnt out as a firebreak. Although the early annual reports recorded the length of firebreak (often hundreds of miles) there was no reference to the width of the break or the total area burnt. It is known that the width of burnt breaks could vary from 20 to 400 m, so that very large areas were involved.

In eastern States, firebreak burning was less common although a variation of ridge-top burning was practiced quite widely up until the early 1960s. In this practice, fires were lit along ridge-top fire trails and allowed to burn down slope under mild burning conditions. The extent of burning down-slope was highly variable depending on the burning conditions. Mostly, however, the extent of burning down-slope was very limited and did not provide an effective barrier to wildfires.

Top-disposal Burning

After selective logging, the heads of individual trees or groups of heads were burnt to remove the slash and to create a localised seedbed. Burning was usually carried out under conditions when the surface litter was moist and the fire would not spread between the heads. This required lighters to ignite individual heads. The actual area burnt was not recorded but rather the gross area treated, so the actual area burnt depended on the weather conditions and the intensity of the selection logging.

Broad-area Burning

The ineffectiveness of both firebreak burning and top-disposal burning to either stop a wildfire or reduce its intensity was clearly demonstrated during the wildfires in the 1950s and early 1960s (Figure 1). These events convinced advocates of fuel reduction burning that low-intensity fire had to be applied to extensive areas of forest if the damage from wildfire was to be reduced. Fire also had to be applied under suitable, safe conditions. The publication of prescribed burning guides (McArthur, 1962; Peet, 1965) resulting from extensive research, enabled agencies to apply low-intensity fires to the forest in a much more planned and controlled way than previous burning.

The main principle of fuel-reduction burning is that a decrease in fuel quantity will slow or stop the spread of a fire, which originates inside, or spreads into, a fuel-reduced area. The variation in fire behaviour that can occur with different fuel quantities is shown in Table 4. It is apparent that the level of fire activity is substantially reduced in areas with lower fuel quantities. In this example, under extreme forest fire danger (index >50) a fire burning in fine (<6 mm diameter) fuel quantities of >10 t ha^{-1} would be very difficult to control using direct attack methods, even if access into the fire area was good.

Fuel-reduction programs are planned to enhance the protection of urban areas and private property adjacent to the forest estate. The increased protection is usually provided through a combination of broad-area burning, to give reliable protection to both the forest and surrounding private property, and more intensive burning, usually on a smaller scale, adjacent to high-value areas such as townships, settlements and forest plantations. Burning to provide a level of protection immediately adjacent to valuable assets may be on a rotation as short as three years and designed to reduce fuel quantities over a very high proportion of the areas (i.e. net area burnt is over 90 per cent). In larger areas chosen to provide reliable protection, burning is often planned on a four to seven year rotation, while longer rotations are used in some areas.

Table 4. Relationship between fire fuel quantity and fire behaviour (McArthur 1973) for a Forest Fire Danger Index (FFDI) = 50[(1)]

Fuel weight (t ha^{-1})	Rate of spread (m hr^{-1})	Flame height (m)	Spotting distance (km)
5	280	3.5	0.8
10	560	8.5	1.7
15	850	14.0	2.8
20	1,200	Crownfire	3.8

[(1)] A FFDI of 50 can be produced by a temperature of 35°C, relative humidity of 20%, wind speed of 40 km h^{-1} and a drought factor of 10.

Large areas usually include considerable variation in both fuel properties and terrain. These factors, combined with the weather conditions, make it impossible to achieve a uniform reduction of fuel over the whole area. Fires are lit on a grid pattern under mild weather conditions, usually in the autumn or spring when the weather is stable. The result is a mosaic of burnt and unburnt patches with unburnt areas comprising 20 to 90 per cent of the total, depending on fuel moisture conditions and the objective of the burn.

During the mid-1960s most State forestry agencies increased their efforts in fuel reduction burning (Figures 3, 4, 5 and 7), initially via the development of broad-area burning using hand ignition and later using aerial ignition. Aerial ignition was introduced into WA in 1965 and into NSW in 1967. Broad-area burning was most systematically applied in WA with the original aim of burning between 12 and 25 per cent of State forest each year (Baxter *et. al.*, 1966). The data for WA (Figure 7) probably underestimate the area of fuel reduction burning prior to 1956 because the areas burnt by extensive firebreak burning were not recorded.

The advent of aerial ignition in NSW and Victoria allowed the application of fuel reduction burning to mountain forests where the terrain was difficult to traverse by foot in a systematic fashion and ground ignition was hazardous. Additional areas of vacant crown lands may have been burnt that may or may not be recorded here. These agencies had a very

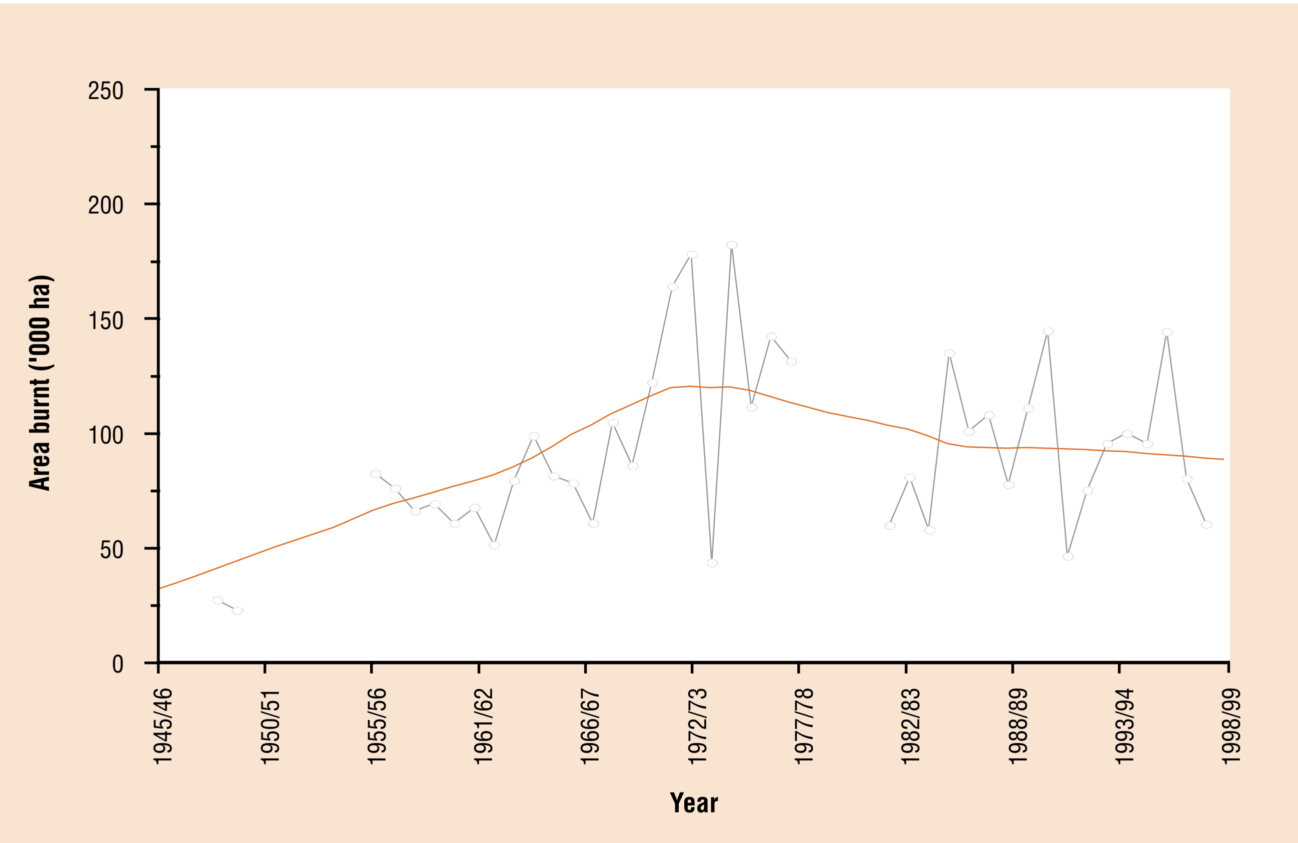

Figure 3. Area of fuel-reduction burning recorded from 1945/46 to 1998/99 in the State Forests of New South Wales. The solid line represents a local weight smoothing of the data illustrating the broad trend of area burnt over time.

proactive fuel reduction burning program for about a decade, with a peak in the total area prescribed burnt in the mid to late-1970s (Figures 3, 4, 5 and 7).

Fuel reduction burning in Tasmania has increased steadily since the early 1960s peaking in the mid-1980s (Figure 6). In the 1980s Forestry Tasmania had a very active fuel reduction burning program in its dry eucalypt forests and Buttongrass moorlands. Introduction of an aerial drip torch for ignition facilitated broad area fuel reduction burning.

The annual area burnt is highly variable due to the seasonal variation of fuel reduction burning conditions. The seasonal variations (i.e. the drought conditions, moisture of the fuel, terrain and aspect) will affect the efficiency of fuel reduction burning by affecting the net coverage of areas burnt and the proportion of the fuel actually burnt.

The net area burnt ranges from 20 to 90 per cent of the total planned area. Most agencies aim to burn between 50 and 80 per cent of the total area during fuel reduction operations.

