FOREST RESOURCE ENHANCEMENT OPPORTUNITIES FOR SOUTH-EAST QUEENSLAND

A review of silviculture studies

QUEENSLAND CRA/RFA STEERING COMMITTEE

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SUMMARY

This report has been prepared for the joint Commonwealth/State Steering Committee that oversees the comprehensive regional assessment (CRA) of forests in the south-east Queensland CRA region. The assessments are part of the process leading to the south-east Queensland Regional Forest Agreement.

This agreement will determine the future of the region's forests and will define those areas needed to form a comprehensive, adequate and representative (CAR) reserve system and those available for ecologically sustainable commercial use.

The intention of this report was threefold: to identify opportunities for resource enhancement in the region, to identify research and development gaps and to recommend research priorities. The information in this report was obtained by reviewing more than 130 studies and papers relevant to silviculture in the native hardwood forests and hardwood and softwood plantations of the region. Most of the reviewed documents were derived from research undertaken on publicly owned (Crown) forests. Although the intention of the review was to consider the possibility of productivity gains that could be achieved through resource enhancement, as well as considering the financial viability and ecological effects of alternative silviculture techniques and the overall strengths and weaknesses of the research undertaken to date, the analysis revealed that most of the information available related to enhancing productivity.

The studies concerning native forests dealt with harvesting, thinning, burning and enrichment planting techniques in both wet and dry sclerophyll forests. The studies concerning hardwood plantations mainly dealt with species selection. Those concerning softwood plantations covered a wider range of aspects, including species selection, nursery practice, thinning, fertilising, establishment and site preparation, weed control, genetic improvement, and pest and disease control.

There were few recent studies that examined the financial viability of alternative practices, particularly in native forests. The extent to which the cost and revenue information and the market assumptions used in the earlier studies remain valid is unknown. Studies on the ecological effects of various forestry practices were limited, although all were recent.

Most of the studies reviewed related to softwood plantation silviculture. Relatively few related to native forests, and even fewer to hardwood plantation silviculture.

The results appear to suggest that in native forests, harvesting, thinning and burning practices aimed at promoting regeneration and reducing competition between trees have the potential to increase the productive capacity of these forests. These practices will require continual re-evaluation in the light of such elements as long-term trends in market demand, utilisation standards and pricing.

The studies specific to hardwood plantations in the region, although few and restricted to considerations for the pulpwood market, appear to suggest that rose gum, blackbutt and Gympie messmate have the most potential for plantation cultivation. However, the studies reviewed did not contain substantial information on effective silvicultural techniques for these species.

For softwood plantations, the techniques developed for nursery practice, site preparation, weed control, fertilising, thinning and residue management appear to be effective in enhancing softwood plantation productivity. Genetic improvement studies have resulted in the development of genetically superior stock of several commercially important species (including Caribbean pine, slash pine, hoop pine and a Caribbean/slash pine hybrid) for the region.

The ecological studies reviewed indicated that selective logging and silviculture can have significant adverse effects including the alteration of the forest structure, age distribution, and the proportions of various flora species; and the distribution, species composition and frequency of understorey species. Such changes can alter the diversity and abundance of forest-dwelling fauna species. These effects may be reduced by a number of forest management practices, including the retention of habitat trees and seed trees.

On the basis of the ecological studies reviewed, it is recommended that while more studies are needed to develop silvicultural techniques that will enhance the productivity of the native forests and plantations in the south-east Queensland region, such techniques must be consistent with the principles of ecologically sustainable forest management. This means that future silvicultural research should incorporate studies of the ecological impacts of the techniques being evaluated (for example, studying the effects of habitat tree retention or ensuring species composition is retained).

The following areas are identified as priorities for research:

For native forests:

- Silvicultural systems that optimise the value of timber production. This research should examine ecological effects and impacts on conservation values of possible optimisation methods. In particular the research should focus on further development of:
  - harvesting and thinning regimes, combined with an evaluation of their financial viability
  - post-harvesting burning with the aim of identifying a frequency and intensity that maximises the potential for regeneration.

For hardwood plantations:

- Species selection
- Genetic improvement of commercial species
- Plantation silviculture for timber production focusing on site preparation, weed and pest control, and optimal fertiliser regimes for different soil conditions.

For softwood plantations:

- Fertiliser schedules to suit atypical soil and site types
- Methods for reducing the potential for pest and disease attack.

It is important that forest management strategies include a continuing commitment both to long-term ecological studies and to maintaining the flexibility required to improve current silviculture practices as more scientific information becomes available.

GLOSSARY

CAR	Comprehensive, adequate and representative
CRA	Comprehensive Regional Assessment
RFA	Regional Forest Agreement

1. INTRODUCTION

1.1 BACKGROUND

There are a number of forest types in south-east Queensland, the most widespread of which are the open native eucalypt (hardwood) forests. There are also significant plantations of exotic and native pine, some minor areas of hardwood woodland, hardwood plantations, cypress pine woodlands and disjunct patches of rainforest.

The emphasis of this report is on the commercially important forest types, so the various forms of rainforest in the region have not been considered as it has been a policy of the Queensland Government since 1994 not to harvest rainforest on publicly owned (Crown) lands. Cypress pine has also been excluded, because of its limited occurrence in the region, and the hardwood woodlands and the low open forests, which have little commercial value, have also been excluded.

1.1.1 Native hardwood forests

Most of south-east Queensland's native hardwood forests are of low commercial productivity relative to other Australian forests used for commercial production. Volumes harvested in south-east Queensland forests are as low as 2–8 cubic metres per hectare in dry forest types, such as spotted gum *(Corymbia citriodora)*, and 8–20 cubic metres per hectare in moist to wet forest types, which include blackbutt *(Eucalyptus pilularis)*, tallowwood *(E. microcorys)*, and brush box *(Lophostemon confertus)*.

Table 1 gives an indication of the land tenure of the region, and the extent of forest within each tenure category.

TABLE 1: TENURE OF THE SOUTH-EAST QUEENSLAND REGION

Tenure category	Area (ha)	% of region	Forested area	% of region
State forest	888 766	14.60	848 339	13.94
Timber reserves	23 987	0.39	23 825	0.39
National parks	485 598	7.98	358 004	5.89
Other crown land	410 796	6.74	276 842	4.55
Freehold	4 277 347	70.28	1 207 075	19.83
Total	6 086 495	100.00	2 714 085	44.60

Source Project SE 1,2 Public Forest Resource Description & Inventory (Draft Report) Table 3.2

1.1.2 Softwood plantations

To supplement timber from the native forests, a large softwood plantation resource was envisaged for south-east Queensland, which began with the planting of hoop pine (*Araucaria cunninghamii* – a native softwood) in the Mary Valley in the 1920s. The total plantation estate in south-east Queensland now covers about 180 000 hectares (Table 2), and is mostly comprised of two exotic species, slash pine *(Pinus elliottii)* and Caribbean pine *(P. caribaea)*, together with a substantial area of hoop pine.

After a number of trials of various exotic pines, it became apparent that two exotic pines – slash pine, a native of south-east U.S.A, and Caribbean pine, a native of Central America – offered the best potential for growth and the highest yield. Subsequent research established that two hybrids of these species yielded growth that was superior to either slash or Caribbean pine on poorly drained sites.

1.1.3 Hardwood plantations

There are also around 1100 hectares of hardwood plantations in the south-east Queensland CRA region, predominantly of rose gum *(E. grandis)*, blackbutt, and Gympie messmate *(E. cloeziana)*. Hardwood plantation establishment in Queensland was initiated in the 1930s by the then-Queensland Forest Service to supply timber for the packing case and small sawlog markets of the time, and were generally established on degraded farmland. These early hardwood plantations (particularly rose gum) suffered from severe insect attack that reduced wood quality, and further establishment of eucalypt plantations was abandoned in the mid-1960s.

1.1.4 Report objectives

Studies aimed at increasing native forest and plantation productivity through silvicultural treatments have been undertaken in the region. In order to find out what is known and to identify future research and development priorities in this area, there was a need to review the results from these studies and evaluate any silvicultural techniques developed on the basis of their productivity gains, financial viability and ecological impacts. This document reports the results of the review.

The objectives of this project, Forest Resource Enhancement Opportunities (project SE 1.3), were to review studies on improving timber yields of native forests and plantations (both hardwood and softwood) in south-east Queensland through silvicultural means, and to identify priorities for future research and development through knowledge gap analysis (refer Appendix 1). The information obtained from this project will contribute to an overall understanding of forest resources and management in the region.

A working definition of ‘forest resource enhancement’ adopted for the purposes of this report is ‘the manipulation of a timber resource (whether natural forest or plantation) through the adoption of particular management and silvicultural regimes, in order to achieve gains in timber production in excess of those which might have been achieved in the absence of such measures’. In the native forests, the main silvicultural regimes are harvesting and thinning practices, enrichment planting, and post-logging burning. Silviculture in hardwood and softwood plantations comprises species selection, tree breeding, management of nursery soils, site preparation, weed control, fertiliser use and thinning practices.

2. METHODS

This report was compiled in the following way:

A literature review to identify published research papers relating to

- productivity enhancement in south-east Queensland forests and plantations
- relevant studies in other forests (limited mainly to information from north-east New South Wales).

Collation and review of information from research reports and other available resources.

Documentation of the silvicultural techniques developed for forest resource enhancement focusing on:

- productivity gains
- financial viability
- ecological impacts
- strengths and weaknesses

Identification of gaps in the research, and recommendations for research priorities.

A workshop was to have been held with technical experts to provide wider input concerning current knowledge and practices and to identify future research and development priorities. However after numerous unsuccessful attempts to organise the workshop, it was cancelled due to the continued unavailability of key participants.

3. NATIVE FORESTS

3.1 DESCRIPTION OF THE FORESTS WITHIN SOUTH-EAST QUEENSLAND

The hardwood eucalypt forests of the region can generally be divided into two broad classes, ‘dry` and ‘wet’ sclerophyll. These forest types are differentiated by the presence of particular flora and associations of flora and by their structural features (the height of the canopy and understorey).

Dry sclerophyll forest is the predominant forest type in south-east Queensland. It is generally an open forest with a low shrubby layered understorey or grassy forest floor, and occurs in drier situations or on less fertile soils than wet sclerophyll. Wet (and moist) sclerophyll forest is usually taller than dry sclerophyll forest and a higher proportion of understorey species have soft, thin leaves. Wet sclerophyll forests generally occur on the better (more fertile) soil types and higher rainfall slopes of the coastal strip, generally where rainfall exceeds 1000 mm per annum.

Table 2 lists the important commercial timber species in each forest type.

TABLE 2: IMPORTANT COMMERCIAL TIMBER SPECIES OF SOUTH-EAST QUEENSLAND FORESTS

Common name	Botanical name
Wet and moist sclerophyll forests	
blackbutt	*Eucalyptus pilularis*
Blackdown stringybark	*E. sphaerocarpa*
brush box	*Lophostemon confertus*
grey gum	*E. propinqua*
grey ironbark	*E. drepanophylla, E. paniculata*
Gympie messmate	*E. cloeziana*
red mahogany	*E. resinifera*
rose gum	*E. grandis*
Sydney blue gum	*E. saligna*
tallowwood	*E. microcorys*
Dry sclerophyll forests	
broad-leaved red ironbark	*E. fibrosa*
forest red-gum	*E. tereticornis*
grey box	*E. moluccana*
narrow-leaved red ironbark	*E. crebra*
spotted gum	*Corymbia citriodora*
white mahogany (or yellow stringybark)	*E. acmenoides*
white stringybark	*E. eugenioides*

The eucalypt forests of the region are generally uneven-aged (multi-aged), and characterised by a high proportion of stems with bole and branch defects.

3.2 BACKGROUND AND CURRENT MANAGEMENT PRACTICE

Native forests cover about 2.54 million hectares of the south-east Queensland region (Table 3). Virtually all of them are hardwood (refer to 1.1). Of the total forest area, about 31 per cent (almost 850 000 hectares) is reserved as State forest, that is, publicly owned (Crown) land that may be used for timber production. Queensland's Department of Primary Industries – Forestry currently actively uses about 440 000 hectares for commercial timber production operations, harvesting about 135 000–145 000 cubic metres of timber products annually. Sawlogs are the main product, comprising about 110 000–120 000 cubic metres per year.

TABLE 3: FOREST AREA, BY TENURE, OF THE SOUTH-EAST QUEENSLAND REGION

Tenure category	Native forest *area (ha)*	Native forest *% of tenure*	Plantation *area(ha)*	Plantation *% of tenure*	Forest in each tenure as % of all forest
State forest	688 898	77.51	159 442	17.94	31.26
Timber reserves	23 695	98.78	131	0.55	0.88
National parks	357 507	73.62	497	0.10	13.19
Other crown land:					
with timber rights	198 393	48.29	2 517	0.61	7.40
without rights	75 932	18.48	—	—	2.80
Freehold	1 191 300	27.85	15 775	0.36	44.47
Total	2 535 725		178 362		100.00

Source Project SE 1,2 Public Forest Resource Description & Inventory (Draft) Table 3.2

The region's hardwood native forests generally are comparatively slow growing, currently around 0.2-0.4 cubic metres per hectare per year for dry forests and 0.5-5.0 cubic metres per hectare per year for moist to wet forests, and produce low harvestable yields of timber—around 2–8 cubic metres per hectare in the dry forests, and 8–20 cubic metres per hectare in moist to wet forest types. These figures are low in an Australian context.

Management for wood production in the public production forests of the region has relied largely on two silvicultural techniques –selection logging, and/or post-logging silvicultural treatment.

3.2.1 Treemarking

Marking trees to indicate selection either for removal or retention is a feature of both selection logging and post-logging treatment. The decision to remove or retain a tree is based on such factors as its current form and vigour (that is, its apparent potential for future growth so as to provide merchantable timber), tree size, the density of the stand in which it is in (trees require space to grow to their potential), the species involved, and the current and projected markets for wood.

Treemarking rules therefore govern the density of the forest and the quality of the trees that remain after logging.

3.2.2 Harvesting by selection logging

While selection logging has historically been the harvesting practice, the rules governing tree selection have evolved as markets for timber and management priorities have changed, and as the behaviour of the forest has become better understood.

The legacy of past selection regimes is long lasting; about half of the public forest managed for timber production has not been harvested to current (that is, post-1960s) prescriptions. The stand structure resulting from the pre-1960 harvesting practices reflects the emphasis on retention of all merchantable stems irrespective of growth potential (meaning that these forests now contain many trees of low commercial quality).

Various silvicultural regimes were practised in hardwood forests in the early decades of the century. Taylor (1994), Carron (1985) and Queensland Department of Forestry (1984) provide overviews of these regimes. Treemarking was practised from the 1920s onwards as part of a silvicultural system based on ringbarking non-merchantable species, harvesting all merchantable trees irrespective of size (girth), burning to stimulate regeneration and thinning the subsequent regeneration or supplementing it with planted nursery stock. Restricted utilisation of the merchantable species limited the effective application of this technique, with post-harvesting stands often containing many poor quality stems.

The management system was revised in 1938. Until then cutters had been paid only for felled trees that yielded sawlogs, which encouraged the felling of trees certain to be useable. With the introduction of ‘economic treemarking’, cutters were paid an allowance for a marked tree even if it proved unusable. The main objective of this system was the progressive development of a forest of high quality stems. The tree marking rules provided for: the protection of seed trees; the complete utilisation of every tree possible; and the retention of trees until maturity. However, many trees that were retained as ‘potentially useful’ had been suppressed by larger trees for so long that they were unable to respond adequately to this treatment (removal of competing trees) intended to release them into a growth phase.

The rules were revised in 1956, resulting in more comprehensive selection prescriptions for a range of specific products, and providing for the retention of seed trees. However these revisions did little to improve stand quality after logging, and forest productivity remained poor. A decade later, in the mid-to-late 1960s, the rules were again revised to ensure better productivity. Under the new rules, all non-vigorous and poorly formed stems were to be removed, the remaining stand was to be adequately thinned and larger, fast-growing trees were to be retained until they reached harvesting maturity.

Current treemarking rules are largely based on the 1960s prescriptions. The main changes are a reduction in the upper (maximum) cutting diameter limit for trees in the wet sclerophyll forests, the development of treemarking rules for blackbutt forests and particular rules for brush box. In the dry forests, a technique which correlates growth potential with crown condition (‘crown scoring’) was developed as a means of predicting the growth potential of trees during the treemarking phase.

3.2.3 Silvicultural treatment

Whereas treemarking for selection logging aims to thin the merchantable (commercial, larger sized) fraction of the stand, treemarking for silvicultural treatment focuses on thinning the non-merchantable trees. Current silviculture in the south-east Queensland native forests requires the removal of poorly formed, non-vigorous or overcrowded stems, with the aim of ensuring adequate regeneration and vigorous growth of the retained trees. To date, more than 150 000 hectares of State forests and timber reserves in south-east Queensland have received silvicultural treatment, with peaks of activity in the 1930s, the post-World War II period and the 1960s.

Although some form of silviculture has been practised in native forests almost since the inception of the Forest Service in the early 1900s, the first formal rules for silvicultural treatments were introduced concurrently with those for treemarking in 1938.

These treatment rules integrated four elements of timber stand improvement:

- the destruction of commercially worthless stems and species
- the destruction of malformed advanced growth (saplings of sub-merchantable size) in poorly stocked areas, to give the favoured advanced growth more room to grow
- thinning amply stocked areas to specified spacing between trees, and
- removing 'ephemeral' competition.

Under the 1938 rules, the average spacing between trees varied from 3.7 metres to 7.6 metres, depending on tree height at the time of the silvicultural operation. The reasons for the 1938 spacing prescriptions are unclear, but apparently were related to an anticipated market for small timber. The rules were revised in the 1940s to reduce the average spacing (that is, to stock more densely).

In the early sixties, when the small timber markets that had been anticipated did not eventuate, treatment objectives were reviewed and wider spacings were introduced, reflecting an increased emphasis on sawlog production. An average spacing of 7.6 metres was adopted. Most silvicultural treatments in the 1960 to mid–1980s period were applied in dry sclerophyll forests containing many non-commercial and suppressed trees, and in stands dominated by small even-aged groups that had resulted from wildfires, selective logging, or previous silvicultural treatment.

As sawlogs and poles are the principal hardwood products of native forests, silvicultural treatment to increase the proportion of these products in the forest remains desirable. However, due to economic constraints, the forestry department's silvicultural efforts remain concentrated on the more productive plantation resource. Today, very little silvicultural treatment occurs in the native production forests with, on average throughout the State, less than about 400 hectares a year having been treated since the late 1980s.

An outline of current silvicultural practices is contained in the Harvesting, Marketing and Resource Management manual (DPI–F).

3.2.4 Enrichment planting

Enrichment planting is the practice of establishing preferred commercial species in gaps in native forests where natural regeneration is limited, due either to poor natural stocking or to other factors.

Stands established using enrichment planting techniques have exhibited better growth rates than natural stands. However the small-scale nature of enrichment planting resulted in relatively high nursery and establishment costs and survival rates were low. Only blackbutt, Gympie messmate and tallowwood provided consistently good survival and growth on a range of enrichment-planted sites. Therefore, while the practice has the potential to re-establish productive forests on sites where natural regeneration is deficient, the costs involved are currently too high for it to be considered economically viable. The practice has not been used in the region (or elsewhere in the State) since the late 1980s.

In the 1970s and 1980s, when the use of enrichment planting was at its peak in the public forests of south-east Queensland, around 80–100 hectares per year were being treated in this way. It was usually confined to sites with a high timber production potential, which means native forests at the wetter end of the environmental gradient (wet and moist sclerophyll forest). Treated forests were typically dependent on regeneration by seedlings rather than lignotubers (a woody mass at ground level which produce new shoots whenever old shoots are destroyed). Planting was required because natural germination and seedling survival had been restricted by a dense understorey, usually of rainforest species, but sometimes by other species such as *Lantana*.

Forest types in which enrichment planting was normally carried out usually had a component of blackbutt, brush box, Sydney blue gum (E. saligna), white mahogany (E. acmenoides), rose gum or tallowwood. Enrichment planting has also been employed in fire-devastated or cleared areas where there was little effective natural regeneration.

3.2.5 Fire

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 in Queensland. 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 in the public timber production forests.

Forestry department policy recognises the potential for adverse environmental effects if prescribed burning is too frequent and a fire-free period of around seven to ten years is recommended. 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.

Current trends are to a reduction in the use of prescribed burning in native forest management, generally in response to increasing constraints both environmental and economic.

3.3 RESEARCH AND DEVELOPMENT

More than half of all research papers relating to native forest silviculture in south-east Queensland forests are concerned with harvesting and thinning practices. In all, 29 papers were reviewed for this report. These are summarised in Tables 4 and 8 (Appendix 2).

TABLE 4: PAPERS REVIEWED ON NATIVE FOREST SILVICULTURE, BY SUBJECT AND YEAR#

Main subject	Number of papers reviewed	Year of publication			
		Pre -1970	*1970-1980*	*1980-1990*	*Post-1990*
Harvesting and thinning	17	4 (+1?)	6	6*	0
Post-logging burning	8	2	1	0	5
Enrichment planting	4	0	0	4*	0

* Papers predominantly or solely sourced from one conference proceedings (Anderson 1983a).
# Note: Literature concerned with ecological impacts is not included in this table.

3.3.1 Harvesting and thinning

Of the 17 papers covering the topic of harvesting and thinning, seven dealt solely with pure moist blackbutt forests (Henry 1956, Curtin 1963, Florence 1968, 1970, Robinson et al. 1971, Florence & Phillis 1971, Greve 1983a), and three were concerned solely with forests of pure spotted gum (Florence et al. 1970, Greve 1983b, Moore & Garthe 1983). The remaining papers considered mixed wet (or moist) forest types (e.g. tallowwood, brush box), mixed dry forest types (e.g. spotted gum–ironbark), or a combination of dry and wet/moist forests. This report has attempted to incorporate the conclusions of all studies under the relevant sections (dry forests or wet forests) below.

All of the reviewed papers on harvesting and thinning in south-east Queensland were written before the mid-1980s, and all of those reviewed for the 1980–90 period were sourced from the proceedings of one conference (Anderson 1983a). Ten of the papers mention the financial viability of the various thinning and harvesting regimes examined (Henry 1956 and 1960, Florence et al. 1970. Robinson et al. 1971, Greve & Garthe 1983, Greve 1983a and 1983b, Moore & Garthe 1983, Garthe 1983a, Curtin 1970), although the level of detail varies considerably. Only three studies mention ecological effects , and then only in fairly general terms (Florence 1968 and 1970, Fisher 1978).

There appears to be a significant gap in the published literature after 1983, which may reflect the shift in emphasis from native forest to softwood plantations.

3.3.2 The dry sclerophyll forests

The drier forest types predominantly regenerate from lignotubers, which may make it difficult to control regeneration. After harvesting or prescribed burning, the extent of regeneration can be higher than is required for optimal rates of growth. Such regeneration can require an intensive thinning regime to avoid growth suppression resulting from intracohort competition. This has been the case in comparable dry sclerophyll forest types in Victoria and Western Australia (see McKinnell et al. 1991).

An early examination of silvicultural treatment of the drier forests dominated by spotted gum–red ironbark *(C. citriodora* with *E. fibrosa, E. paniculata,* and *E. acmenoides)* at Stapylton was carried out by Henry (1960), and is likely to have concerned itself with the treemarking rules that had been introduced in 1956 (Circular 1366). This research found that minimal treatment (involving only thinning of the forest by removing commercially useless stems) conferred an economic advantage equivalent to an additional eight per cent return per year over untreated stands. Further, areas which received more intensive treatment showed only a slight improvement in value increment over the minimal treatment. In view of the relatively low maximum growth rates considered possible in this forest type, any additional return as a result of more intensive silvicultural treatments was therefore considered insufficient to justify the additional expenditure.

In respect of regeneration of clearings in spotted gum–ironbark forests, Henry and Florence (1966) found that lignotuberous seedlings are suppressed by the effects of crown competition to a distance of about 25 metres from the canopy edge; conversely, seedling regeneration in large gaps can be excessive, and may result in the ‘locking up’ of the advanced growth pool due to excessive intracohort competition.

Florence et al. (1970) reported on a number of silvicultural experiments including trials of a newly introduced set of rules (called Circular 1784) to the cutting girth limit schedule that had regulated logging prior to 1968. The authors surmised that the productive condition of the spotted gum *(C. citriodora)* forests could be improved. The trialled schedule required logging of all merchantable size classes in the forest, using spacing and tree quality as criteria for selection, rather than girth alone. It was considered the alternative schedules would increase the volume of wood immediately available for harvest, but would reduce log size and decrease wood quality. While no explicit financial analysis was undertaken, the authors considered that the prevailing log price structure (under which larger diameter logs were worth more per cubic metre than smaller diameter logs) combined with an industry trend to accept smaller, cheaper, lower quality logs would facilitate acceptance of the new schedule by the milling industry.

Grimes and Pegg (1979) provided further evidence to support the view that productivity of the spotted gum forests could be improved, concluding that 23 years of logging in State forests of the Maryborough region aimed at removing short-boled, poorly-crowned trees (coupled with some silvicultural treatment), had increased the merchantable growing stock (trees with stem diameter of 40 centimetres or greater) by 18 per cent, equivalent to an increase in harvest volume of 7 per cent.

The authors went on to conclude that if markets could be found for trees with a diameter of 20 centimetres, the increases would be 50 per cent and 17 per cent respectively.

Garthe (1983a) conducted a more recent evaluation of the effectiveness of harvesting and silvicultural treatment in these dry forest types (predominantly spotted gum) under the Circular 1366 rules introduced in 1956, and a number of alternative sets of rules. Under most of the alternative rules trialled, trees that were to be retained had to meet minimum standards of form and vigour, and merchantable stands were retained up to their optimal utilisable diameter, that is, the diameter beyond which defect was regarded as major (ibid.).

The results of these treatments varied according to the pre-existing structure of the forest and the intensity of the silvicultural thinning required by the alternative rules. Under the alternative rules applied in one experiment in an overmature dry forest (experiment 261 in State forest 957 Tiaro), all of the merchantable trees in the stand were removed. While this had the effect of enhancing diameter increments on the remaining trees, it also resulted in much reduced volume production per hectare for the next cutting cycle. Garthe (ibid.) concluded that a more conservative retention standard might result in greater productivity in similar forest types and stand conditions.

The other two experiments examined by Garthe (ibid.) were conducted in spotted gum forests with good size distributions (experiment 259, at Gungaloon, and experiment 122 at Dalby). The experiments were conducted to test various regimes for spotted gum forests: experiment 259 tried a wider spacing than currently the practice under Circular 1366, and experiment 122 tested Circular 1784 against more intensive harvest and treatment standards (the so-called 'Dalby High Standard' rules, which set higher standards for trees to be retained, and wider treatment spacings and higher standards for the sub merchantable stand). In experiment 259, the alternative rules improved growth (measured by diameter increment of the stem of the retained trees) and enhanced the productivity of the stand. In experiment 122, the treatment produced an increase in diameter of retained stems of all size classes but reduced total stand volume. Both experiments indicated that reduced stockings post harvest/treatment gave increased diameter growth at the sacrifice of merchantable volume for at least 30 years post harvest (or treatment) and that recovery time to pre-harvest/treatment stand volumes was increased. Garthe also found there was a significant proportion of lower quality timber left standing after routine harvesting using Circular 1784 specifications and that average log quality should be better in the next harvest for stands subject to 'Dalby High Standard' rules.

Garthe also studied regeneration in the spotted gum–ironbark and grey gum–grey ironbark forests, forest types in which most species regenerate from lignotubers. Gaps of 0.2– 0.4 hectares are often required for the release of lignotubers (Garthe 1983b). Specifically, Garthe examined the silvicultural desirability of thinning treatments to release the lignotubers at various stages in the logging cycle. He concluded that the logging practices of the time commonly created gaps greater than those required to release the lignotubers and that, regardless of the forest condition, treatment of spotted gum resulted in increased diameter increments, a slightly reduced volume increment (per hectare), and perhaps improved value production. Garthe further established that from a silvicultural viewpoint, treatment mid-cycle (around 15 years) is required in all except advanced regrowth spotted gum forests, although he was not able to establish the economic viability of such a treatment.

Five papers considered the financial aspects of various harvesting and/or thinning operations in the drier forest types, but only two analysed such aspects in any detail.