During the last decade, there has been a declining trend in the use of fire for fuel reduction and bio-diversity management. Cheney (1994) cites a number of general trends over the last ten years that have influenced fire management practices:

- Reduction in funding to government forestry agencies for fire management.
- Decline in manpower in government forestry agencies.
- Sharp decline in expertise at line and sector level of fire management.

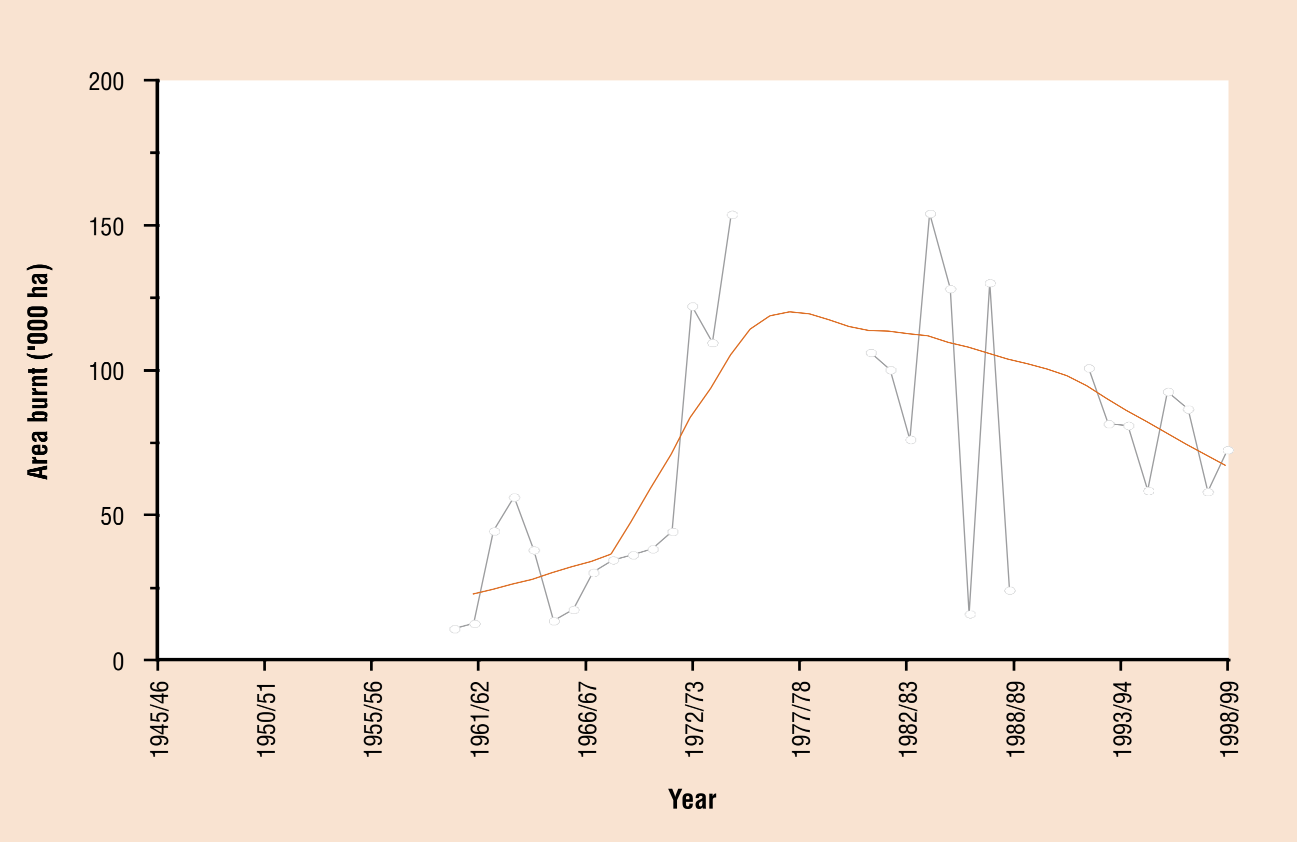

Figure 4. Area of fuel-reduction burning recorded from 1945/46 to 1999/00 in State forests in Queensland. The solid line represents a local weight smoothing of the data illustrating the broad trend of area burnt over time.

- Decline in the areas prescribed burnt for fuel or habitat management.
- Shift away from forestry agency suppression to suppression by rural fire services in Queensland, ACT, Tasmania and NSW.
- Increased funding to emergency management agencies.

These trends, together with the political attractiveness of spending money on suppression during major events means that less money is spent on preparedness, including prescribed burning for fuel reduction and more is spent on emergency response.

Probably the greatest constraint on prescribed burning in recent years is the concern of urban populations over smoke pollution. The non-methane hydrocarbon emissions from bushfire smoke, when mixed in with chemicals from urban emissions, can cause an increase in ozone concentrations. However, it is the relatively innocuous but visible particulates from the bushfire smoke that are of concern to most people. Despite effective programs to manage smoke from prescribed burning, planning constraints and political pressures have reduced the window of opportunity for effective prescribed burning within several hundred kilometres of major cities.

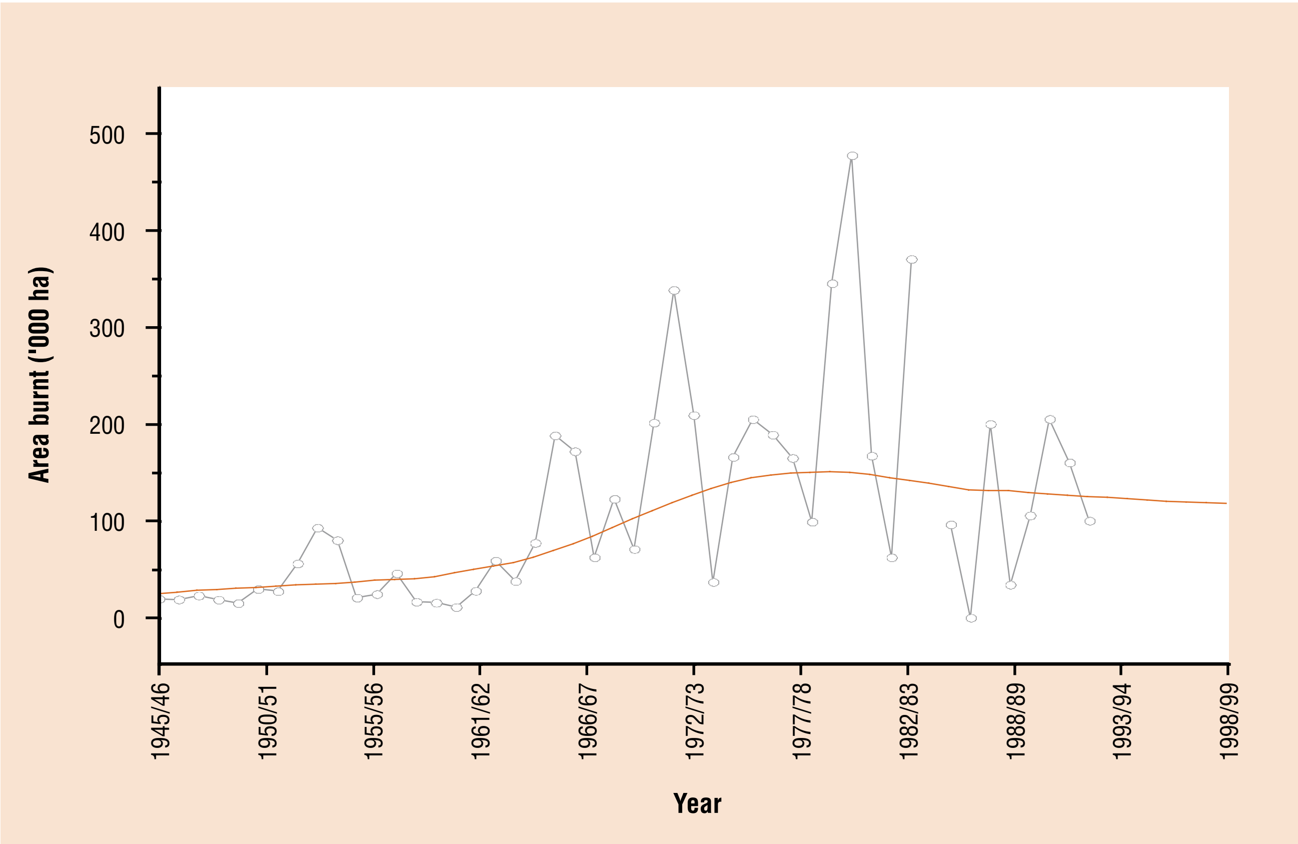

Figure 5. Area of fuel-reduction burning recorded from 1945/46 to 1992/93 in the State Forests of Victoria. The solid line represents a local weight smoothing of the data illustrating the broad trend of area burnt over time.