In one of the detailed analyses, Greve (1983b) examined the economics of silvicultural treatment in a stand of naturally-regenerating spotted gum in the Maryborough district, focussing on the yields required for treatment to be financially viable. Greve's paper used actual costs of natural regeneration treatment operations and assumed two cutting cycles (harvesting either at 30 years or 40 years) and two stumpage rates (the price of the log at the stump), based on the harvest being suitable as mill logs only or as mill logs plus poles. Greve calculated that the annual volume increments necessary for treatment to be viable appeared to be in the range of about 1–2 cubic metres per hectare, depending on the stumpage rate (i.e. the higher the stumpage rate, the lower the increment necessary to achieve economic viability). It was considered that treatment would be capable of producing volume increments of this magnitude.

In the Dalby experiment mentioned earlier (experiment 122), Garthe studied the economics of two different logging and treatment rules (‘high standard’ versus ‘Dalby hardwood treatment rules’) in a virgin (that is, unharvested) spotted gum stand. The main differences between the ‘high standard’ treemarking rules and the ‘Dalby hardwood treatment rules’ are outlined in the paper. Briefly, under the ‘high standard’ rules, the standards applied to stems to be retained during harvesting operations were more strict than those in the ‘Dalby hardwood treatment rules’. Under the latter there was a wider range of average and minimum spacings.

At harvest, yield under the ‘high standard’ rules was greater (by 1.8 cubic metres per hectare) than that achieved under the ‘Dalby hardwood treatment rules’, an improvement representing an additional $35.06 per hectare in revenue, based on 1969 prices. Compounded over an assumed cutting cycle of 30 years at 3 per cent and 5 per cent, this higher yield equated to a financial advantage of $85.10 and $151.53 (1969 values) respectively per hectare. However, while the ‘high standard’ rules led to a significant improvement in individual tree diameter increment over all sizes, there was an apparent loss of total (merchantable) stand volume (at next harvest). The choice of one set of rules over the other would therefore depend on management intentions for the area. If the intention were to grow high quality sawlogs in a short period, and total stand volume were not important, the ‘high standard’ rules should be favoured. Conversely, if stand productivity (that is, the production of timber per hectare over all sizes) were more important, then the Dalby rules would be preferable.

Three papers considered but often did not quantify the costs of various treatments and harvesting (Henry 1960, Florence et al. 1970, Moore & Garthe 1983). Of these, Moore and Garthe cautioned that increased growth rates (and thus increased financial value) from the more intensive treatment may not compensate for the loss of potential products, such as mining and landscape timber, that would be result from the rules in use at the time (the ‘Dalby hardwood treatment rules’). Changes that have occurred since many of these papers were written, such as changes to cost structures, and changed market conditions, mean that the conclusions drawn in these papers should be viewed with caution today.

3.3.3 Wet sclerophyll forests

Due to the general shade intolerance of wet sclerophyll eucalypt species, a high level of disturbance (removal of overtopping crowns and exposure of the soil by bulldozer, or burning of logging debris and understorey vegetation) is required to provide a satisfactory seed bed, and stimulate regeneration. This may involve a small proportion of the area in the case of ‘top disposal’ burns (burning the crowns of felled trees), or the majority of the area in the case of broadcast burns. The production of seed by many species of wet sclerophyll timber trees in south-east Queensland is subject to temporal variation (that is, varies from year to year) (Garthe 1983b), a factor that must be considered if natural seedling regeneration is desired for a site.

Some studies referred to ‘irregular’ and ‘even-aged’ blackbutt forests, and some clarification of these terms is warranted. The terms ‘irregular’ or ‘regular’ are generally used in the context of describing the vertical structure (profile) of the forest. The terms can be used to describe a range of forest configurations from one in which there is a single canopy of trees with little understorey (a regular structure), through to one in which it is difficult to discern any distinct vegetative layers (an irregular structure).

Even-aged forests may result from past wildfires or clearing, and are not necessarily of a regular structure, as might be thought. For example, a wildfire may result in regrowth of mixed species, some of which may grow faster than others. In this instance, faster-growing blackbutt may overtop slower growing species such as tallowwood or brush box (which are able to tolerate lower levels of light). This could result in an irregular forest structure, despite all the trees being of a similar age. Uneven-aged forests can result from highly selective logging, or fire in dry sclerophyll forests (which are generally fire-resistant) so that only an occasional tree dies, or is removed. In these circumstances, regeneration may not develop in readily identifiable, even-aged patches.

The use of the term ‘blackbutt forest’ also appears to have changed over time, and may be misleading. In recent times, the term might be used to describe a forest in which the forest is entirely, or predominantly (that is, more than 50 per cent) blackbutt. However in the past (until about the 1980s), the term was used to indicate that commercially significant amounts of blackbutt were present in the stand. In some instances, a mixed species forest comprising but not dominated by blackbutt was nevertheless termed ‘blackbutt forest’ in order to denote the management intent for the forest; that is, the intent may have been to increase the blackbutt component of the forest through harvesting or treatment of the other species.

A number of studies examined thinning in ‘even-aged’ blackbutt forests (Henry 1956 and 1960, Robinson et al. 1971). Two strengths of the research into thinning are the period covered, and its comprehensiveness. Some studies involved periods of 20 or more years, although not all individual studies were that long. Tree spacings of from 4.9 metres by 4.9 metres through to 7.6 metres by 7.6 metres were considered. The studies showed that generally, the wider the spacing, the larger the stem size and the greater the financial return, generated in the form of increased stumpage.

Even-aged blackbutt forests on high quality sites respond well to a relatively heavy, early, non-commercial thinning and the higher return from the larger stems more than compensates for the slight volume loss occasioned by the thinning required to achieve the wide spacing. Robinson et al. (1971) concluded that spacings wider than 7.6 metres by 7.6 metres may further increase the return, although no studies that tested such a regime were found.

‘Irregular’ blackbutt forests were the subject of four studies reviewed for this report (Florence 1968 and 1970, Florence & Phillis 1971, Garthe 1983a).

Florence and Phillis (1971) developed a logging schedule for a particular stand in northern New South Wales that was similar to a treatment Florence et al. (1970) had already proposed for spotted gum in south-east Queensland. The treatment involved logging through all merchantable size classes while retaining all growing stock meeting specified standards of bole and crown quality, and post-logging treatment to retain high quality advanced growth. However, because the treatment was developed to meet the conditions and needs of a particular stand, the authors advised caution in applying it to all mixed species forests of the type. No evidence was found of any trials of the logging schedule in south-east Queensland forests.

Curtin (1963) carried out studies in northern New South Wales blackbutt forests in an attempt to identify the ideal stocking rate for maximum production in an irregular blackbutt forest. This research was based on a method developed by French foresters in 1930 for silver fir selection forests; however, once again there is no indication that this method was ever trialled in south-east Queensland forests.

An indication of the productive capacity of blackbutt in south-east Queensland is provided by Fisher (1978), who found that blackbutt in mixed species forests at Benarkin achieved merchantable productivity of 4.5 cubic metres per hectare per year over a period of 40 years.

Garthe (1983a) conducted a more recent comparison of silvicultural alternatives at Maroochy in an irregular blackbutt forest with a high component of turpentine *(Syncarpia glomulifera)* and brush box (experiment 170). This research compared the standard harvesting and treatment rules (Circular 1366) with an alternative treatment involving relogging and retreating areas previously logged under the standard rules. The alternative rules achieved higher productivity as a result of removing many larger trees of poor growth and releasing (for growth) sub-merchantable (smaller sized) blackbutt.

Garthe also examined logging and natural regeneration in a wet sclerophyll blackbutt forest, although neither the structure (even or uneven-aged) nor composition of the forest ('regular' or 'irregular') was explicitly stated (Garthe 1983b). Garthe considered that while the contemporary logging practices met the requirements for overwood removal, soil disturbance and initial removal of competition, the availability of seed was sometimes doubtful due to the biennial production of seed in some locations. Appropriately timed (spring-summer) regeneration burns were considered necessary to reduce weed competition and promote good regeneration from seed.

In the same paper, Garthe also referred to rose gum–brush box (wet sclerophyll) forests. He concluded that, as was the case with wet sclerophyll blackbutt, the then-current logging practices were effective in promoting regeneration in the rose gum–brush box forests; however, the rose gum seed supply was considered even less dependable than blackbutt. Garthe's comments about seed production were particularly relevant, given that the prevailing guidelines specified the retention of only three seed trees per hectare. Garthe also concluded that post-logging burning played an important role in reducing weed competition in the rose gum-brush box forests (ibid.). Garthe alluded to the need to vary management techniques should seed supply be inadequate. This could involve an increase in seed tree retention to allow for variation in seed crops, or enrichment planting.

Of the three studies that examined financial aspects of timber production in wet sclerophyll forests, two were concerned with blackbutt (Henry 1956, Robinson et al. 1971), and the remaining paper looked at the economics of planting Gympie messmate for poles (Greve & Garthe 1983). The stumpage figures used in Henry's study are considered too dated to draw any valid conclusions. A dilemma faced by many forest managers is illustrated by the research of Robinson et al. (1971), who determined that while thinning even-aged blackbutt to a 4.9 metre by 4.9 metre spacing yielded the highest merchantable volume, the greatest financial return was achieved by increasing the spacing to 7.9 metres by 7.9 metres. However some caution was advised in the interpretation of these results, as it was considered that fluctuations in pulplog and sawlog values since the study was carried out could vary the conclusions drawn.

A limited number of studies have evaluated the ecological effects of thinning and harvesting practices in south-east Queensland forests. These studies found that such practices can be detrimental to forest ecology, causing changes in species composition, richness and abundance (McIlroy 1978, McEvoy et al. 1979, Kehl & Corben 1991, and Preen 1981).

Within a forest stand, silviculture may alter the structure, age distribution, and ratio of the various tree species (species composition), as well as the distribution, species composition, and frequency of occurrence of understorey species (such as epiphytes, vines, shrubs and herbs), throughout the various stages of forest development (Queensland Department of Primary Industry-Forestry 1990). The changes caused by selective logging and silviculture can significantly alter the diversity and abundance of forest dwelling species, as many depend on the continued existence of a particular habitat type for their survival (McEvoy et al. 1979 and Kehl & Corben 1991). A number of studies conducted in south-east Queensland have shown changes in fauna species richness and abundance following harvesting and subsequent regrowth thinning of native forests (Kehl & Corben 1991, Flower et al. 1995 and Eyre & Smith 1997). Changes in the populations of certain species in these forests may be attributed to several factors including reduction in habitat and foraging trees, changes in micro-climate, habitat fragmentation, increased intensity of run-off and deterioration of stream water quality.

3.3.3.1 Habitat trees

The removal of large or mature trees may reduce the number of habitat trees available for tree-dwelling fauna (Kehl & Corben 1991). Arboreal mammals and nesting birds generally depend upon large mature and over-mature trees (that is, trees with stem diameter of more than 50 centimetres) both for foraging and to provide hollows for den and nesting sites (Eyre & Smith 1997, Kehl & Corben 1991). Some species, such as the yellow-bellied glider *(Petaurus australis)*, prefer hollows in live trees over dead trees and forage in the more robust trees (Eyre & Smith 1997). In many logged areas, a significant proportion of the hollow resources are present in stags (dead trees) as a result of silvicultural treatment (Ross 1998). Yellow-bellied gliders have been observed to rely on these hollows in areas where the presence of live hollow-bearing trees is limited (Eyre & Smith 1997). Stags represent a short-term resource in terms of hollows, as they are prone to removal by relatively low-intensity fires. In consideration of this, logging and silvicultural treatment may be incompatible with the habitat requirements of species such as the yellow-bellied glider (Eyre & Smith 1997). Other habitat attributes that would be affected by intensified logging and enhanced silvicultural management include tree height, forest structure and tree spacing (all of which either affect the mobility of species, or alter the protection the forest affords them), and species composition (Kehl & Corben 1991).

The potentially adverse effects of selective harvesting and thinning can be reduced by a number of forest management practices. Hollow nesting species benefit from the retention of habitat trees. It is considered essential that hollow-bearing trees be retained during harvesting in order to ensure the conservation of hollow-dependent fauna in logged forests (ibid.). It has also been recommended that seed trees be retained in order to regenerate species required for foraging (ibid.). Current practices employed by the Queensland forest service endeavour to retain the essential characteristics of a forest while harvesting for timber (Queensland Forest Service 1991). This includes preserving some habitat trees, seed trees and trees of different species and ages within a stand (Queensland Forest Service 1991 and Kehl & Corben 1991). The introduction of a code of practice for native forest timber harvesting is likely to result in an increase in habitat tree retention requirements. The retention of at least six habitat trees on every hectare was recommended by Lamb et al. (1998) and schedule 6 (Trees to be retained for wildlife conservation) of the Code of Practice for Native Forest Timber Production (Department of Natural Resources 1998) provides guidelines to ensure retention and recruitment of such trees is adequate.

3.3.3.2 Reduction in range of available food sources

Selective harvesting, thinning and enrichment planting can leave gaps in the food sources for forest dwelling fauna (Queensland Department of Forestry 1987; Queensland Department of Primary Industries—Forestry 1990). Nomadic species such as the yellow-bellied glider rely on a range of plant species flowering at different times of the year for a constant supply of food (Eyre & Smith 1997). ‘Traverser’ species such as the rainbow lorikeet *(Trichoglossus haematodus)* rely on their ability to travel long distances (either daily or on a migratory basis) to take advantage of seasonal flowering. Such feeding sites may be critical at particular times of the year or in the event of infrequent climatic fluctuations such as droughts (Porter 1993). A significant proportion of the birds and arboreal animals in Australia exhibit migratory or nomadic feeding strategies comparable to the above species (Queensland Department of Forestry 1987). Less mobile species are likely to be more sensitive to habitat fragmentation (Porter 1993). To ensure the conservation of nomadic specialists, temporal as well as geographic distribution of food sources needs to be considered with reference to retaining habitat trees (Porter 1993, Innis 1989). Consideration of issues such as seasonal feeding is imperative when selection logging and enrichment planting of commercially viable eucalypt species occurs over large areas (Queensland Department of Forestry 1987), or when land is cleared for the purpose of establishing plantations (Porter 1993).

The diversity and abundance of microchiropteran bats in the Conondale Ranges appears to decline for a period after harvesting, due to changes in the stratification of the forest stand, which reduce the diversity of foraging niches available. However, in one naturally regenerating forest plot, the bat population recovered to its pre-logging state 34 years after the selective logging operation (de Oliveira et al. in press).

Innis (1989) found that disturbance and the subsequent change in flora species composition benefitted the brown cuckoo-dove *(Macropygia amboinensis)*, a species that feeds preferentially upon the fruits of colonising plants. Currawongs *(Stepera graculina)* also appear to have benefitted from disturbance regimes that promoted the spread of colonising species that fruit abundantly; increased currawong populations can have negative effects for smaller bird species (Ford 1993).

3.3.3.3 Change in microclimate

The removal of larger trees and the construction of snig tracks or access roads can significantly alter forest microclimates (Department of Forestry 1983). Studies have suggested that the impact of microclimate change is significant on particularly sensitive species such as the marbled frogmouth *(Podargus ocellatus plumiferus)* (Kehl and Corben 1991). Generally however, it is considered that microclimate changes have pronounced implications for species such as amphibians and reptiles (Hannah & Smith 1995) and may also lead to a change in the structure and assemblage of flora such as lianas, epiphytes and ground plants (Queensland Department of Forestry, 1983).

Changes in microclimates can also promote weed invasion and the intrusion of opportunist species (Preen 1981, Catterall & Kingston 1993b). The effects of changes in microclimate can be reduced by management practices such as tree marking guidelines that minimise excessive openings in forest canopies (Dale 1983). Retention of the understorey of selectively logged sites can reduce the impact on the habitat of the marbled frogmouth (Kehl & Corben 1991). In addition, forest management practices that ensure the quick regeneration of understorey, or longer rotation cycles (periods between logging) could also contribute to species conservation by permitting understorey flora and microclimates to return to a pre-logging state (Kehl & Corben 1991). Well-located and engineered snig tracks and ramps can also reduce the level of disturbance during timber harvesting (Queensland Department of Forestry 1983).

3.3.3.4 Habitat fragmentation

The presence of roads and large snig tracks and large, intensively logged areas can alter the movement patterns of small animals (Burnett, 1992; Queensland Department of Primary Industries–Forestry 1990). It has been observed that small terrestrial (ground-dwelling) and arboreal (tree-dwelling) mammals will confine their home range to one side of a large linear environmental discontinuity such as a road (Burnett 1992). Their movements may also be affected by silviculture and selective logging practices as logging results in a changed mosaic pattern of suitable and unsuitable habitat (especially in the short-term) (Queensland Department of Primary Industries–Forestry 1990).

In areas where habitat fragmentation occurs, the remaining patches of habitat are subject to ‘edge effects’ that can further reduce the ideal habitat of a species. This can be due to microclimatic changes that allow the encroachment of plant species that in turn may alter the vegetation structure; or to the influence of predators from the open habitat that make forays into the patches of closed habitat (Catterall & Kingston 1993b, Ford 1993). When logging disturbs large areas of forest, flora and fauna species may become confined to pockets of smaller populations in smaller areas of remnant habitat (Flower et al. 1995). These fragmented populations are less likely to be viable in the long-term, as they are more susceptible to genetic problems such as reductions in heterozygosity, mortality, predation and local extinction as a result of natural or anthropogenic disturbance such as prescribed burning, drought or storms (Flower et al. 1995, Catterall & Kingston 1993a,b).

A secondary implication of fragmentation may be the alteration of key ecosystem processes (Fisher 1980). This effect is due to the potential loss of key guilds such as pollinators, frugivores (animals that spread seeds by eating fruit), and insectivores. These guilds serve to disperse pollen or propagules (such as seeds) or control insect populations. Alterations to such processes may result in a reduction in the genetic diversity of flora populations, changes in flora species composition, or insect plagues (Ford 1993).

Catterall and Kingston (1993b) state that in order to ensure the preservation of species, a ‘minimum critical area’ with a ‘minimum viable population’ is required, referring to the size of area and number of individuals required to ensure a population’s viability. They also state that fragmented populations need to be connected by corridors of appropriate habitat in order to avoid being subjected to the negative effects associated with habitat fragmentation (Catterall & Kingston 1993a,b).

3.3.3.5 Soil erosion, runoff and stream water quality

The removal of trees and the decrease in other vegetation cover associated with timber harvesting practices can induce accelerated soil erosion and stream sedimentation (Vanclay 1992, Queensland Department of Forestry 1983). Harvesting can also lead to nutrient fluxes, increases in organic matter and changes in its composition (Bunn et al. 1998, Borg et al. 1988). Without buffer strips to protect riparian (river bank) zones, harvesting would cause changes in light regimes over river and stream edges by reducing shading.

All the factors just mentioned can dramatically reduce water quality and stream health, affecting such factors as dissolved oxygen concentrations and algal quantity; these in turn can alter the composition and quantity of aquatic flora and fauna communities, and the functioning of the stream ecosystem (Bunn et al. 1998, Campbell & Doeg 1989, Kehl & Corben 1991). Without the shade provided by riparian vegetation within ‘buffer strips’, stream temperatures would rise. Such shade is therefore extremely important for maintaining aquatic ecosystem processes (Clinnick 1985) and can limit the response of aquatic plants to an increase in nutrient concentrations (Borg et al. 1988, Bunn et al. 1998). Increases in the deposition of organic debris can obstruct stream flow and contribute to higher dissolved nutrient levels (Campbell & Doeg 1989, Bunn et al. 1998).

Most cases of severe erosion are a consequence of poorly located and engineered snig tracks, undrained roads and snig tracks, and earth or log-filled stream crossings (Vanclay 1992, Queensland Department of Forestry 1983). Sedimentation levels in streams are likely to peak during the first couple of years following logging and then decrease proportionally as vegetation cover increases towards a pre-logged state (Queensland Department of Forestry 1983). In order to limit the amount of damage done to streams during timber harvesting, a number of management practices may be employed. It has been stated that water quality in logged catchments can be protected by excluding logging from 'buffer strips' on either side of streams (Clinnick 1985, Queensland Department of Forestry 1991). Buffer strips isolate the stream, filtering sediments (Clinnick 1985) and limiting inputs of solar radiation (Bunn et al. 1998). However, their success is a function of their width and hill slope, and little is known regarding an appropriate width to ensure effectiveness in forested areas of south-east Queensland (Campbell & Doeg 1989). It has also been recommended that secondary gullies be protected by buffer strips, because of their role in periods of high water flow (Kehl & Corben 1991).

3.3.4 Post-logging burning

Eight studies concerned with prescribed burning, all carried out in south-east Queensland, were reviewed. Of the eight, three dealt predominantly with dry sclerophyll forests (Henry 1961, Henry & Florence 1966, Vanderwoude 1997); three examined both dry sclerophyll forest and moist sclerophyll blackbutt (House 1995, Guinto et al. 1997a, b); one was concerned exclusively with wet and intermediate (that is, intermediate between wet and dry) sclerophyll blackbutt (Russell & Roberts 1996); and one looked at sclerophyll shrub woodland and forb heath in the Wallum (Just 1977). These studies focussed on the effects of different burning frequencies on the main commercial timber species in south-east Queensland; some incorporated the monitoring of prescribed burning for periods from 20 years (House 1995) to 40 years (Guinto et al. 1997a, Vanderwoude 1997).

Early work carried out by Henry (1961) in the dry sclerophyll spotted gum–ironbark forests of the Maryborough region found that burning in conjunction with logging and treatment was not successful in achieving regeneration, principally due to a lack of flexibility in co-ordinating these treatments with good seed fall, and the long period required for regeneration to occur. He recommended that logging should be followed by annual post-logging burns to control weed growth until good germination of the major species occurred, and then by a period of protection from fire long enough to ensure lignotubers developed to a fire-resistant stage.

Research by Henry and Florence (1966) indicated that the spotted gum component of these forest types could be increased by timing silvicultural treatments (principally harvesting and thinning) to coincide with seed fall patterns. They also found evidence that lignotuberous seedlings remained static for at least 15 years in lightly stocked stands and forests gaps where regeneration had been expected to develop well.

Florence (1964) also researched the use of burning to promote regeneration in the wet sclerophyll blackbutt forests of Cooloolabin (now Mapleton) State Forest (in south-east Queensland). A series of experimental burns demonstrated that blackbutt seedling establishment largely failed on burnt sites; however, excellent germination and survival occurred where soil had been heavily disturbed by tractor work. This research raised the possibility that growth-restricting factors may have been responsible for the poor germination in the relatively less intensively burnt areas. More intensive burns, or significant soil disturbance associated with heavy machinery may therefore provide a favourable environment for successful regeneration.

No examination of the financial viability of using prescribed burning to promote regeneration was discussed in any of the papers reviewed.

The effect of fire on the composition of forest understorey has implications for the conservation of species such as the marbled frogmouth, which appears not to re-inhabit logged areas of wet sclerophyll forests for at least 70 years after logging (Kehl & Corben 1991). Specifically, hot top disposal burns inhibit regeneration of the rainforest understorey, reducing the ability of species such as the marbled frogmouth to inhabit these areas (Kehl & Corben 1991).

In contrast to the limited information on post-logging burning in south-east Queensland, the ecological considerations of prescribed burning covered both the effects of fire on the soil nutrients and biodiversity. House (1995) recognised that the effect of prescribed burning practices on biodiversity in south-east Queensland must be considered if ecosystem sustainability is to be achieved along with the sustainable timber yield. Prescribed burning represents a significant human-induced disturbance that overlays already complex cycles of disturbance. Prescribed burning may contribute significantly to alterations in species richness, abundance and composition (Vanderwoude et al, 1997, Kehl & Corben 1991, McEvoy et al, 1979 and House, 1995). 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 burning procedures (House 1995).

3.3.4.1 Effect on flora

It is recognised that the recruitment of plant species in south-east Queensland forests is adversely affected by frequent burning (Guinto 1997). In dry sclerophyll forest it has been found that some seed regenerators (eg. *Hakea gibbosa)* become particularly rare in the presence of regular burning (House 1995), while grasses are favoured. It is thought that frequent fires may decrease the regenerative capacity of a forest (Guinto 1997). House (1995) has recognised that community composition may be adversely affected by regular prescribed burning. In wet sclerophyll forests, the practice of clearing and burning of the understorey prior to underplanting may remove the naturally-occurring rainforest understorey species assemblage from a site for decades, or indefinitely if understorey regeneration times exceed logging intervals (Joint Conservation Groups 1990).

The disturbance of native forest by elements such as fire may increase its susceptibility to weed invasion. The establishment and spread of exotic opportunist weed species can be associated with changes in fire regimes, with disturbed, fragmented vegetation exhibiting a lower resistance to exotic weed invasion (Humphries 1994).

3.3.4.2 Effect on fauna

Prescribed burning practices have the potential to change habitat types by altering the composition of the forests. Such changes may threaten the conservation of some fauna species (McEvoy et al 1979).

Prescribed burning at various intensities can influence the species composition of avian fauna and affect the relative abundance of birds, reptiles and amphibians (Porter & Henderson 1983, Hannah & Smith 1995). The abundance of birds that shelter in the understorey is likely to decrease in areas subject to prescribed burning, while the abundance of other species will be relatively unaffected. Some common and aggressive species such as magpies *(Gymnorhina tibicen* subsp. *tibicen)* benefit from prescribed burning (Porter & Henderson 1983). In turn, an increase in the numbers of species such as magpies and currawongs can result in increased predation and reduced recruitment of smaller insect and nectar-eating bird species (Ford 1993), with similar effects as discussed relating to habitat fragmentation.

Frequent burning may result in the replacement of rainforest species with hard-seeded, fire-tolerant opportunist species, adversely affecting fauna that use the rainforest understorey (Kehl & Corben 1991). Fire also constitutes a hazard for trees that provide hollows for den sites. Trees with hollows are more susceptible to fire damage (especially with greater fire intensities), which causes them to decay and fall sooner than they would otherwise. Stags are very susceptible to fire (Eyre & Smith 1997). Studies on the black-breasted button-quail *(Turnix melanogaster* [Gould]) have revealed a steep decline in their population following fire (Flower et al. 1995) because they require a developed understorey (Smith et al. in press).

3.3.4.3 Effect on soils

Fire is thought to disrupt nitrogen cycles in native forests by releasing large quantities of volatilised nitrogen from leaf litter and the soil surface, into the atmosphere, which results in a changed balance of mineralised and immobilised nitrogen (House 1995).

Examination of the effects of prescribed burning on the soil nutrient status of dry sclerophyll forests found that even annual burning did not lead to any loss in soil nitrogen or organic carbon, but did significantly increase available phosphorus (Guinto et al. 1997a,b). This increase in available phosphorus may give some nutritional advantage to established trees. However the nitrogen and phosphorus available to successive stands may be diminished by regular burning, with the result that recruitment of eucalypt species may be affected (Guinto 1997). On the other hand, Guinto (ibid) found that, as may be expected, the quantity and the nutrient content of leaf litter in dry sclerophyll forest decreased with increased burning frequency..

In marked contrast to related studies in dry sclerophyll forests, studies of the effects on soil nutrients caused by biennial burning in wet sclerophyll forest dominated by blackbutt found that soil nitrogen and carbon decreased and available phosphorus was unchanged (Guinto 1997, Guinto et al. 1997a,b). Guinto (1997) found that, as in dry sclerophyll forests, the quantity and nutrient content of the litter layer in the blackbutt site decreased with increased burning frequency. However, Guinto et al. (1997b) state that the loss of nitrogen does not appear to be in accord with the low intensity burning practised in these wet sclerophyll forests, and that the differences in burning responses of individual soil chemical properties at the two sites (wet and dry sclerophyll) may be partly explained by differences in site quality and the number of times the forests have been burnt. Nevertheless, the frequency of burning in wet sclerophyll forest types may need to be reduced in order to maintain soil nitrogen availability, and more research is required on this aspect.

As forest systems tend to change slowly, the long-term cumulative effects of fire management are considered to be more important than immediate effects of fire on soil and litter processes (House 1995).

In general, prescribed fire may also cause changes in soil water-infiltration rates, soil loss and soil organic content, potentially affecting the water quality of nearby catchments (Campbell & Doeg 1989).

Exposure of soils with a high clay content would lead to high turbidity and sedimentation in surrounding streams in the event of heavy rain (Campbell & Doeg 1989).

3.3.5 Enrichment planting

All four research papers on enrichment planting were sourced from one conference proceedings (Anderson 1983a). Three dealt with enrichment planting in the wet/moist blackbutt, Gympie messmate and/or tallowwood forests (Garthe 1983c, Garthe 1983d, Greve 1983). The remaining paper (Anderson 1983b) was more general and did not specify the forest types to which it related.