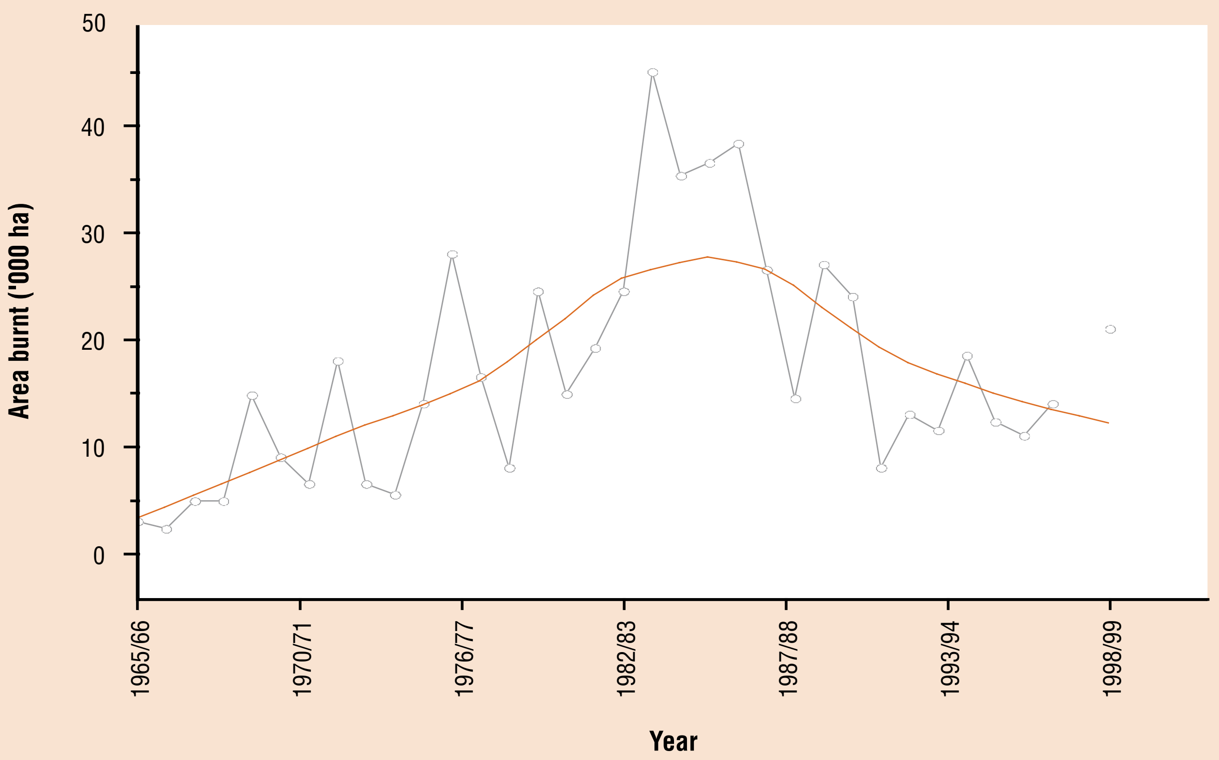

Figure 6. Area of fuel-reduction burning recorded from 1945/46 to 1997/98 in Buttongrass moorlands and dry eucalypt forest in Tasmanian State Forest. The solid line represents a local weight smoothing of the data illustrating the broad trend of area burnt over time.

3.3 REGENERATION/SILVICULTURAL BURNING

Silvicultural Burning

Silvicultural burning is usually a moderate-intensity prescribed burn carried out after a partial-cut logging operation, and is designed to remove logging slash, prepare the seedbed and stimulate seed or lignotuber regeneration. Silvicultural burning is conducted in the Jarrah forest of WA and the Silvertop Ash forests of SE NSW. Statistics from WA record silvicultural burning separately from fuel reduction burning, although there is probably some overlap in the data. The area classified as silvicultural burning of Jarrah was up to 80,000 ha yr^{-1} in the mid-1950s then declined to generally less than 5,000 ha yr^{-1} in the 1970s and 1980s when the treatment was considered to be effectively carried out by fuel reduction burning. After 1995, the areas treated by silvicultural burning increased to around 40,000 ha yr^{-1}.

A form of silvicultural burning after logging of Silvertop Ash in NSW was commenced after 1980 but it is not known if these areas are included in the fuel reduction burning statistics for that State.

Slash Burning

Slash burning is a part of the regeneration method used for clearfelled tall wet eucalypt forests in WA, Victoria and Tasmania. These fires are usually of high intensity and planned to remove the logging slash fuel and accumulated organic matter to create a uniformly distributed ash bed on to which seed falls. This creates an even-aged eucalypt forest.

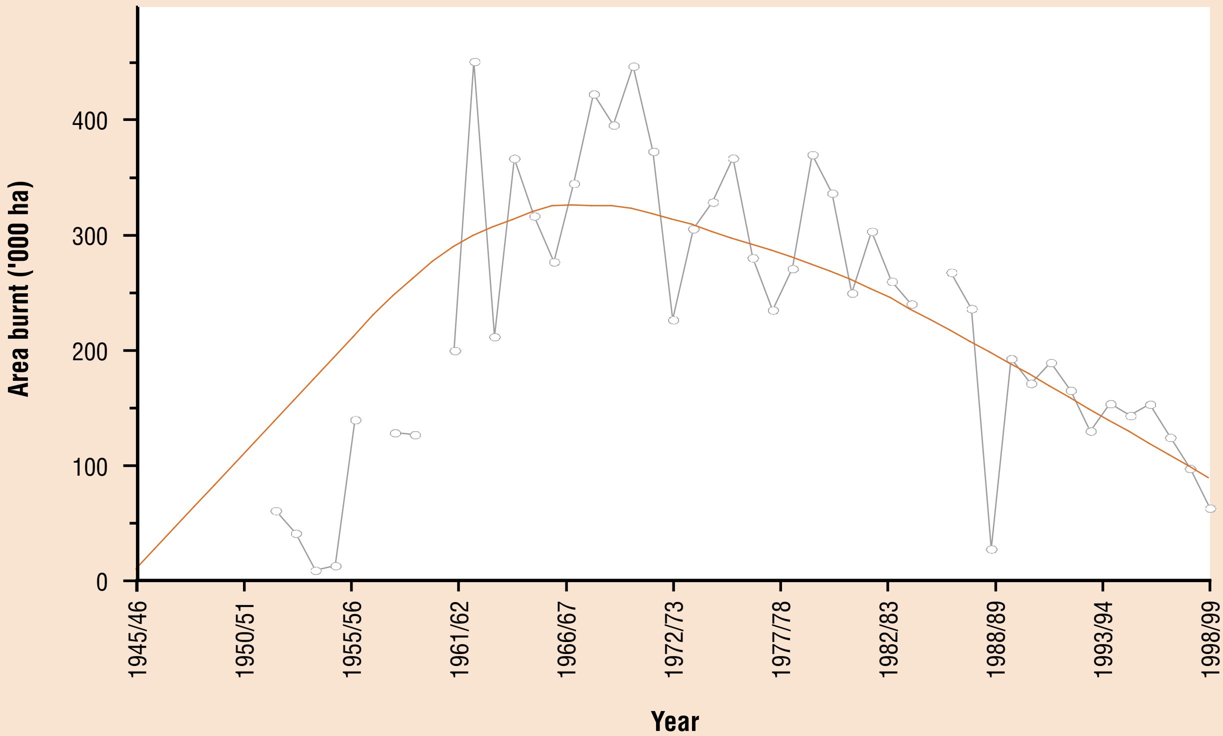

Figure 7. Area of fuel-reduction burning recorded from 1945/46 to 1999/00 in the southwest forest districts of WA. The solid line represents a local weight smoothing of the data illustrating the broad trend of area burnt over time.

In Tasmania and Victoria, high-intensity fires were used for the regeneration of *E. regnans* (Mountain Ash) and *E. delegatensis* (Alpine Ash) on a significant scale in the early 1960s. Specific data for slash burning were not recorded but it may be possible to use the annual areas regenerated of these species to approximate the areas burned.

In WA, slash burning in Karri forest commenced on a significant scale in 1968. The area burned has fluctuated between 4,000 and 10,000 ha yr^{-1} since 1971.

Ecological Burning

Fire can be used for ecosystem management by providing an appropriate fire regime (fire frequency, intensity, seasonality and patchiness) to meet specific goals relating to particular species, populations or communities (e.g. as part of a recovery plan for a threatened species). Since fire has a fundamental role in the development of forest ecosystems, it follows that fire has a place in maintaining them. Good (1981) argued that because fire is a major environmental factor over which some control can be exercised, and many native species depend on fire for their continued existence, fire will always have a place in flora and fauna management, but its effective application has been infrequent. Ecological burning has been included in the data for prescribed burning for WA. The scale of ecological burning in other States is unknown, although probably fairly small.

Slash Disposal During Plantation Establishment and Re establishment

Establishment of conifer plantations increased during the review period (Snowdon and James, 2007) and generally involved the clearing of native forests of low productivity and either broadcast burning or heaping the slash into windrows and burning. These fires are lit when fuel is dry and in a way that aims to maximise the fuel consumption. Adequate data on the areas involved are not available. Some indication of areas burnt might be obtained from plantation establishment records but it would be necessary to identify the former vegetation (grassland, shrublands or forest) and whether or not burning was used prior to establishment.

The area subjected to slash disposal burning after final harvesting operations has declined since the mid-1980s, but the practice is still used in some areas (Snowdon and James, 2007).

Fuel Reduction Burning Under Plantations

Low-intensity burning has been used to modify fuels in pine plantations (Billings, 1979; Hunt and Crock, 1985; Watts and Bridges, 1989). Fuel reduction burning began on a trial basis in plantations of *Pinus elliottii* (Slash Pine) in southeast Queensland in the late 1960s. By the late 1970s virtually all the plantations were burnt at least once during a rotation (Hunt and Crock, 1985). The Queensland tables in Appendix 1 list the recorded fuel reduction burns in pine plantations from 1981/82 to 1999/2000 based on Queensland Department of Primary Industries (Queensland Forest Service) annual reports. The average area treated annually between 1981/82 and 1999/2000 was 12,200 ha, but there were no data on the fuel consumption from these treatments.