Enrichment planting has been successful in a range of wet sclerophyll sites, although only blackbutt, Gympie messmate and tallowwood were found to provide consistently good survival and growth on a range of sites (Garthe 1983c). Control of weed competition was important to success. Areas suitable for enrichment planting include forests with regeneration and growing stock problems, forests where species change is desirable for commercial reasons, and cleared areas requiring reforestation (Garthe 1983d). For example, in Sydney blue gum forests, unreliable seed production brought about an investigation into the viability of enrichment planting (Department of Forestry 1981). (Enrichment planting has not been used anywhere in the State since the late 1980s, see earlier text).

Anderson (1983b) concluded that treemarking rules for harvesting areas that are to be enrichment planted need to be more intensive (that is, more trees should be marked for removal) than those applying to harvesting operations where natural regeneration is relied on. Stems to be retained in such areas should have high growth potential with well-formed vigorous crowns and straight boles, and all merchantable stems of more than 60 centimetres diameter should be removed (Anderson 1983b, Garthe 1983d).

Site preparation is necessary to facilitate enrichment planting, and in areas where logging debris is not excessive, mechanical site disturbance (extending snig tracks and general clearing of about 50–60 per cent of the area) should be carried out. Burning is not considered necessary where sites have been mechanically disturbed, but where this has not occurred, top disposal burning should be done late in the calendar year. Planting should generally take place between November and February, as soon as possible after site disturbance or burning, and plants should be 4 to 5 metres apart, and at least 6 metres from any retained stems. Destruction of commercially useless trees should also be carried out parallel to, or following the planting operation (Garthe 1983d).

Costs associated with enrichment planting were found to be variable, and this was largely attributable to the cost of site preparation. These costs ranged from $30–$80 per hectare in 1983 (excluding the nursery costs of plants), while the cost of silvicultural treatment varied from $40–$90 per hectare (Garthe 1983d). Greve (1983) examined the economics of enrichment planting versus treatment of naturally regenerated blackbutt stands at Mapleton and concluded that the latter was viable (assuming existing costs and stumpage rates and a required real rate of return of 5 per cent). Conversely, to be financially viable, enrichment planting required a higher stumpage rate than existed at the time, as well as substantial reductions in costs (of around $60 per hectare).

With the exception of Florence (1968), who examined the role of blackbutt in east coast forests generally, the ecological effects associated with enrichment planting were not discussed in the papers reviewed. Florence cautioned that any attempt to artificially increase the proportion of blackbutt stems in native forests needed to be evaluated in terms of the sensitive ecological relationships between the frequency of blackbutt in stands, and the physical attributes of sites influencing water availability. He further considered that unless markets for small product sizes were available, blackbutt should not be established on sites where it does not occur naturally, and which are defined by clear ecological boundaries. Doubts were also expressed by Florence (1970) concerning the extent of the potential yield of high quality blackbutt timber when the species was planted on poorer quality sites.

4. HARDWOOD PLANTATIONS

4.1 MAIN PLANTATION SPECIES

The species mentioned in the literature in relation to hardwood plantations in south-east Queensland are primarily eucalypts, including rose gum *(Eucalyptus grandis)*, blackbutt *(E. pilularis)* , Gympie messmate *(E. cloeziana)*, grey box *(E. hemiphloia)*, narrow-leaved ironbark *(E. crebra)*, red ironbark *(E. sideroxylon)*, Sydney blue gum *(E. saligna)*, red mahogany *(E. resinifera)*, tallowwood *(E. microcorys)*, Dunn's white gum *(E. dunnii)*, and spotted gum *(Corymbia citriodora).*

TABLE 5: COMMERCIAL PLANTATION TIMBER SPECIES IN SOUTH-EAST QUEENSLAND

Common name	Botanical name
blackbutt	*Eucalyptus pilularis*
blue gum (Sydney) (Tasmanian/southern)	*E. saligna* *E. globulus*
Dunn's white gum	*E. dunnii*
grey box	*E. hemiphloia*
Gympie messmate	*E. cloeziana*
narrow-leaved ironbark	*E. crebra*
red ironbark	*E. sideroxylon*
red mahogany	*E. resinifera*
rose gum	*E. grandis*
spotted gum	*Corymbia citriodora*
tallowwood	*E. microcorys*

4.2 HISTORY AND CURRENT MANAGEMENT PRACTICES

The Department of Primary Industries–Forestry began establishing eucalypt plantations in the 1930s and currently has about 1800 hectares, of which about 1100 hectares are located in the south-east Queensland CRA region. The eucalypt plantations are predominantly rose gum, blackbutt and Gympie messmate, and were generally established on degraded farmland, cleared of regrowth, rotary-hoed and planted at stockings of 1000 to 1500 stems per hectare. They were established to supply the then-existing timber packing case and small sawlog markets.

Plantation eucalypts were frequently attacked by leaf eating psyllid insects (particularly lerps), in consecutive seasons, greatly reducing growth. Wood borers (Xylorictids) caused severe damage to rose gum, greatly reducing the commercial value of the timber. A study of the severity of attack showed that rose gum is particularly susceptible to borer attack when planted 'off site' (that is, in areas outside its normal ecological range).

The Department of Primary Industries – Forestry abandoned eucalypt plantation establishment in the mid-1960s, due to a combination of three factors: a lack of markets for the thinnings, the poor performance of rose gum and blackbutt planted off site, and the difficulty of sawing the small eucalypt logs, the wood from which was prone to splitting and warping. Economic resources were concentrated on establishing the more productive *Pinus* species in plantations.

However, since the mid-1980s there has been increasing interest in hardwood plantations and Primary Industries - Forestry has a draft Strategy for Hardwood Plantation Research and Development. The strategy recommends concentrating further research on Gympie messmate, Dunn's white gum, blackbutt, red mahogany, tallowwood, spotted gum, western/Chinchilla white gum *(E. argophloia)*, and yellow stringybark *(E. acmenoides)*, which have all shown promise in south-east Queensland.

There is currently little information on the ecological impacts of hardwood plantation management within south-east Queensland.

4.3 PAST RESEARCH AND DEVELOPMENT

A total of 21 papers on hardwood plantation silviculture were reviewed (Tables 6 and 9 [Appendix 3]).

TABLE 6: PAPERS REVIEWED ON HARDWOOD PLANTATION SILVICULTURE, BY SUBJECT AND BY YEAR#

Main subject	Number of papers reviewed	Year of publication			
		Pre -1970	*1970-1980*	*1980-1990*	*Post-1990*
Species selection	9	1	0	3	5
Establishment, site preparation, and thinning	4	0	1	2	1
Fertilising	6	0	0	3	3
Genetic improvement	1	0	0	0	1
Pests	1	0	1	0	0

Note: Literature concerned with ecological impacts is not included in this table

4.3.1 Species selection

The nine papers reviewed in relation to species selection considered a wide variety of species, including non-eucalypts (Ryan & Bell 1989, Hawkins 1961). All but two of the papers (West & Mattay 1993, Cromer 1996) were concerned with determining eucalypt species suitable for plantation cultivation in south-east Queensland.

Hawkins (1961) provided a progress report on 11 years of species trials carried out in the Darling Downs region designed to assess the use of trees for a wide range of uses, including woodlots. Although the results were considered preliminary, species recommended for woodlots included grey box, narrow-leaved ironbark and red ironbark. The report did not include either the location of the markets or a list of the timber products considered, and no further reports on these trials appear to have been published.

Rose gum, a south-east Queensland species, and the closely related Sydney blue gum, are the species most widely planted in subtropical zones on the east coast of Australia (Cromer 1996, Florence 1996). Research initiated by the Shell Company of Australia and undertaken jointly by the Queensland Forest Service (now DPI–F) and CSIRO, investigated the potential growth rates of a number of species, mainly eucalypts, on different soils under various fertiliser regimes (Cromer et al. 1991). The study involved an analysis of climate and soils for an extensive area of land between Coffs Harbour and Cairns. Each of the six sites selected for the species-provenance trials contained up to 15 species, although no list of the species trialled was included in the paper. This research concluded that blue gum was the best tree for fast-growing pulpwood plantations over a wide range of sites (ibid.).

Anderson (1983b) examined a range of eucalypt species, tree spacings and silvicultural treatments at Tuan in south-east Queensland, and concluded that blackbutt was the most productive of the hardwoods trialled, and that its growth compared favourably with slash pine (an exotic softwood species) up to 15 years of age. While not stated by the author, it is presumed that the growth of slash pine exceeded blackbutt from age 15. However, more recently Florence (1996) has suggested a cautious approach to the planting of blackbutt, pointing out that its natural distribution within the east coast forests indicates it does not occur on sites where it would be subject to severe water stress, or where pathogenic and other harmful organisms are active. Similarly, research into rose gum by Ross and Thompson (1991) determined that its natural distribution implied it was most competitive in soils of at least moderate fertility, especially in relation to their nitrogen, phosphorus, potassium and calcium status.

An indication of the potential for eucalypt plantations in south-east Queensland was provided by Ryan (1993), who stated that early growth trials (planted from the 1940s) of red mahogany, tallowwood, Gympie messmate and rose gum yielded merchantable standing volumes ranging from 6.6–29.3 cubic metres per hectare per year, despite inadequate site preparation, weed control, fertilising, thinning, and no genetic improvement. He concluded that there was considerable capacity to achieve better growth than had been realised in the past.

Trials near Gympie involving 148 Australian species, including species other than eucalypts, found that a number of species previously unknown in cultivation showed fast growth rates (Ryan & Bell 1989). The trial included the wattle species *Acacia cincinnata, A. crassicarpa. A. deanii, A. flavescens, A. plectocarpa* and *A. nerifolia,* all of which showed growth comparable with better known commercial species such as *A. mearnsii, A. melanoxylon,* as well as river red gum *(E. camaldulensis)* and rose gum. These trials also revealed substantial variation both between and within provenances of some species. These trials were primarily established to assess the potential of these species for fuelwood, and did not look at their suitability for wood production.

As the economic viability of particular species in plantations is closely linked to establishment, site preparation and thinning activities, this aspect is discussed in the next section.

4.4 ESTABLISHMENT, SITE PREPARATION AND THINNING

Three of the four papers (McIntyre & Pryor 1974, Schonau 1984, Bonny 1991) dealing with establishment, site preparation and thinning were concerned with the potential of rose gum as a plantation species. Two of these studies (McIntyre & Pryor 1974, Bonny 1991) concerned trials carried out in Coffs Harbour (northern New South Wales), while the third (Schonau 1984) outlined experience in South Africa.

Determining effective tree spacing in hardwood plantations, both at establishment and subsequently through thinning operations, is not a simple matter. Factors which must be taken into account include the desired product (for example, sawlogs or pulpwood), available capital and the characteristics of both the site and the particular species. This decision on spacing also influences the rate of plantation growth and subsequent branch size. In many places, including south-east Queensland, the absence of a market for potential thinnings has been a strong influence on silviculture and the rate of plantation establishment.

In addition, Anderson (1983b) – a paper reviewed under the ‘species selection’ section (1.3.1) of this report – also looked at establishment spacing in south-east Queensland. This paper looked at blackbutt, Gympie messmate and rose gum. This study concluded that pulpwood crops of hardwood species might be established on the coastal lowlands of southern Queensland with a 10–12 year rotation period, provided trees were spaced no less than 3 metres apart, and adequate site preparation (including mound ploughing) and fertilisation was undertaken.

Florence (1996) indicated that a wide spacing pattern, such as 4.5 metres by 4.5 metres (500 stems per hectare), might be considered in some circumstances. Such circumstances might apply with a species such as rose gum, which cannot tolerate shade from surrounding trees and which, due to a lack of markets for thinnings, might not be thinned until 15 to 25 years of age. Florence also suggested that the possibility of either a non-commercial or an early commercial thinning might enable an initial spacing of around 3 metres by 2.5 metres (equating to 1300 stems per hectare). However, he cautioned that if planted too widely apart on low to moderate quality sites, rose gums can branch excessively, increasing the frequency of knots in the timber and therefore decreasing its financial value.

Spacings of 3 metres by 2 metres (1667 trees per hectare) on better sites, and 3 metres by 2.5 metres (1333 trees per hectare) on below average sites have been recommended for rose gum in South Africa (Schonau 1984). However, no evaluation of the effectiveness of this spacing regime under Australian conditions was found.

Only two papers (Greve & Garthe 1983, Ryan 1993) specifically looked at the financial aspects of plantation establishment, and both papers referred to trials in south-east Queensland. Greve and Garthe (1983) established that at an interest rate of 5 per cent, 25-30 year rotations for high value Gympie messmate poles on both good forest sites and disused farmland managed by farmers would be viable, but that high overheads (up to 113 per cent of direct costs) rendered 20-year rotations on forest sites uneconomic. On disused farmland, it was considered that rotation periods as short as 20 years could be achieved, as cleared land would reduce the establishment costs and farmer's overheads were lower (estimated to be around 20 per cent). Value per hectare was found to be highest at lower stockings of around 75 stems per hectare. Using a sensitivity analysis of factors affecting (primarily pulpwood) plantation economics, Ryan (1993) concluded that returns were sensitive to productivity, rotation length, stumpage and interest rates, but were not sensitive to the total costs of establishment. These somewhat conflicting results may reflect the higher costs associated with the establishment of high value pole plantations (with fewer stems per hectare), versus the economies of scale that can be achieved in pulpwood plantations (with a higher stand density).

With the exception of Ryan and Bell (1989), who found that some of the species trialled showed the potential to become weeds, none of the papers looked at the ecological effects of plantation establishment activities.

4.5 FERTILISING

Fertiliser use was specifically considered by seven papers, four of which looked at the response of rose gum to the application of fertilisers in plantation situations (Cromer et al. 1981, Birk & Turner 1992, Cromer et al. 1993a,b). Only two of the studies (Cromer et al. 1993a,b) were specific to south-east Queensland, while another (Birk & Turner 1992) was undertaken at Coffs Harbour. A study by Schonau and Herbert (1989) reviewed the effects of fertilising eucalypts at plantation establishment in a range of countries, including Australia.