Studies by Billings (1979) and Norman (1985) showed that it was possible to use fuel reduction burning to manage fuels after thinning *Pinus radiata* (Radiata Pine) plantations in Victoria. Even though fuel reduction burning in *P. radiata* plantations is an economical and effective fire protection practice, it can cause unacceptable levels of stem damage to the high-value crop trees. Woodman (1982) quantified the amount of ground fuels in unthinned and first thinned stands at ages 12 and 18 years (Table 5). Six years after the first thinning the fine and coarse ground fuels decreased by 7.6 and 13.0 t ha^{-1} respectively. Although a substantial amount of the coarse fuel remained after the first-thinning operations, the fine fuel had decomposed and become incorporated into the duff layer.

Billings (1980) found that fuel reduction burning in *P. radiata* plantations significantly reduced the quantity of elevated needle fuel in thinning slash as well as needle fuel on the ground, and estimated that such fires removed between 10 and 12 t ha^{-1}. There was no immediate evidence of fire damage to the crop trees. However, there are few data recorded on the operational practices of fuel management in pine plantations after thinning. Most of the plantation records are maintained on a compartment

Table 5. Ground fuel quantities (t ha^{-1}) in *Pinus radiata* plantations at the ages of 12 and 18 years (Woodman 1982).

Fuel component	Age 12 Unthinned	First thinned	Age 18 Unthinned	First Thinned
Fine fuel [1] – duff	9.8	9.8	13.4	11.4
Fine fuel [1] – litter	5.6	13.3	4.4	4.1
Coarse fuel [2]		18.3	0.4	12.9
Total	**15.4**	**41.4**	**18.2**	**28.4**

[1] Fuels $\leq$6 mm diameter
[2] Fuels >6mm diameter

basis, and each compartment record would need to be reviewed in order to determine the use of fire in managing the fuel before plantation establishment and after silvicultural treatments. In Victoria, Tasmania, SA and NSW fuel reduction burning in *P. radiata* plantations is considered to be negligible.

In WA, burning is carried out in plantations of *P. pinaster* on a regular basis but the data are incorporated into the figure for prescribed burning in native forests.

4. FUEL CONSUMPTION RATES

Uncertainties in assigning a fuel consumption figure to areas reported as burnt derive from variation in actual area burnt within the reported area, variations in fuel type, and the conditions under which the fires burnt. The actual area burnt by low-intensity prescribed fire for fuel reduction is rarely recorded. The area recorded for wildfires and regeneration or plantation clearing burning is probably close to the actual area burnt.

4.1 WILDFIRES

The area burnt by an individual wildfire can be assumed to be the recorded figure. Under mild conditions, wildfires are controlled directly with the aim to keep the area burnt to a minimum. The largest areas burnt usually occur under conditions of significant drought when the fuel moistures are relatively low and uniform across the landscape. Such conditions favour complete combustion. Areas of unburnt fuel left during indirect attack (when the control line is established at some distance from the fire perimeter) are burnt out deliberately as part of the fire control operation to prevent the fire flaring within the control line and escaping. Severe wildfires burn into littoral areas beside creeks and few pockets of unburnt fuel remain unless they are areas that have been burnt within the past two years or they already have patchy and low fuel loads.

There are few reliable data on fuel consumption during wildfires. Most fine fuel less than 25 mm is consumed, but the fraction of larger components burnt depends strongly on seasonal drought. O'Loughlin *et. al.*, (1982) conducted a high intensity fire in 97 ha of unlogged subalpine *E. radiata*, *E. delegatensis* and *E. dalrympleana* forest. The Keetch Byram drought index was >100 mm and the Forest Fire Danger Index was 24 (High to Very-High Fire Danger). The fire consumed 100 per cent of material <50 mm (22.5 t ha^{-1}); 74 per cent of the material 50-100 mm (4.3 t ha^{-1}); 57 per cent of branches 100–200 mm (7.8 t ha^{-1}); and 26 per cent of material >200 mm (14.9 t ha^{-1}). Overall, this fire burnt 50 per cent of the total ground fuel load of 100 t ha^{-1}. Consumption of standing live fuels and bark was not measured.

The total fuel load in Jarrah forests of WA is lower than for dry forests in the eastern States, reflecting perhaps the history of fuel reduction burning reducing the larger size classes over time. Burrows (1994) measured 36.5 t ha^{-1} of fuel (>6 mm diameter) in 7 year-old fuels. Allowing for a fine fuel load of 16 t ha^{-1} and available bark fuel of 7.5 t ha^{-1} the total fuel in routinely fuel-reduced Jarrah forest immediately prior to the next fuel reduction operation is about 60 t ha^{-1}.

Greater fuel consumption might be expected at higher levels of drought and at higher fire dangers due to lower moisture contents and higher wind speeds maintaining combustion of large fuels. A fuel consumption of 50 per cent of total fuel load may be a reasonable figure to apply to wildfires under a wide range of burning conditions (see Table 5 of Raison and Squire, 2007).

The quantity of fine fuel in a forest is affected by the burning history but when the period after a fire exceeds about 10 years the fine fuel load is reasonably constant for a particular forest type. The quantity of large material is much more variable and will depend on the forest type, the logging history and the fire history. In dry sclerophyll mixed eucalypt forest comprising *E. obliqua*, *E. rubida*, and *E. radiata*, Tolhurst *et. al., (*1992) reported that the fuel load of branches and logs >25 mm ranged from 11.6 to 177.7 t ha^{-1}. The average from 30 locations covering a total of 366 ha was 71 t ha^{-1}.

The quantity of fuel in wet forests may be considerably higher than in dry forests, particularly in regrowth forests that contain downed material from a fire-killed overstorey or an earlier partial (sawlog only) harvest. For example, in Tasmanian Ash forests resulting from the 1967 wildfires, the downed fuels may have a mass of several hundred t ha^{-1}.

4.2 BROAD-AREA FUEL REDUCTION BURNING

Most agencies record the gross area planned to be burnt. Actual areas are rarely surveyed, although a visual estimate of the area burnt may be made either during the operation or soon after. Experience and limited surveys using infra-red scanning suggest that the area burnt is generally over-estimated.

Operationally, prescribed burning operations that achieve less than 25 per cent of the area burnt are unsatisfactory from a hazard reduction point of view and should be reburnt. In eastern Australia, agencies aim to burn 50-60 per cent of the planned target area. Success largely depends on the season of burn and the fuel moisture variation due to topography. Most burning is conducted in autumn in southern NSW, Victoria and Tasmania, and in winter-spring in Northern NSW and Queensland. If the burns are conducted after a prolonged summer drought and before the onset of significant rains, the coverage will be high (approaching 60-70 per cent of the planned area). If the burns are conducted after a wet summer or after significant autumn rains the burnt area will be largely confined to northern and western aspects, and much of the southern and eastern aspects will remain unburnt. The fraction of area burnt will be of the order of 30-40 per cent of the planned area.

In WA, the planned coverage is usually greater than 70 per cent. The flatter topography and the more reliable burning weather means that this target is often achieved, and the area burnt may be as high as 95 per cent of the target area. A figure of 85 per cent of the planned area should be a reasonable assumption for autumn burns and 70 per cent for spring burns, with an average of 80 per cent.

There will be a difference in fuel consumption for prescribed burns in spring and autumn, depending on the level of drought and the influence of recent rain. McArthur and Cheney (1966) found that consumption of pine fuels containing thinning slash increased from 15 per cent (6.5 t ha^{-1}) to 80 per cent (34.4 t ha^{-1}) 2 and 30 days after rain respectively. Most of the increase resulted from the consumption of branches 25-75 mm and duff under drier conditions.

Tolhurst *et. al., (*1992) found that a prescribed fire reduced litter and twig loads (<25 mm) by 60 per cent in spring and by 80 per cent in autumn. Neither fire had any measurable effect on material >25 mm, although some consumption of larger material would be expected, particularly in autumn. Under extended drought conditions, prescribed fires would consume similar fractions of surface fuels as occur in wildfires, even though rates of spread and intensities are lower. The number of occasions that burns are conducted under such conditions is probably low.

Raison *et. al., (*1985) studied the combustion of understorey biomass and surface litter (<6 mm) during low-intensity experimental burns in three sub-alpine eucalypt communities that had been unburnt for 7 years. Consumption of understorey ranged from 2.4-3.9 t ha^{-1} (54-71 per cent of initial mass), and consumption of litter ranged from 7.5-9.2 t ha (47-56 per cent).

The wide range of burning conditions that characterise fuel reduction burns and variations in understorey biomass fuel with forest type make it impossible to be precise about fuel consumption. Assuming that fuels are approaching equilibrium loads at the time of burning, a general figure of 7 t ha^{-1} has been assumed for spring burning and 13 t ha^{-1} for autumn burning. The recorded area statistics do not, however, differentiate between spring and autumn burning.

The fine fuel loading in grassy forests in Queensland is lower than for other dry forests, but the fraction consumed is higher. A fine fuel load of 8 t ha^{-1} and a consumption of 95 per cent have been assumed for broad-area fuel-reduction burning in Queensland dry forests.

4.3 FUEL REDUCTION BURNING IN PLANTATIONS

Watts and Bridges (1989) estimated that prescribed fires in Slash Pine (*P. elliottii*) near Casino in NSW reduced the fine fuel (<25 mm diameter) weight from 25.6 to 11.6 t ha^{-1}; a reduction of 54 per cent. This study also estimated that the pre-burn large fuel (>25 mm diameter) mass was 91.0 t ha^{-1}, made up of hardwood (75 per cent), pine (24 per cent) and *Lantana camara* (1 per cent). Post-fire measurements showed an increase in large diameter fuel after fire, apparently due to the effects of variation resulting from relocating sample transects. These results showed that the low-intensity (<350 kW m^{-1}) fires were ineffective in reducing large fuels. Although the prescribed fire failed to reduce the large fuel weight, it did char about 90 per cent of the pine and 32 per cent of the hardwood.

4.4 LAND CLEARING BURNS

The amount of fuel consumed by fires applied to native vegetation cleared to establish pines depends on the way the fuel has been prepared for burning. Broadcast burning, where trees are left as they are felled, will consume the least quantity. More fuel will be consumed where the trees are stacked in piles or windrows and these are stoked (compacted while the burning is in progress). In the latter situation, fuel consumption may exceed 95 per cent.

Estimates of fuel consumption during broadcast burning of native vegetation cleared for pine plantations in the Tumut region of NSW were (0-25mm) 100 per cent, (36.2 t ha^{-1}); 25-75 mm (100 per cent, 24.6 t ha^{-1}) ; 75-300 mm (60 per cent, 30 t ha^{-1}) (McArthur 1969). No measurements were made of consumption of logs >300 mm. Observations were that very little bolewood of the felled timber was consumed (<10 per cent). Logs on the forest floor prior to clearing did burn and the consumption would be expected to be higher than observed in wild fires.

A moderate to high-intensity broadcast burn of a cleared of eucalypt forest consumed 82 per cent of debris <70 mm diameter; 50 per cent of all debris was lost during burning (Stewart and Flinn, 1985).

No estimates were found for fuel consumption in windrow burning. It is conservatively estimated that the consumption of material <300 mm could rise to 80 per cent and material >300 mm to 40 per cent.

4.5 REGENERATION BURNING

Harwood and Jackson (1975) found that 51 per cent of woody material was consumed during an autumn burn in harvested Tasmanian wet mixed eucalypt forest with a rainforest understorey.

Slijepcevic (2001) studied the combustion of logging slash during regeneration burns in wet *E. obliqua* forest in southern Tasmania. Biomass loss ranged from 308-453 t ha^{-1} or 58-63 per cent of the fuel present. Most mass loss occurred from the >7 cm diameter fuel components.

4.6 SLASH BURNING FOR RE-ESTABLISHMENT OF PINES

Slash burning between pine rotations can be either broadcast or windrow burning. The amount of slash will depend on the quality of the stand, stand thinning history and the efficiency of the utilisation of the harvested material. Consumption of pine slash is likely to be higher than for eucalypt slash. Flinn *et. al.*, (1979) measured 79.6 t ha^{-1} of slash after logging of a 27-year old unthinned *P. radiata* plantation. The slash had been roughly heaped into rows by the logging operation and burning reduced the slash to 12.9 t ha^{-1}, a consumption of 84 per cent. The total slash fuel load for a plantation that had experienced one or more thinnings would be less than cited above because decay would significantly reduce the debris from these operations.

There was a substantial change of emphasis in the late 1970s to early 1980s from burning to chopper rolling of harvest residues. This was especially so on the low fertility soils of SW Victoria and SE South Australia (Snowdon and James, 2007). In SA, burning of killed timber not salvaged after the 1983 wildfires might be significant because in many compartments the salvage operations removed only the largest logs for storage.

A synthesis of Australian studies on fuel consumption in varying fire types is provided by (Raison and Squire, 2007).

5. FUEL ACCUMULATION PATTERNS

The amount of fuel available that actually burns under prevailing weather conditions is one of the most important factors affecting the behaviour and management of fires. Fuel consumption depends on fuel moisture content and fuel characteristics (i.e. structure, composition, continuity and load), which are determined by fuel build-up since the previous fire. The rate of fuel accumulation is important in determining:

- The quantity of fuel at any time since the last fire. An increase in fuel load can have a dramatic effect on rate of spread and intensity of forest fires. In dry sclerophyll forest, doubling fuel load will double rate of spread (Peet, 1965 and Mcarthur, 1967) and quadruple fire intensity.
- The effectiveness of prescribed burning for fuel management, (i.e. Will determine the period of effective fuel reduction) (Raison *et. al.*,1983).

Fuels in the eucalypt forest are very heterogeneous. They can be stratified into a relatively compacted horizontal surface fuel with an aerated, less-compacted layer above. In some forest types the strata are quite distinct (e.g. shrubs and grasses over litter (Tolhurst and Cheney, 1999; Cheney *et. al.*, 1990; Cheney *et. al.*, 1992).
Fuel structures can be described in terms of overstorey and understorey vegetation, rather than by attempting to quantify all the physical attributes. The fuel can be stratified according to its vertical position in the forest. These stata are described below:

- Bark and Canopy - the forest canopy cover (and biomass) and the mass and characteristics of bark. The bark type of different eucalypt species can have a large impact on the rates of fuel accretion, and on the generation of firebrands (burning embers that can be transported long distances in the updraught to create spotfires).
- Elevated fuel layer - shrubs and juvenile understorey plants of at least 2-3 m in height. The individual fuel components generally have an upright orientation, and the spatial variability of the elevated fuel is high.
- Near-surface fuel layer - grasses, low shrubs and heath sometimes containing suspended components of leaves, bark and twigs from the overstorey vegetation. The height of this layer can vary from just centimetres to >1 m above the ground. The orientation of the fuel layer components includes a mixture ranging from horizontal to vertical. The layer may be continuous or discontinuous. Slash fuels from thinning and pruning operations will become part of this fuel layer. The persistence and flammability of slash fuels comprising branches and tops is poorly known.
- Surface fuel layer - leaf, twigs and bark derived from the overstorey and understorey plants. The fuel components are generally layered horizontally. For the initial three years after

establishment of a plantation, the surface fuel will most likely be a grassy fuel. The amount of fuel will depend on the effectiveness of grazing and/or herbicide application to control grass competition. This layer usually makes up the bulk of the fuel load in most forests and determines the flame height of a surface fire.

The accumulation of forest litter fuels after fire depends on the difference between the rate of accession and decomposition of litter. The build up of the near-surface fuel and elevated fuel layers depends largely on the rate of net biomass production by the understorey vegetation.

Table 6. Summary of parameters describing patterns of litter accumulation following fires in a range of forest types in Australia. The fuel accumulation equation is of the form of W_t = wss(1-e^{-kt}) where W_t = litter quantity (t ha^{-1}) after time t (years), w_{ss} = steady-state quantity of accumulated litter (t ha^{-1}) and k = a decay constant.

Forest/Vegetation Type	Location	Litter Component (mm diam)	w_{ss}	k	Reference
Grassy Open Forest	Rockhampton, Qld	?	6.50	0.45	Walker, (1981)
Blackbutt forest – *E. pilularis*	North coast, NSW	<25	16.8	0.31	Raison *et. al.*, (1983)
Old Mixed dry sclerophyll	Blue Mtns, NSW	<25	13.7	0.18	Raison *et. al.*, (1983)
Mixed dry sclerophyll – with understorey	Blue Mtns, NSW	<25	23.8	0.13	Raison *et. al.*, (1983)
Regrowth forest – *E. sieberi* (non wiregrass understorey)	South east coast, NSW	<6	11.7	0.61	Gould, (1996)
Regrowth forest – *E. sieberi* (wiregrass understorey)	South east coast, NSW	<6	12.6	0.30	Gould, (1996)
Subalpine eucalypt forest	ACT	<6			Raison *et. al.*, (1986)
E. pauciflora			16.9	0.32	
E. dives			14.9	0.42	
E. delegatensis					
pole			13.0	0.70	
mature			22.9	0.31	
Jarrah Forest – *E. marginata*					
High rainfall (>980 mm yr^{-1}), 50% canopy cover	Southwest WA	<6	15.6	0.16	Burrows, (1994)
High rainfall (>980 mm yr^{-1}), 35% canopy cover	Southwest WA	<6	11.1	0.17	Burrows, (1994)
Low rainfall (750–980 mm yr^{-1}), 35– canopy cover	Southwest WA	<6	8.10	0.18	Burrows, (1994)
Karri Forest – *E. diversicolor*					
Old growth	Southwest WA	<13	29.4	0.19	Raison *et. al.*, (1983)
Regrowth	Southwest WA	<25	36.3	0.21	McCaw *et. al.*, (1996)
Pinus radiata	ACT	?	17.0	0.29	Walker, (1979)
Buttongrass moorlands (low productive site)	Tasmania	?	11.73	0.11	Marsden–Smedley & Catchpole, (1995)
Buttongrass moorlands (med productive site)	Tasmania	?	44.61	0.04	Marsden–Smedley & Catchpole, (1995)

The pattern of the fuel accumulation after fire in Australia varies widely with forest type and environmental conditions (Birk and Simpson, 1980; Walker, 1981; Raison *et. al.*, 1983; Gould, 1996). These authors developed models describing the pattern and rate of build-up of litter fuels after burning. Their general model is in the form of an exponential function rising to a maximum or steady state fuel load:

$$\mathbf{w_t = w_{ss}(1\text{-}}e^{-kt}\mathbf{)}$$

where w_t is the weight (t ha^{-1}) of the litter accumulated at time t (years); w_{ss} is the steady-state quantity of accumulated litter fuel (t ha^{-1}) and k is a decay constant.