For any species, the main avenue for increasing yield is to exploit the full site potential by improving soil conditions, particularly at the time of planting. However, the eucalypt response to fertilisers is complex, and optimal results may only be achieved where all aspects of establishment are complementary and properly carried out (ibid.). As an example of this complexity, Cromer et al. (1981) found that fertilisers produced different responses in Tasmanian/southern blue gum (*E. globulus*) when grown in different environments using seed from a single source.

Low nutrient availability due to infertile soils was identified as a major factor limiting the growth of eucalypt plantations in Australia (Cromer et al. 1991 and 1993a). Best results have been achieved through the application of nitrogen and phosphorus fertilisers at or soon after planting (McIntyre & Pryor 1974, Cromer et al. 1981, Schonau & Herbert 1989); however, the response has been observed to decline with age (Birk & Turner 1992). Repeat fertiliser applications are recommended at thinning in order to maintain initial growth responses (Birk & Turner 1992). Cromer et al. (1993b) considered that for hardwood plantations established on former agricultural sites, the addition of fertiliser should be a normal part of management practice, rather than a measure to be undertaken after soil reserves run down.

Cromer et al. (1991) determined that after 18 months, fertilised rose gum at Toolara (in south-east Queensland) reached a mean dominant height (height of the tallest 150 stems per hectare) ranging from 6.9–8.9 metres, while basal area (the horizontal cross sectional area of stems at 1.3 metres above ground level) varied from 4.0–5.8 square metres. This study was followed by a two-part study designed to determine the main environmental factors that might limit the growth of rose gum in sub-tropical Australia (Cromer et al. 1993a,b). In these studies, fertilisers were applied at regular intervals during the first three years after planting. Quantities applied over the three years included 1536 kilograms per hectare of nitrogen and 461 kilograms per hectare of phosphorus. The mean annual increment in volume in fertilised plots at the age of three years was found to have reached 34.2 cubic metres per hectare per year – the highest growth rate reported from any plantation in Australia at the time, for trees of that age. However the quantity of fertilisers used in these experiments was extremely high, and was considered to be beyond the biological or economic optimum (Cromer et al. 1991). By way of comparison with these results, trees from the same seedlot in plots without fertiliser were found to have produced a mean annual increment of only 6.1 cubic metres per hectare per year (Cromer et al. 1993a,b). A similar conclusion was reached by Birk and Turner (1992), based on experiments involving rose gum near Coffs Harbour. Their research indicated that productivity could be more than doubled in less than 10 years through intensive fertilisation and control of *Acacia*.

While soil water availability is considered a significant factor limiting tree growth (Stone 1982, Schonau & Herbert 1989), research involving irrigation, fertiliser applications, and a combination of both found no response to irrigation, and no interaction between fertiliser application and irrigation (Cromer et al. 1993a, b).

There is little information regarding the impacts of fertilising that is specific to hardwood plantations in south-east Queensland. The general impacts of fertiliser use are addressed in the softwood plantations chapter (Fertilising: ecological impacts). Only two of the reviewed studies (including one two-part study – Cromer et al. 1993a, b) explicitly mentioned the possible ecological effects of fertiliser application. While fertilisers can replace nutrients removed through harvesting, Birk and Turner (1992) consider that the effects of high rates of uptake by plantations on site buffering capacities require further investigation. Significantly, the emphasis of the rose gum trials established by Cromer et al. (1993a, b), which led to such high growth rates, was on ensuring that growth was not limited by a lack of nutrients. As a consequence, the authors concluded that the quantities used were likely to exceed the biological optimum.

No research specific to south-east Queensland was found to quantify the financial viability of fertiliser application. However research overseas found that at harvesting age improvements in yields from fertilising various *Eucalyptus* species ranged from 20–40 per cent on an 8–10 year rotation, while the real internal rate of return on fertilisation costs vary between 15.4–41.0 per cent per year (Schonau & Herbert 1989).

4.6 PESTS

Although only one paper was found which specifically dealt with pest damage in plantation-grown eucalypts (Carne et al. 1974), many papers mentioned pests to some degree.

In an investigation of insect damage to plantation-grown eucalypts, including Dunn's white gum and rose gum, at Coffs Harbour, Carne et al. (1974) found that plantations established on converted farmland were extensively grazed by beetles emerging from the old grasslands. However this grazing declined as the trees grew older and the structure of the plantation changed (ibid.). Rose gum, southern blue gum, and Dunn's white gum have also been found to be susceptible to damage from foliage feeders and wood borers in south-east Queensland (Anderson 1983b, Ryan 1993).

A number of ways of minimising losses from these pests were suggested in the literature, including the use of silvicultural practices to accelerate the growth of the trees in order to shorten the period in which they are susceptible, through to the planting of susceptible sites in years in which beetle numbers are low (Carne et al. 1974). Thinning and pruning were also suggested as means of minimising the risk of infection by foliage pathogens, by improving air circulation in the crown of the trees (Ryan 1993).

5. SOFTWOOD PLANTATIONS

5.1 MAIN SOFTWOOD PLANTATION SPECIES

The main exotic softwood plantation species mentioned in the research reviewed were Caribbean pine *(Pinus caribaea)*, slash pine *(P. elliottii)*, loblolly pine *(P. taeda)* and F_1 and F_2 hybrids of *P. elliottii* x *P. caribaea*. Hoop pine (*Araucaria cunninghamii*), a species native to south-east Queensland, has also been established in plantations, and has been the subject of research.

The current area of softwood plantations (both exotic and native), is about 180 000 hectares, of which the largest area comprises exotic pine species. Of the exotic pines, the most extensive plantings have been slash pine. More recently, Caribbean pine and Caribbean/slash pine hybrids are the most commonly planted.

5.2 RESEARCH AND DEVELOPMENT

Ninety-two papers were reviewed on softwood plantation development (Tables 7 and 10 [Appendix 4]).

TABLE 7: PAPERS REVIEWED ON SOFTWOOD PLANTATION SILVICULTURE, BY SUBJECT AND BY YEAR#

Main subject	Number of papers reviewed	Year of publication			
		Pre -1970	*1970-1980*	*1980-1990*	*Post-1990*
Species selection	7	0	2	5	0
Seed collection / seed orchards	1	1	0	0	0
Nursery practice	11	0	6	1	4*
Thinning	11	1	3	6	1
Fertilising	8	0	1	0	7*
Establishment, site preparation, and planting	20	1	0	10	9*
Weed control	3	0	0	1	2
Genetic improvement	20	3	2	5	10*
Pests and disease	4	1	0	2	1

* Papers predominantly sourced from various DPI–F internal conference proceedings (Department of Primary Industries - Forestry 1993 a&b, 1994 & 1995).

Note: Literature concerned with ecological impacts is not included in this table

Most of the material reviewed was published; however, internal Department of Primary Industries—Forestry publications were also reviewed. The department considers some of its recent softwood research to be commercially sensitive, a standard industry position, and therefore did not make it available for review. This restriction limits the effectiveness of any literature review, in that apparent ‘gaps’ identified in research and development activities may in fact be the subject of ongoing commercially sensitive studies.

5.2.1 Species selection

Four of the seven papers reviewed on the subject of species selection were concerned with slash pine, Caribbean pine or a hybrid of the two (van Allen 1979, Lewty 1989 and 1990, Simpson 1990). The remaining papers dealt with trials of klinki pine *(A. hunsteinii)* (Bragg 1979), chiapensis pine *(P. strobus* var. *chiapensis)* (Nicholson & Bragg 1980), and Guadalupe Island pine *(P. radiata* var. *binata)* (Huth 1982).

Species and provenance trials of exotic pines commenced in Queensland in the 1930s. However it was not until 1952 that there was a rapid expansion of the research program into grafting techniques, selection, pollen dispersal, seed-orchard establishment, controlled pollination and progeny testing (Ryan 1990).

Lewty (1989) observed that the geographic locations in which a particular species may be successfully cultivated in plantations will largely reflect the edaphic and climatic conditions governing the species’ natural distribution. This observation is supported by trials involving klinki pine, chiapensis pine and Guadalupe Island pine in south-east Queensland, all of which have proved unsuccessful (Bragg 1979, Nicholson & Bragg 1980, Huth 1982).

The importance of Caribbean pine increased with the realisation that it could outgrow slash pine by a margin of 20–40 per cent on well-drained sites in sub-tropical areas (Francis & Shea 1991). While slash pine is better suited to conditions of poor soil drainage than Caribbean pine, a hybrid of the two was found to combine the fast growth rate of the Caribbean pine with the better form and tolerance to waterlogging of slash pine (Slee 1969, Simpson 1990, Lewty 1990).

Only one study addressed the financial viability of the different species. In a comparison of growth between slash pine and Caribbean pine established in the 1950s on uncultivated sites, van Altena (1979) found that at age 21 years, Caribbean pine produced 20 per cent greater merchantable volume (though the actual figure in cubic metres per hectare was not specified), except on wet sites. Valuing all stems above 22 centimetres diameter as sawlogs, and stems 12 to 22 centimetres diameter as pulp logs, the margin favouring Caribbean pine was 84 per cent (ibid.). A weakness of this study appears to be that the slash pine seed was collected from the best of locally grown plantation trees, whereas the Caribbean pine was sourced from imported bulk collections from natural stands in Belize (central America). It is not clear to what extent modern establishment, site preparation, and fertiliser regimes might vary these conclusions.

The selection of exotic pine species for softwood plantations may significantly affect Queensland fauna. Exotic pines represent a relatively unsuitable vegetation type for Australian fauna, which have long been recognised as having limited ability to use the environment provided by exotic pine plantations (Barnett et al. 1976, Friend 1980, McIlroy 1978, Pattemore 1985, Suckling 1982, and Porter 1980). Studies specifically within south-east Queensland have also found that proportionally few species are found in exotic pine plantations in comparison to areas of native vegetation, particularly when the plantations are established on wet sclerophyll forest sites (Pattemore 1985, Schulz 1994, and Porter 1980). Pine plantations provide few structural features that birds can use. (Schulz 1994). There are few nesting hollows and an obvious lack of nectar-producing trees or shrubs (Porter 1980, Pattemore 1985); as a result bird species with exacting habitat requirements are not readily found in pine plantations in south-east Queensland. Studies in exotic pine plantations on the coastal lowlands of south-east Queensland indicate that only about half of the native mammals, reptiles and amphibians use pine plantations in comparison to adjacent areas of native forest

(McIlroy 1978, Suckling, 1982 and Queensland Department of Forestry, 1974). Further, the species occurring in plantations tend to be the more robust generalists, or species that undergo a niche shift in order to use the modified environment (Pattemore 1985).

It is believed that the long-term conservation of species, especially within areas dominated by exotic pine plantations, may be dependent upon the retention of native vegetation in the form of ‘scrub breaks’ (Queensland Department of Forestry 1974; Friend 1980, Schulz 1994). The maintenance of scrub breaks in hoop pine plantations is recommended by Fisher (1980). Such breaks, which would remain undisturbed by prescribed burning, silvicultural and harvesting practices, could provide critical habitat for native species such as black-breasted button-quails (Flower et al. 1995, Smith et al. in press), and marbled frogmouths (Smith et al. in press), especially along gullies and watercourses (Friend 1980; Schulz 1994). However, hazard reduction burns in exotic pine plantations serve to maintain a structurally simplistic environment which can preclude the use of the plantation by many bird species (Pattemore 1985).

As hoop pine is a species native to the south-east Queensland region, plantations of this species in general are able to develop and support a more diverse vegetative understorey and tend to be more suitable for native fauna than exotic pine plantations (Queensland Department of Forestry 1974).

5.2.2 Seed collection/seed orchards

Only one study (Florence & McWilliam 1954) dealing with seed collection and seed orchards was found. This early research concentrated on the influence of spacing on cone and seed production for loblolly, hoop and slash pine, principally the latter. A spacing of 7.3 metres by 7.3 metres was suggested for seed orchards of slash and hoop pine, representing a compromise between maximal cone production per hectare and maximal cone production per tree, although the authors cautioned that maximal seed production varies with the age and development of the stand. A strength of this study was that it provided estimates of seed production both for single trees, and stands, at optimum spacing. However the research is now 44 years old and the effect of modern silviculture, such as improved genetic stock, site establishment practices, and fertiliser use, on these conclusions is not clear. No financial analysis was carried out in the study.

5.2.3 Nursery practice

Of the 11 papers reviewed, seven looked at Caribbean pine or a hybrid of Caribbean pine and slash pine, two concerned slash pine (Bacon et al. 1977, Simpson 1978), and the remaining two focussed on hoop pine (Lewty et al. 1993a, b).

Exotic pine nurseries in south-east Queensland operate on a three-year rotational cropping system, and aim at the production of physiologically-hardened (that is, conditioned to withstand some degree of frost and moisture stress) bare root planting stock of around 35–40 centimetres height for winter planting. Seedlings are monitored to ensure they receive adequate nutrition and water, and are also subject to conditioning treatments of root severing and topping. For Caribbean pine, root severing (involving limited severing of the roots to slow down root development), and topping (trimming off the tops of seedlings to ensure uniformity of size for machine planting), is carried out.

The economics of Caribbean pine plantation establishment rely on field-cultivated, open-rooted (no soil on the roots) stock for planting out, in preference to tubestock or container-grown stock. Unlike slash pine, Caribbean pine does not produce a true dormant bud, and therefore continues growing through winter. To overcome this, the technique of ‘root wrenching’ (root severing) was developed. Survival of open-rooted Caribbean pine was found to increase with increased frequency of root wrenching prior to lifting (removal from the nursery grounds). However too much conditioning can be detrimental to field performance. Advantages of root wrenching include reduced shoot growth, an increased root/shoot ratio, and improved root production (Bacon & Hawkins 1977, Huth & Baxter 1994, Francis & Shea 1991). Research by Bacon and Hawkins (1997) led to the development of nursery techniques that permitted successful open-root planting of Honduras Caribbean pine *(Pinus caribaea* var. *hondurensis),* eliminating the final barrier to the acceptance of this species of pine in the Queensland plantation program. Dipping the seedling roots in a clay slurry after lifting , combined with machine planting also increased field survival (Shea & Armstrong 1978, Bacon et al. 1977, Bacon & Bachelard 1978). The practice of topping seedlings back to a height of 26–30 centimetres three to four months prior to field planting, aids machine planting by restricting seedlings to an ideal size for the equipment used (Shea & Armstrong 1978).

A nutrition regime for a slash pine nursery at Beerburrum was based on the replacement of nutrients lost through leaching and removal of nursery stock (Simpson 1978). The regime involved the application of an inorganic fertiliser containing 215 kilograms of nitrogen, 36 kilograms of phosphorus, 123 kilograms of potassium, 56 kilograms of calcium, and 22 kilograms of magnesium. However the extent to which these recommendations are uniformly applicable to slash pine nurseries is not clear.

A directed glyphosate application combined with a selective knockdown herbicide grass control regime was found to be an effective post-emergent weed control strategy in Caribbean pine nurseries. However as Caribbean pine seedlings less than 24 weeks of age are sensitive even to very low doses of glyphosate, it was recommended that glyphosate be applied using a technique which avoids splashes or drift, such as wick type or spot applicators be used (Costantini et al. 1989).

In coastal south-east Queensland, best results for Caribbean pine in the nursery have been achieved by sowing in late July/early August, and planting out in late May to early August (Shea & Armstrong 1978). Research leading to the successful cold storage (3–4 degrees Celsius) of open-rooted seedlings in sealed containers for one month after lifting was also significant, providing forest managers with the flexibility to successfully store stock until planting conditions are favourable (Ward et al., 1993). However Shea and Armstrong's research was unable to determine the extent to which poorer post-planting performance of stock subjected to seven months cold storage was attributable to the storage, or exposure to more severe conditions in the field.

The field performance of hoop pine container-grown stock has been found to be comparable with tubestock of a similar size at planting, and the advantages of container stock are considered to outweigh any disadvantages. However, the later age development of large tubestock was found to be superior to that of average-sized container stock (Lewty et al. 1993a,b). Although the prescriptions used to evaluate the container-based hoop pine nursery system (Lewty et al. 1993b) was based on experimental work carried out 10–12 years earlier, the evaluation of the field performance of this stock (Lewty et al. 1993a) was limited by the fact that large block plantings of container stock raised under this operational prescription had not been carried out.

The financial aspects of nursery practices were considered by four papers (Bacon & Hawkins 1977, Bacon et al. 1977, Costantini et al. 1989, Lewty et al. 1993b). The first three of these dealt with Caribbean pine costs, while the fourth was concerned with hoop pine. The financial advantage of open-rooted Caribbean pine stock over tubestock is highlighted in the early research by Bacon and Hawkins (1977). In 1974, they found that 750 000 tubed Caribbean pine seedlings were raised for 47 dollars per thousand while comparable figures for open-rooted stock were 6 300 000, and 7 dollars per thousand. Although Costantini et al. (1989) did not quantify their conclusions in dollar terms, they did indicate that the introduction of selective knockdown herbicides had significantly reduced weed control costs in the nursery. Research by Lewty et al. (1993b), established that the costs of propagating hoop pine compared favourably with the costs of producing container cuttings of exotic pines, and predicted there was potential for further cost savings in the future.

5.2.4 Establishment, site preparation and planting

Most of the 20 studies reviewed examined combinations of slash pine, Caribbean pine or the F_1 hybrid (Costantini & Grimmett 1994, Lewty et al. 1994, Huth & Robinson 1994, Walker 1994), slash pine (Pegg 1967, Francis et al. 1984), Caribbean pine (Lewty & Francis 1982, Francis 1983, Costantini & Foster 1987) and hoop pine (Holzworth 1980, Dale & Johnson 1987). The remainder of the papers considered either a mix of species or were of a more generic nature.

Knowledge of site capability provides useful input into the selection of site preparation systems and design, taxon selection, and fertiliser prescription. Site classification for *Pinus* plantation development uses edaphic information to make inferences about the physical, chemical and biological processes of a site that affect productivity. Soil types are used to determine taxon suitability and drainage requirements (Foster & Costantini 1991).

A classification for hoop pine was developed by Primary Industries —Forestry in which soil types are grouped into three productivity classes based on inherent soil fertility and structure, ranging from class A (most productive) to class C (least productive). There is broad correlation for hoop pine plantations between site index, soil type and annual rainfall that can be used to predict site index limits of unplanted areas. Use of modern management techniques such as better weed control and improved seed and provenance stock have the potential to increase site index (Holzworth 1980). A major strength of this site index research by Holzworth (1980) is that it was derived from plots measured over a 10-year period.

For both slash and Caribbean pine, cultivation by ploughing and plough-mounding have been found to be as effective in survival, growth, and ‘windfirmness’ as the more expensive deep or shallow ripping (Francis & Bacon 1983, Francis et al. 1984). Mounding assists drainage and cultivation results in more uniform plantations and earlier canopy closure. It is considered that site preparation should closely precede planting out (Francis 1984, Costantini & Foster 1987). Further, increasing the size of the mound profile permits the successful establishment of Caribbean pine on wet sites (Bacon et al. 1982).

For site preparation on second rotation hoop pine sites, planting lines are pushed through harvesting debris with a bulldozer fitted with a ‘V’ blade in areas of relatively level sites (less than 10–12 degrees slope). On steeper country, the logging debris is burnt under mild conditions, with cereal cover crops established in the inter-row area to stabilise the freshly exposed soil (Dale & Johnson 1987). Costantini et al. (1997) reviewed the current site preparation systems in hoop pine plantations on steep country, based on ‘bulldozer push and burn’ and ‘broadcast burn’, and suggested alternative management practices involving residue retention and mulching. The aim of these alternatives is to improve the soil physical environment and protect against erosion and degradation of soil chemical processes.

All exotic planting is carried out in late autumn and winter (Ryan 1990). However for the F_1 hybrid, planting in January to April has been found to maximise initial growth (Lewty et al. 1994) although the parameters for planting under correspondingly drier conditions are not well understood (Huth & Robinson 1993).

Only six of the twenty articles reviewed considered the ecological impacts of site preparation to any degree. Costantini and Grimmett (1994) stated that the effects of site preparation operations on the soil will depend on:

- soil moisture and strength conditions at the time of site preparation;
- soil properties, such as texture, structure, and aggregate stability;
- site preparation equipment and techniques used;
- degree of organic matter incorporation / relocation achieved;
- the post-site preparation surface condition achieved (surface roughness, mound shape, and surface cover); and
- post-site preparation history (e.g. cover cropping, grazing, weed and cover reduction, fertilizing and mechanical operations).

The importance of site assessment in defining site capability and assessing the potential to reduce erosion through plantation design was stressed by Foster & Costantini (1991a,c). The development of site preparation classes for *Pinus* plantations is described as an attempt to optimise productivity, within the constraints of minimising soil loss, and not exceeding a prescribed tolerable soil loss (Foster & Costantini 1991b). Osborne et al. (1994b) acknowledged that site preparation is likely to play a key role in plantation sustainability and consider that an understanding of the major limitations for each soil class is essential for the management of long-term sustainability. Costantini et al. (1997) considered that residue retention and mulching in second rotation hoop pine plantation establishment can improve the soil physical environment and protect against erosion and degradation of soil chemical processes.

Salinity has developed in coastal regions near Maryborough, Bundaberg and Byfield following large-scale plantation establishment of slash and Caribbean pine, and has the potential to become a serious problem in south-east Queensland (Thomas et al. 1980, Bevege & Simpson 1981). Problem sites are associated with Cainozoic deposits, usually Quaternary alluvia overlaying tertiary sediments. Site surveys are necessary to identify problem areas prior to establishment, and these present additional establishment costs. Research into this problem is aimed at the identification of salt tolerant species, and prediction and assessment of probable hazard areas (Bevege & Simpson 1981).

The establishment phases of softwood plantations within south-east Queensland, including site preparation and road construction, may have significant environmental effects in the form of surface soil loss, watershed degradation and reductions in runoff and stream water quality (Costantini et al. 1993b, Cassells et al. 1982). This phase of a softwood plantation is a critical period for accelerated sheet and rill erosion as mineral soil is exposed due to low vegetation cover (Costantini et al. 1993c). Increased sediment loads in watercourses resulting from sheet and rill erosion will in turn contribute to gully and channel erosion of the watercourse (Cassells et al 1982, Costantini et al. 1993b).

The integrity of a watercourse is dependent upon the degree of disturbance, or lack of it, experienced by the riparian vegetation (Bunn et al.. 1998). Erosion within softwood plantations may be reduced by having ‘buffer strips’ to protect riparian zones (Cassells et al. 1982 ,Costantini et al. 1993a,b) and by avoiding snigging across watercourses.

Costantini (1988) suggests that soil condition, such as soil bulk density and soil strength, should be a major consideration in the management of pine plantations. Soil is sensitive to the use of heavy machinery. Poor tillage practice and compaction generally impair regeneration of vegetation (ibid.). Soil compaction may also increase runoff during rain due to a decrease in infiltration capacity (Langford 1977).

Examination of the financial aspects of softwood plantation establishment, site preparation, and planting was limited to an examination of soil survey costs (Osborne et al. 1994), hoop pine planting and site preparation methods, and practices (Ward et al. 1995, Costantini et al. 1997). In hoop pine plantation establishment operations on steeper slopes, the existing residue management systems (‘push and burn’ or ‘broadcast burn’ depending on slope and surface conditions) were found to cost less than alternatives involving residue retention and mulching. However this conclusion did not take account of the costs associated with under and over burning, or the real costs of environmental damage (Costantini et al. 1997).

5.2.5 Fertilising

Three of the seven papers reviewed on this topic examined the fertilising of hoop pine (Simpson 1995, Xu et al. 1995, Bubb et al. 1995), one looked at slash pine (Mannion 1977), and the remainder referred to *Pinus* species in general.

Simpson et al. (1994) considered that fertilising forest plantations is one of the most cost-effective silvicultural practices for increasing productivity and profitability.

Phosphorus has been recognised as the major factor limiting growth of exotic pine plantations on the coastal lowlands of south-east Queensland, and once this phosphorus deficiency is corrected, good growth responses to nitrogen are obtained by adding other nutrients (Lewty 1989, Simpson et al. 1994, Osborne et al. 1994a). Francis et al. (1984) found the addition of nitrogenous fertilisers (in the presence of added phosphorus) at establishment brought about improved root growth, and hence windfirmness, in slash pine planted on the coastal lowlands. Deficiencies of nitrogen, potassium and copper have also been found on sites such as podzols, and later-age (greater than about 13 years) fertilising of slash pine with phosphorus may be required if productivity is to be maintained (Simpson & Grant 1991). Simpson and Grant (1991) and Simpson et al.(1994), provided a comprehensive review of current fertilising practices in exotic pines, including rates, forms, method of application and timing of application. However, there is an increasing need for more sophisticated nutritional management to maximise productivity at minimal cost, maintain or improve site productivity in the long-term (that is, address sustainability), and ensure that adverse off-site consequences (such as fertiliser runoff) are minimised (Simpson et al. 1994).

While fertilising hoop pine at establishment has generally met with little success, the application of fertilisers to established plantations between the ages of five and thirteen years on marginal sites has been shown to improve productivity for up to six years (Lewty 1989, Xu et al. 1995). Nitrogen deficiency is a major factor limiting the development of hoop pine on marginal sites, and it is suspected that phosphorus deficiencies may be a secondary limiting factor (Simpson 1995, Xu et al. 1995, Richards & Bevege 1969).

Although fertiliser costs are acknowledged as a significant component of plantation expenditure (Osborne et al. 1994a), only one paper (Osborne et al. 1994) explicitly stated the magnitude of these costs, indicating that current expenditure for the application of mono-ammonium phosphate was around 100 dollars per hectare for new plantings of exotic pines. Xu et al. (1995) indicated that economic analyses are required to assess the profitability of using nitrogen fertilisers to optimise hoop pine stands before its use can be recommended.

Growth simulations using computer-based models have suggested increases in wood yield at the end of the rotation due to the addition of phosphorus are between 6 per cent and 14 per cent. Real rates of return on the money invested in fertilising were found to be between 9 per cent and 16 per cent (Simpson & Grant 1991).

There is relatively little information on the ecological effects of fertilising softwood plantations within south-east Queensland. The main concern is the potential for adversely affecting water quality. After application, fertilisers may leach into watercourses via drainage lines and overland flow (Campbell & Doeg 1989, Cornish 1989).

The potential contamination of streams by fertilisers is dependent on a number of factors. These include fertiliser mobility, rate of fixation by soil, rate of uptake by vegetation, application method and the proximity of drainage lines or watercourses to application sites (Cornish 1989). It has been recognised that broadcast fertiliser use, as opposed to spot application methods for example, could alter the amount of nitrogen leached into streams (Cornish 1989). In areas highly susceptible to soil erosion, fertilisers which are sorbed to soil particles could also enter watercourses via soil movement and stream sedimentation (Forestman & Associates 1997). This is of significant consideration for recently established or recently logged plantations.

The potential effects of increased nutrient levels in streams could include decreased water quality and potential eutrophication (excessive nutrients), decrease in habitat suitability for stream biota and changes in aquatic ecosystem function (Campbell & Doeg 1989). However, the addition of fertilisers to plantations in Australia generally occurs at a relatively low intensity and in consequence it is advocated that such use does not adversely affect watercourses, except when they are small and/ or unshaded, slow flowing or contain large amounts of organic matter (Department of Forestry–Queensland 1974, Campbell & Doeg 1989, Borg et al. 1988).

Current fertiliser prescriptions are designed to suit the major soil and site types generally encountered, so that special diagnosis and treatment will be required for atypical sites. It is likely to be some time before establishment or maintenance of fertiliser schedules can be adequately defined for all situations (Osborne et al. 1994; Simpson & Grant 1991).

5.2.6 Weed control

Weed control in exotic pine plantations can be divided into two main categories – those established on former native forest sites and those established on improved pasture grazing lands. In the former, exotic pines face competition from a range of woody weeds and some grasses, which are controlled by a combination of cultivation and herbicide application. Exotic pines are less tolerant of pastures than woody weeds and native grasses, and therefore face severe competition when planted on former improved-pasture grazing lands (Ryan 1990).

Of the four main studies reviewed on this topic, two dealt with exotic pines, principally the F_1 hybrid, one referred to hoop pine, and the remaining study was concerned with Caribbean pine.

In contrast to slash pine, newly established Caribbean pine is relatively tolerant of woody weeds, indicating that woody weed control in Caribbean pine may be unnecessary. Conversely, native grasses compete strongly with Caribbean pine, a fact that may have implications for the planting of Caribbean pine on improved pasture lands (Lewty & Francis 1982).