The pattern of litter fuel accumulation after fires varies widely with forest types and environmental conditions (Walker, 1981). Characteristics of these litter fuel accumulation curves have been established for some major eucalypt forest types (see Table 6). The fuel load in dry sclerophyll forest with 50 per cent canopy cover builds up rapidly for the first 10 years and then reaches an equilibrium fuel load of about 15 t ha^{-1} by about 15 years (Raison *et. al.*, 1983; Burrows, 1994; Gould, 1996). If there is a substantial layer of shrubs, the elevated fuel load may be still increasing 25 years after burning (Van Loon, 1977).

Sufficient studies have been carried out in dry forests in Australia to define the accumulation of litter fuel after fire and to make the generalised assumptions above. However, some forest types have been little studied, especially in relation to elevated fuels, and long-term equilibrium fuel mass.

6. DISCUSSION

Interpretation of fire statistics is fraught with difficulty, and numbers and trends must be treated with extreme caution. The criteria and conventions for classifying fires are rarely recorded and are influenced by the local requirements of the agency compiling them at the time. These conventions are inevitably influenced by the slow and, thereby, often forgotten changes in departmental policy, fire laws, land use practices and community attitudes.

During the period covered by this review, the area of land receiving fire protection has increased, as has the level of protection, and there have been marked changes in land tenure and land use. There is no consistent land base from which to establish trends in the recorded number of fires and area burnt. Even 'forest land' cannot be clearly defined in terms of tree cover: it is simply the land for which the forest agency is responsible and contains both forested and non-forest land.

There are no fire statistics for most private land, be it forested or not, and often few fire data for land under crown lease or in conservation reserves. This lack of consistency means that qualitative observations and expert opinion on the general trends for fire occurrence and area burnt in rural Australia is needed to interpret the trends in the recorded data from forestry agencies.

There has been a change in community attitudes towards fire and an increase in regulation of fire over the period of this review. Early in the period, fire was accepted as a tool used by graziers, particularly on crown-lease land, to improve the grazing quality of unimproved pastures. Also, forest land was regularly burnt by farmers as a means of protection from wildfires. By the end of the review period (year 2000), increased regulation has restricted the use of fire by forestry agencies, farmers and the general rural population alike.

The view of the authors is that there has been a very large decline in the area of forest land burnt in Australia over the period of this review. This decline is very much greater than the statistics recorded by forestry agencies suggest.

Figures 1 and 2 suggest that there has been a decline in the number of wildfires occurring on forest land while there is no trend in area burnt. However, the small area receiving protection before 1960 means that the area burnt by wildfire on the same land base over the period of review has also probably decreased. However, Figures 1 and 2 make it obvious that wildfire is one of the major disturbance forces in the forested regions of Australia and is strongly affected by seasonal conditions. During a mild season, very little land is burnt, but during a severe fire season wildfire has the ability to affect large segments of the landscape over very short periods of time. Devastating wildfires occurred in many years including 1939, 1952, 1961, 1967, 1968, 1983 and 1994. These wildfires burnt vast areas of native vegetation and often resulted in loss of life and property. However, the extreme weather conditions that result in fire disasters usually occur in only one State, and rarely more than two States, in any one year while the other States often experience a mild fire season. The presence of a very severe fire season in some States may not show up in national forest fire statistics.

There is clear evidence from case studies that fuel reduction programs using low-intensity prescribed burning have reduced the impact of individual wildfires and made them easier to control. However, within an entire State it is difficult to ascertain how the prescribed burning programs might have contributed to reducing the area burnt, and how much this may have been due to regulation of burning activities or improvement in fire suppression capacity. Forestry agencies believe that their fuel reduction programs have reduced the area burnt and impact of wildfires on forest land. There is circumstantial evidence for this (e.g. in WA, where prescribed burning has been widely used, there have been relatively few extensive wildfires after the 1961-62 season; in NSW wildfire areas were low on State forest, but widespread on other land tenures).

The data for fuel reduction burning show an increase in area burnt after the early-1960s and a decline after the mid to late-1970s. This decline is most evident in WA and is largely due to public concerns about smoke pollution.

There are only limited data on the use of prescribed fire for other forest management objectives. Although more accurate records for fire activities exist in recent years, the tables in Appendix 1 are still incomplete. Collation of sensible data on these activities would require examination of individual compartment records that have information on not only the area burnt but also the forest type and the likely original fuel loads and possible consumption rates.

Recent advances in remote sensing and geographic information systems (GIS) and their adoption by natural resource management agencies can lead to the creation of databases that can be used to examine the spatial extent of fires in more detail. Such databases do not yet exist on a national scale and State agencies have advanced to different degrees in the application of GIS for fire management.

The data for fuel consumption are very limited. Studies were often for specific purposes, and based on very limited sampling, and rarely included all the fuel components that are needed to determine changes to carbon balance caused by burning. The fuel consumed by wildfire can range from <10 t ha^{-1} under mild conditions to hundreds of t ha^{-1} when the wildfire consumes debris from earlier wildfire or forest harvesting operations under extreme weather conditions. By far the greatest area burnt by wildfire occurs under severe conditions of extended summer drought and very high to extreme fire danger. Fuel consumption will be highly dependent on the quality of fuel available, which depends on forest history, previous fires and prior harvesting activities. Using average fuel consumption rates will produce unreliable estimates of carbon emissions in fire.

The fuel consumption figures for fuel reduction by low-intensity prescribed fire are probably reasonably reliable. Some prescribed fires in autumn are carried out before significant rains wet the coarse fuel components and will have consumption rates that approach that of wildfires, but these operations are relatively infrequent. By far the greatest uncertainty lies in the fraction of the designated (and recorded) area actually burnt. This can be as low as 10 per cent for operations conducted under unsuitable conditions to 100 per cent for small burns under dry conditions. An approximate figure for the fraction of the recorded area actually burnt could be 80 per cent for the data from WA and 50 per cent for the data from other States.

The area burnt by prescribed fire for all management purposes is likely to continue to decline in the immediate future. This decline is unlikely to be offset by an increase in burning to meet ecological objectives until there is a change in community attitudes towards the role of fire in the Australian environment. The area burnt by wildfire is likely to remain static for most seasons with an increase in the area burnt during severe seasons (e.g. in NSW in 2001-02, in NSW, ACT and Victoria in 2003).

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8. APPENDIX 1

8.1 APPENDIX 1

FIRE STATISTICS TABLES - NUMBER OF FIRES AND AREA BURNT

The data for these tables were drawn mainly from State forestry agency annual reports. Such data include the number of fires, area burnt on the State Forest estate (mainly multiple-use native forest tenure, but including plantations), the protected area, and the area burnt by different managed fires (i.e. prescribed fires for fuel reduction, regeneration and silvicultural management). Data for the tables were drawn from various sources as summarised in Table 7. The blank spaces indicate either '*no data available*' or that data could be available if it were extracted from individual records for the forest management unit in question (i.e. forest compartment records, logging coupe records, plantation compartment, individual prescribed burning plans etc.). The extraction of data at this level was beyond the scope of this review, and would be a time consuming and costly exercise. This review is based on accessible data.

Table 7. Summary of the data sources used to derive the number of fires and area burnt for the Fire Statistics tables in Appendix 1.

	ACT	NSW	QLD	SA	TAS	VIC	WA	AUS
Annual Reports		√	√			√	√	
Direct from State agency		√		√	√			
State special reports		√				√		
CSIRO reports	√			√				√
Other sources					√			

Table 8. Number of fires and area burnt in Queensland.

Queensland											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed Fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46	89		2609.8								
1946/47	144		2652.5								
1947/48	41		2801.8								
1948/49	155		2891.7								
1949/50	50		2927.6								
1950/51	55		2995.8								
1951/52	455	57.9	3078.0								
1952/53	75		3195.1								
1953/54	119		3220.3								
1954/55	69		3204.1								
1955/56	105		3257.0								
1956/57	140		3272.0								
1957/58	120	21.8	3273.0								
1958/59	69	3.4	3293.5								
1959/60	38	2.1	3310.5								
1960/61	212	42.6	3309.8	10.6							
1961/62	18	1.3	3322.1	12.4							
1962/63	186		3277.8	44.4							
1963/64	130		3262.2	56.1							
1964/65	192	100.2	3339.3	37.8							
1965/66	114	27.2	3462.4	13.4							
1966/67	124	13.6	3529.0	17.3							
1967/68	212	35.9	3585.9	30.0							
1968/69	440	116.7	3650.1	34.4							
1969/70	119	18.6	3725.7	36.1							
1970/71	190	12.6	3794.4	38.2							
1971/72	233	104.9	3824.6	44.2							

Table 8. Number of fires and area burnt in Queensland.

Queensland											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed Fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1972/73	225	40.9	3882	122.0							
1973/74	47	3.6	3934	109.3							
1974/75	146	22.2		153.6							
1975/76	44	8.1	3972.7								
1976/77	98	149.0	4022.9								
1977/78	261	112.0	4060								
1978/79	37	3.0	4198.8								
1979/80	206	62.8	4311.1								
1980/81	157	67.0	4297.0								
1981/82	64	35.0	4441.0	106.0							12
1982/83	270	197.0	4440.0	100.0							14
1983/84	10		4461.0	76.0							20
1984/85	81	19.0	4471.0	154.0							10
1985/86	78	15.0	4483.0	128.0							13
1986/87	126	44.0	4513.0	15.8							7
1987/88	99	14.0	4504.0	130.0							21
1988/89	87	33.0	4515.0	24.0							4
1989/90		73.9	4498.5								
1990/91		28.9	4394.8								
1991/92		37.9	4314.4								
1992/93		48.7	4312.9	100.6							11.9
1993/94		22.5	4310.5	81.3							21.4
1994/95		90.2	4309.3	80.8							20.2

Table 8. Number of fires and area burnt in Queensland.

Queensland											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed Fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000)	Slash disposal ('000 ha)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1995/96		21.8	4310.4	58.3							2.7
1996/97		47.7	3300.0	92.5							11.1
1997/98		37.6		86.4							8.8
1998/99		1.5		57.9							9.1
1999/00		024.7		72.4							8.5

Table 9. Number of fires and area burnt in New South Wales.

New South Wales											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed Fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46	101	3.7	2654.4								
1946/47	206	22.2	2692.5								
1947/48	45	1.0	2692.5								
1948/49	405	30.3	2694.2	27.2							
1949/50	100	5.2	2927.6	22.7							
1950/51	125	2.9	2952.9								
1951/52	1006	527.7	3046.6								
1952/53	171	3.2	3059.4								
1953/54	534	66.6	3061.2								
1954/55	138	6.1	3064.7								
1955/56	247	8.7	3092.3								
1956/57	644	47.4	3127.7	82.4							
1957/58	968	217.8	3144.9	76.0							
1958/59	195	4.3	3162.0	66.1							
1959/60	130	2.4	3183.9	69.2							
1960/61	694	51.4	3235.1	60.6							
1961/62	233	5.1	3266.8	67.6							
1962/63	344	6.1	3278.5	51.2							
1963/64	359	21.9	3289.0	79.3							
1964/65	1201	87.1	3255.8	98.8							
1965/66	568	66.6	3248.6	81.3							
1966/67	223	6.2	3246.7	78.2							
1967/68	330	10.8	3249.9	60.7							
1968/69	939	352.9	3272.1	104.5							
1969/70	124	17.5	3281.2	85.8							
1970/71	383	10.7	3384.9	122.0							
1971/72	441	31.0	3440.6	163.9							
1972/73	431	72.4	3451.7	178.0							

Table 9. Number of fires and area burnt in New South Wales.

New South Wales											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed Fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1973/74	134	2.9	3533.6	43.5							
1974/75	403	108.1	3559.2	182.2							
1975/76	146	8.5	3594.1	111.3							
1976/77	309	17.9	3626.0	142.2							
1977/78	542	33.5	3640.9	131.4							
1978/79	231	11.7	3642.0								
1979/80	567	103.8	3666.6								
1980/81	822	273.6	3733.7								
1981/82	245	18.3	3770.7								
1982/83	499	168.1	3683.1	59.8							
1983/84	83	3.6	3685.6	80.8							
1984/85	464	34.8	3745.5	57.9							
1985/86	272	12.4	3776.5	134.9							
1986/87	606	83.8	3826.9	100.7							
1987/88	305	24.1	3828.4	107.9							
1988/89	328	44.2	3856.0	77.6							
1989/90	431	42.8	3877.9	111.0							
1990/91	703	125.5	3897.5	144.5							
1991/92	660	115.0	3681.2	46.3							
1992/93	157	9.6	3699.4	75.1							
1993/94	498	131.9		95.4							
1994/95		126.0		99.9							
1995/96		23.9		95.3							
1996/97		17.5		144.2							
1997/98		87.9		80.1							
1998/99		5.4	2123.0	60.2							
1999/00		1.1									

Table 10. Number of fires and area burnt in the Australian Capital Territory.

Australian Capital Territory											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46											
1946/47											
1947/48											
1948/49											
1949/50											
1950/51											
1951/52											
1952/53											
1953/54											
1954/55											
1955/56											
1956/57											
1957/58											
1958/59											
1959/60											
1960/61											
1961/62											
1962/63											
1963/64											
1964/65											
1965/66											
1966/67											
1967/68											
1968/69											
1969/70											
1970/71	1	0.5									
1971/72											
1972/73											

Table 10. Number of fires and area burnt in Australian Capital Territory.

Australian Capital Territory											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1973/74											
1974/75											
1975/76											
1976/77											
1977/78											
1978/79	13										
1979/80	13										
1980/81	14										
1981/82	7										
1982/83	29	320									
1983/84											
1984/85											
1985/86	30										
1986/87	9										
1987/88	23										
1988/89											
1989/90											
1990/91											
1991/92											
1992/93											
1993/94											
1994/95											
1995/96											
1996/97											
1997/98											
1998/99											
1999/00											

Table 11. Number of fires and area burnt in Victoria.

Victoria											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46	133	33.7	1986.2	19.4							
1946/47	103	20.4	1999.4	18.8							
1947/48	171	28.6	2000.4	22.8							
1948/49	148	10.1	1999.2	18.6							
1949/50	124	9.7	2014.9	14.9							
1950/51	355	99.1	2019.6	29.5							
1951/52	282	417.7	2086.2	27.4							
1952/53	246	8.7	2094.3	55.8							
1953/54	466	53.1	2099.2	92.7							
1954/55	316	30.8	2222.9	79.9							
1955/56	170	7.1	2228.0	20.8							
1956/57	207	46.7	2240.0	24.4							
1957/58	627	88.4	2248.7	45.8							
1958/59	465	102.8	2250.1	16.5							
1959/60	728	497.8	2251.2	15.5							
1960/61	607	58.7	2255.7	11.1							
1961/62	476	67.7	2258.9	27.7							
1962/63	343	32.3	2259.8	58.9							
1963/64	570	118.0	2262.6	37.8							
1964/65	481	327.0	2269.5	77.2							
1965/66	529	28.7	2269.5	188.1							
1966/67	412	15.6	2269.7	171.6							
1967/68	787	221.5	2286.5	62.2							
1968/69	391	29.0	2296.3	122.5							
1969/70	304	5.0	2290.9	70.7							
1989/90	619	26.3	7450.0	105.5							
1990/91	832	27.5	7450.0	205.0							
1991/92	606	15.3		160.0							

Table 11. Number of fires and area burnt in Victoria.

Victoria											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1992/93	247	4.8		100.0							
1993/94											
1994/95	802										
1995/96	376	12.8	7700.0								
1996/97											
1997/98											
1998/99	711		7700.0								
1999/00											

Table 12. Number of fires and area burnt in Tasmania.

Tasmania											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46	189	19.4									
1946/47	189	7.4									
1947/48	291	43.3									
1948/49	138	4.0									
1949/50	216	5.6									
1950/51	443	35.2									
1951/52	135	15.3									
1952/53	334	23.4									
1953/54	97	23.0									
1954/55	181	12.9									
1955/56	51	1.6									
1956/57	149	7.6									
1957/58	178	8.9									
1958/59	143	26.3									
1959/60	233	20.6				0.1					
1960/61	479	175.6				1.1					
1961/62	137	11.3				1.2					
1962/63	126	8.9				1.0					
1963/64	252	27.1				0.3					
1964/65	146	4.8				0.5					
1965/66	317	52.2		3.0		1.0					
1966/67	264	172.4		2.3		0.9					
1967/68	230	38.8		4.9		0.4					
1968/69	87	4.4		4.9							
1969/70	118	6.0		14.8							
1970/71	114	8.5		9.0							
1971/72	179	33.5		6.5		2.7					
1972/73	305	140.8		18.0		4.6					

Table 12. Number of fires and area burnt in Tasmania.

Tasmania											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1973/74	62	6.0		6.5		5.9					
1974/75	48	2.0		5.5		8.5					
1975/76	141	20.0		14.0		7.1					
1976/77	59	4.0		28.0		6.5					
1977/78	199	40.0		16.5		7.0					
1978/79	90	4.0		8.0		5.7					
1979/80	183	37.0		24.5		9.0					
1980/81	141	23.0		14.9		8.2					
1981/82	163	105.0		19.2		9.6					
1982/83	255	62.0		24.5		9.3					
1983/84	113	20.0		45.0		7.2					
1984/85	71	2.2		35.3		5.2					
1985/86	43	0.9		36.5		4.1					
1986/87	93	5.1		38.3		7.1					
1987/88	181	29.0		26.5		3.4					
1988/89	72	9.0		14.5		5.6					
1989/90	101	15.0		27.0		4.5					
1990/91	113	8.5		24.0		5.8					
1991/92	86	15.5		8.0							
1992/93	28	4.0		13.0		5.8					
1993/94	54	13.0		11.5		5.6					
1994/95	132	69.0		18.5		1.7					
1995/96	65	3.0		12.3		4.4					
1996/97	90	10.0		11.0		7.9					
1997/98	135	31.0		14.0		7.1					
1998/99	65	5.0				9.9					
1999/00	101	9.0		21.0		9.3					

Table 13. Number of fires and area burnt in South Australia.

South Australia											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number burnt ('000 ha)	Area protection ('000 ha)	Area under burning ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow disposal ('000)	Slash burning ('000 ha)	Other burning ('000 ha)	Prescribed
1945/46											
1946/47											
1947/48											
1948/49											
1949/50											
1950/51											
1951/52											
1952/53											
1953/54											
1954/55											
1955/56											
1956/57											
1957/58											
1958/59											
1959/60			44.4								
1960/61			45.8								
1961/62			47.2								
1962/63	9		49.6								
1963/64	7		52.4								
1964/65	4		53.9								
1965/66	7		56.1								
1966/67	8		58.1								
1967/68	7		60.5								
1968/69	9		62.7								
1969/70	6		65.4								
1970/71	7		67.7								
1971/72	3		69.7								
1972/73			71.4								

Table 13. Number of fires and area burnt in South Australia.

South Australia											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1973/74	7		72.7								
1974/75	14	0.3	74.6								
1975/76	17	0.1	75.6								
1976/77	13		76.5								
1977/78	16		77.1								
1978/79	10	2.9	74.7								
1979/80			75.2								
1980/81			75.6								
1981/82			77.1								
1982/83			58.3								
1983/84		2.9	59.1								
1984/85			61.0								
1985/86		0.2	62.9								
1986/87			65.5								
1987/88	3	0.1	67.5								
1988/89	1		69.4								
1989/90	20	0.2	71.4								
1990/91	8		73.6								
1991/92	16		74.2								
1992/93	17		75.2								
1993/94	14		75.7								
1994/95	18		75.6								
1995/96	15		76.3								
1996/97	16	145	76.8								
1997/98	15		77.5								
1998/99	15										
1999/00	13	0.5									

Table 14. Number of fires and area burnt in Western Australia.

Western Australia											
	All Fires			Native Forest			Plantations				
	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1945/46	363	13.6	421								
1946/47	356	0.6	434								
1947/48	252	0.1	466								
1948/49	278	0.5	466								
1949/50	527	0.4	405								
1950/51	558	12.9	405								
1951/52	217	0.2	470								
1952/53	324	8.2	470	60.7	31						
1953/54	289	1.6	936	41	63						
1954/55	324	5.0	936	8.8	80.1						
1955/56	278		936	12.8	17.8						
1956/57	313			139.4	16.5						
1957/58	359				22.6						
1958/59	530	13.6		128.2	30.2						
1959/60	434	9.1		126.6	23						
1960/61	232	1.0									
1961/62	355	193		199.7	28.7						
1962/63	463	27		450.2	35.2						
1963/64	231	4.0		211.6	23.2						
1964/65	281	8.6		366.3	23.6						
1965/66	214	1.4	1700	316.3	41.8						
1966/67	251	2.4	1800	276.5	21.0	0.1					
1967/68	365	2.3	1800	344.5	17.3	0.2					
1968/69	248	1.9	1800	422.2	21.4	0.8					

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	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1969/70	252	13.1		395.1	17.3	1.6					
1970/71	494	5.6		446.3	4.9						
1971/72	171	3.5		372.3	3.3	0.9					
1972/73	249	5.1		226.3	7.1	2.4		2.5			
1973/74	211	7.7		305.2	5.1	0.1		2.5			
1974/75	266	1.0		328.4	11.8	0.1		1.1			
1975/76	254	8.8		366.4	1.3	1.0		2.4			
1976/77	183	3.8		280	2.7	1.8		2.8			
1977/78	227	55.7		234.6	1.7	1.8		2.7			
1978/79	382	8.5		270.5	1.8	1.9		2.5			
1979/80	235	3		369.5	1.6	2.2		2.0			
1980/81	158	1.9		336.1	0.8	2.2		0.9			
1981/82	178	7.4		249.4	5.7	3.2		3.7			
1982/83	106	2.3		303	3.9	2.4		4.1			
1983/84	133	4.2		259.5	5.1	2.3		3.5			
1984/85	140	2.5		240	4.1	2.2		2.1			
1985/86						2.4					
1986/87	170	12.7		267.3	5.0	1.9		3.0			
1987/88	139	5.7		235.8	5.8	1.1		0.4			
1988/89	279	11.3		27.5	4.8	1.4		0.3			
1989/90	158	1.7		192.4	5.5	1.1		1.1			
1991/92	191	14.4		189.2	5.3	1.2		1.1			
1992/93	227	3.5		165	7.6	1.4		1.3			
1993/94	220	6.1		129.7	1.18	1.9		1.1			
1994/95	267	4.6		153.3	10.4	2.3		0.4			

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	Wildfires			Prescribed fires			Establishment				Fuel Management
Year	Number	Area burnt ('000 ha)	Area under protection ('000 ha)	Prescribed burning ('000 ha)	Silvicultural burning ('000 ha)	Regen burning ('000 ha)	Broadcast burning ('000 ha)	Windrow burning ('000 ha)	Slash disposal ('000)	Other burning ('000 ha)	Prescribed burning ('000 ha)
1995/96	271	11.6		143	28.3	1.3		0.2			
1996/97	217	3.3		152.7	32.2	2.1					
1997/98	115	5.7		124.1	43.7	1.8		0.9			
1998/99	189	19.6		97.1	39.8	0.9		0.2			
1999/00	201	2.4		62.8	13.9	2.1					

Publications

Series 1 Sets the framework for development of the National Carbon Accounting System (NCAS) and document initial NCAS-related technical activities.

Series 2 Provides targeted technical information aimed at improving carbon accounting for Australian land based systems.

Series 3 Details protocols for biomass estimation and the development of integrated carbon accounting models of Australia. Of particular note is:

28. The FullCAM Carbon Accounting Model: Development, Calibration and Implementation for the National Carbon Accounting System.

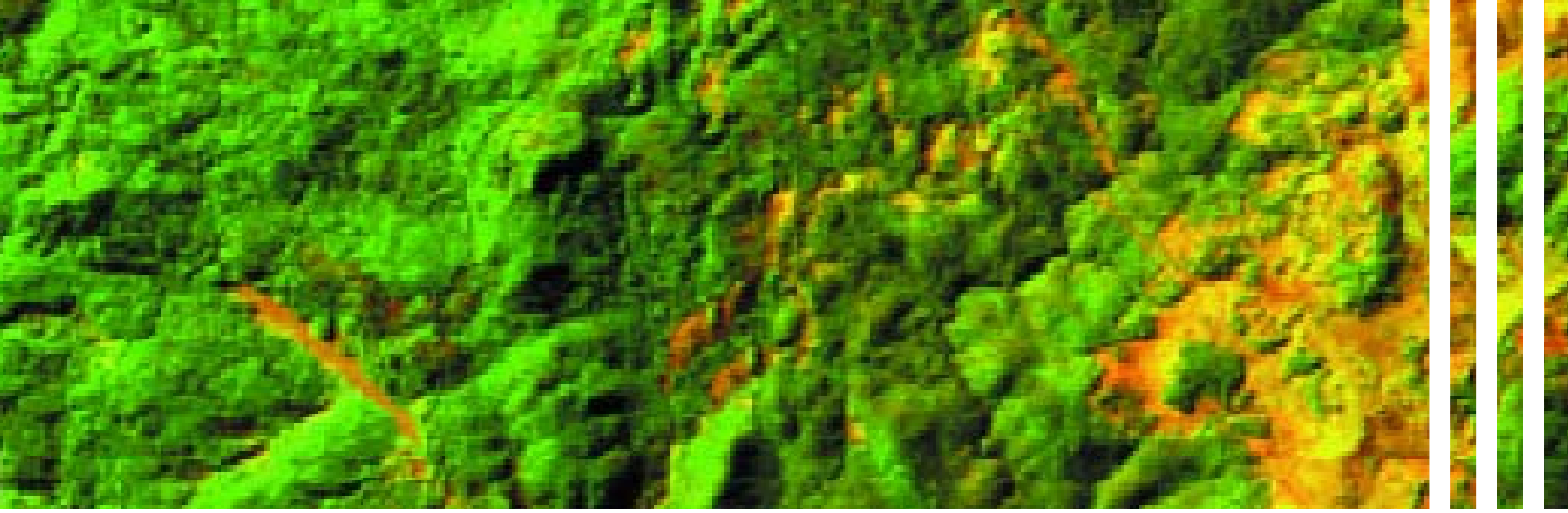
Series 4 Provides an integrated analysis of soil carbon estimation and modelling for the NCAS, incorporating data from paired site sampling in NSW, Qld and WA. A preliminary assessment of nitrous oxide emissions from Australian agriculture is also included.

Series 5 Provides details on the improvement and verification of land cover change analyses, calibration of the FullCAM model and impacts of tillage on soil carbon.

Series 6 Includes:

45. Review of C:N Ratios in Vegetation, Litter, and Soil Under Australian Native Forests and Plantations.
46. Update on the National Carbon Accounting System Continuous Improvement and Verification Methodology.
47. Total Biomass Measurement and Recovery of Biomass in Log Products in Spotted Gum (Corymbia maculata) Forests of SE NSW.
48. Recovery of Biomass as Green Sawn Boards after Milling of Spotted Gum (Corymbia maculata) Sawlogs from NSW South Coast Forests.
49. The Decay of Coarse Woody Roots Following Harvest in a Range of Forest Types.

National Carbon Accounting System publications can be viewed or downloaded at:
http://www.climatechange.gov.au/ncas/publications



The National Carbon Accounting System provides a complete accounting and forecasting capability for human-induced sources and sinks of greenhouse gas emissions from Australian land based systems. It will provide a basis for assessing Australia's progress towards meeting its international emissions commitments.