While grasses and cereals are used to reduce soil erosion and aid in weed management in hoop pine plantations, they also compete with the commercial crop for soil moisture and nutrients. Planting at a spacing of 5 metres by 2.4 metres, comprising a 3 metre weed-free zone oriented across the slope is therefore considered a compromise between growth and soil conservation in hoop pine (Costantini 1989).

For other commercial exotic species (including the F_1 hybrid), tended bandwidths of 3.4 metres have been recommended on previous pasture sites, with maintenance at less than 20 per cent weed cover for 12 months. At Byfield and Gympie, the importance of controlling woody weeds rather than grass has been shown to influence volume growth on first rotation sites (Keys 1993).

Analyses of the financial aspects of chemical versus non-chemical weed control, and the extent of weed control were covered in three of the papers reviewed. Costantini (1989), citing unpublished departmental data, states that a 3 metre wide weed-reduced plant zone for hoop pine is considered economically rational, in addition to being a compromise between production and soil conservation. A 1.8 metre wide weed-reduced plant zone during the first year of establishment has been suggested as an alternative to blanket application of the 3 metre band, as this will still maintain optimal growth. However a major economic consideration is whether the cost of maintaining an extra 1.2 metres of unnecessarily weed-reduced area in the first year exceeds the cost of extending the band to 3 metres in the second year (Costantini 1989). Keys (1994) found that maximising the growth potential of plantations of Caribbean and slash pine through the correct application of weed control prescriptions significantly improved financial returns. This paper advocated an increase in weed-reduced band width to 3.4 metres, with maintenance of weed cover at less than 20 per cent for 12 months. At a discounted interest rate of 6 per cent, Keys concluded that the best tending regimes (maximum weed control) will return around 200 dollars per hectare over that achievable with minimal tending regimes. Grimmett and Podberscek (1994) looked at non-chemical weed control alternatives such as mulching, cover cropping, grazing and biological controls, and concluded that it was difficult to place any single non-chemical alternative above herbicides in terms of convenience, economy and reliability.

Of the non-chemical measures considered, mulching and manual techniques were considered to have the highest costs, and grazing and biological control were considered least costly. Herbicide use was considered moderately costly (Grimmett & Podberscek 1994, Grimmett & Ward 1995). A limitation of this study was the fact that the analysis was carried out on a qualitative basis, as comprehensive cost data were not available for all the non-chemical alternatives considered.

Weed control in hoop pine plantations in the region has the potential to reduce the ability of such plantations to sustain fauna (Fisher 1975). A significant proportion of understorey in hoop pine plantations is threatened by misting applications of hormonal weedkillers to control *Lantana* (Fisher 1975). Understorey vegetation is important in providing habitat for birds and other fauna in pine plantations; therefore altering understorey composition is likely to affect the populations of fauna found in this habitat (Fisher 1975).

Although conclusive studies on the effect of herbicide application have not been undertaken in south-east Queensland, Langford and O'Shaughnessy (1977) suggest that herbicides may adversely affect water quality. Herbicides may sorb to soil particles and enter watercourses during soil erosion processes (Forestman & Associates 1997). Chemicals also enter watercourses through direct application to the water surface and spray drift (Langford & O'Shaughnessy 1997). The toxicity to stream biota is difficult to quantify; however, herbicides may affect growth and reproduction, with other potential long-term implications resulting from the bio-accumulation of chemicals in species higher up the food chain (Langford & O'Shaughnessy 1977). Campbell & Doeg (1989) suggested that herbicide contamination of watercourses may have significant impacts on species such as freshwater algae; however, more studies are needed to determine any potential harm. Herbicide contamination of streams may be limited or avoided by consideration of chemical choice, droplet size, weather patterns and avoiding spraying within buffer strips (Langford & O'Shaughnessy 1977).

From an ecological perspective, non-chemical alternatives to weed control in plantations were considered to have the highest sustainability in relation to the conservation of soil nutrients, moisture conservation, soil structure and erosion control (Grimmett & Podberscek 1994).

5.2.7 Thinning

Most of the 11 studies dealing with thinning were concerned with exotic pines, and most were written in the 1980s. Some of the research was based on long-standing experiments (Fisher 1978, Anderson, Bacon & Shea 1981) and investigated a wide range of tree spacings in hoop pine, from 2.9 metres to 4.9 metres (Robinson et al. 1971). Four papers dealt with thinning in hoop pine plantations (Robinson et al. 1971, Fisher 1978, Reilly 1981, Hogg & Nester 1991).

Hoop pine plantations were originally managed to produce maximum quantities of high quality wood with minimal sacrifice of volume production (Grenning 1957, in Hogg & Nester 1991). However this management regime was found to produce low unit area yields per thinning, in addition to small average stem volumes (Shea et al, 1979). Under current regimes, a commercial thinning, from 750 stems per hectare (at establishment) to 400 stems per hectare, occurs when the plantation is aged 25 years. The plantation's end-of-rotation harvest is planned to occur at 50 years. An alternative management practice is to thin the stands non-commercially (that is, remove stems unable to be sold because of their small size) to their final stocking at an early (unspecified) age (Hogg & Nester 1991, Reilly 1981). The former practice is the most widely adopted in current silvicultural management. An inverse relationship between thinning intensity, and both volume production and (financial) value production in hoop pine plantations was established by Robinson et al. (1971).

Commercial thinning schedules for exotic pine plantations were also directed at maintaining plantations at the lowest stockings that would yield maximum volume increment (Bevege 1972). As a result of research into the thinning of Caribbean pine in the early 1980s, it was determined that pre-commercial thinning maximised financial returns, while repeated commercial thinning did not (Anderson, Bacon & Shea 1981, Shea, Harvey & Anderson 1984). Much the same conclusion was reached by Hawkins (1971) with regard to slash and Caribbean pine plantations.

Of the seven papers that considered the financial aspects of thinning softwoods, three were written before 1980, three were carried out in the 1980s, and the remaining paper was written in 1991. Three of the papers deal with hoop pine (Robinson et al. 1971, Reilly 1981, Hogg & Nester 1991), two with Caribbean pine (Anderson et al. 1981, Shea et al. 1984), and the remaining two papers (Robinson 1969, Hawkins 1971) refer to both slash and Caribbean pine.

Hogg and Nester (1991) found that volume production in hoop pine peaked at around 1000 stems per hectare; however, under the pricing structure in use at the time, standing value production was found to peak at around 400 stems per hectare. They also stated that the pricing structure used to evaluate alternative stocking plays an important part in determining optimal stocking. For this reason, the conclusions drawn in many of the earlier studies are of limited use.

In Caribbean pine, Shea et al. (1984) examined a new regime featuring pre-commercial thinning only, development of zones for pulp and mill log production, wide inter-row spacing, and pruning only in areas in which mill logs were grown. While this new management regime was promoted as being more economically sound than ones being used at the time, it was acknowledged that the stocking which optimises value production is sensitive to pricing method. This study also found that the maxima for sawnwood volume, merchantable volume and value did not coincide under any pricing option (Shea et al. 1984).

5.2.8 Genetic improvement

Genetic improvement is an area of research considered to be particularly commercially sensitive by both the public and private sectors. As mentioned earlier in this chapter, this renders the tasks of gaining an insight into up-to-date research and identifying research and development gaps difficult to complete.

Substantial research has been undertaken by the forestry department, aimed at achieving genetic improvement of several commercially important plantation species, including Caribbean pine, slash pine, hoop pine, and a Caribbean/slash pine hybrid. The department consider that large genetic gains should be obtainable through mass selection, intensive selection of superior phenotypes and their cloning in seed orchards, use of mass pollination techniques, and mass cloning of superior trees (Nikles & Newton 1983, Nikles & Dieters 1986). The vegetative propagation of families (preferably clones) of hoop pine is also considered economically advantageous, although low multiplication rates prevent its widespread use (Haines & Walker 1993).

To date, hoop pine progeny trials have shown significant gains in stem straightness but smaller improvements in growth traits such as diameter and height. Of the exotic pines, the F_1 hybrid has shown particular potential, and has generally outperformed its parental species. On well-drained sites, the hybrid and derivatives differed only slightly from pure Caribbean pine, but clearly surpassed slash pine in both height and girth. On poorly drained sites, the hybrid and derivatives surpassed both parental species (Slee 1969). Later research by Powell and Nikles (1996) confirmed this result, and determined that the hybrid maintained its growth advantage over the range of sites studied, while straightness was intermediate between the parental species. While the growth and form of the F_1 hybrid cuttings are generally comparable with seedlings, there is some evidence they may rely more heavily on timely post-establishment fertiliser applications than seedlings (Walker 1994).

From a financial perspective, a 10 per cent gain in volume is considered achievable in hoop pine as a result of genetic improvements. In 1993, this was estimated to equate to around 600 dollars per hectare at establishment (Haines & Walker 1993). For the F_1 hybrid, volume gains alone suggest a discounted marginal value at establishment of 540 dollars per hectare for clonal forestry over family forestry (Haines 1993).

Examination of adverse ecological effects was limited to two articles which looked at the implications of genetic improvement on potential threats from pests and disease. Given that clonal forests will comprise only a limited number of genotypes, it is essential to use of numbers of clones sufficient to provide some genetic diversity in order to limit risks from pathogens and insects (Hood & Wylie 1993, Haines 1993).

The range of literature reviewed indicated the advanced status of research in Queensland relating to genetic improvement of softwood plantation species, particularly the exotics. A major strength of the research reviewed is the realisation that silviculture in the future should aim to be site-specific in order to fully capitalise on developments in clonal forestry (Lewty, Nester, Huth & Simpson 1993).

5.2.9 Pest and disease control

The establishment and management of monocultural (single species) plantations confers a number of market, silvicultural and economic advantages. The regular spacing of trees is also silviculturally advantageous in that it enables favourable economies of scale of operations, and facilitates mechanised planting and harvesting.

However monocultures can also have disadvantages in that they may provide a favourable environment for the widespread establishment and development of pests and diseases, particularly during periods of environmental stress (such as drought).

Considering the concentration of exotic and hoop pine plantations in south-east Queensland, little research on pests was encountered in the research. For example, the pine bark weevil *Aesiotes notabilis,* is endemic to Australian rainforests, with one of its natural hosts being *Araucaria* (which includes hoop pine) (Brimblecombe 1945), although Nikles (1973) observed that hoop pine is essentially free of serious pests. Similarly, the introduced bark beetle (*Ips grandicolis*) has been found in the slash pine plantations in south-east Queensland, and has the potential to cause significant economic damage.

The potential for increased susceptibility to pest and disease attack associated with clonal forestry in general, and the need to manage these risks, was acknowledged in the previous section. This is another area in which the published literature indicates that an increased research effort may be warranted.

The effect of specific fungi on both exotic and hoop pine plantations were the subject of three of the four papers reviewed. These can be divided into the Basidiomycetes Class of fungi *(Armillaria, Phellinus* and *Poria)* and the Ascomycetes Class (primarily *Rosellinia arcuata).* In hoop pine plantations, two fungi, *Phellinus* (Fomes) *noxius* and *Junghuhnia* (Poria) *vincta* , are considered the most important root rot pathogens, and can cause significant mortality. In the absence of appropriate control, the fungi gradually increase during a rotation, and carry over to the next one via logging debris (Bolland 1984 and 1985, Hood 1995).

Fungi of the genus *Armillaria* appear to be the main pathogen capable of causing significant damage in both young Honduras Caribbean pine and slash pine, and have the potential to cause considerable losses in second rotation plantations. A research project established to test a hypothesis that the severity of *Armillaria* root rot increased with application of ammonium nitrogen and decreased with nitrate nitrogen was discontinued due to successive years of high mortality due to causes other than *Armillaria* (Bolland 1985).

The fungus *Rosellinia arcuata* was discovered for the first time in Queensland in 1976, and pathogenicity tests proved it has the potential to kill seedlings of hoop pine, Honduras Caribbean pine and tallowwood. *Phytopthora cinnamomi* is another fungus known to cause lethal root rot in Queensland pine plantations (Bolland 1985).

Control of the Basidiomycete root rots should begin with control in the first rotation, and may be achieved by avoiding thinning, and treating stumps to prevent entry of the pathogen. In the absence of appropriate controls, second-rotation plantation establishment has the potential to increase the spread of these pathogens. Other methods applied to second-rotation conifers overseas range from delaying planting through to treating stumps with biological control agents. In the case of the Ascomycetes class of fungi, control strategies have not been applied to plantation conifers either in Australia or overseas, and it is yet to be ascertained if losses to the pathogen are significant enough to warrant control (Bolland 1985).

Although all of these pathogens and pests have the potential to cause significant financial loss, none of the papers reviewed quantified either the extent of the possible losses, nor the cost of alternative treatments. It appears that further research into this aspect may be warranted.

Of concern is the fact that other than the paper by Hood (1995), no recent research on pest and disease control was evident. Priorities for future research identified by Hood (1995) include studies to confirm the role of spores in establishing new disease centres in hoop pine plantations, trials to verify the efficacy of biological stump treatments, and excavation studies to enable extrapolation of the average true extent of an infection centre of *P. noxius* from above-ground symptoms.

6. CONCLUSIONS

In south-east Queensland a great deal of research has been devoted to softwood plantations, particularly of exotic species. In contrast, there are few published studies concerning silviculture in native forests and hardwood plantations. While most silviculture studies concerned with hardwood plantations were undertaken recently, most of those concerning native forests were undertaken before 1980. Overall, the substantial majority of studies were derived from research conducted on publicly owned (crown) forests.

In broad terms, the silviculture studies concerning native forests dealt with harvesting, thinning, burning and enrichment planting techniques in both wet and dry sclerophyll forests. The results appear to suggest that harvesting, thinning, and burning practices aimed at removing non-productive stems, reducing competition and promoting regeneration have the potential to increase the productive capacity of these forests. Although the conclusions varied between individual studies, this general consensus was true of both the dry sclerophyll spotted gum forests and the wet sclerophyll blackbutt forests.

The studies concerning hardwood plantations mainly dealt with species selection. These studies, although limited, appear to suggest that rose gum, blackbutt and Gympie messmate have the most potential for plantation cultivation in south-east Queensland. However, the studies reviewed did not generate sufficient information on effective silvicultural techniques for these species. To bridge this knowledge and information gap, Department of Primary Industries–Forestry has developed a draft Strategy for Hardwood Plantation Research and Development which identifies silviculture, genetic resources, forest protection and wood products as priority areas for research.

Studies on silviculture in softwood plantations have covered a wide range of aspects, including species selection, nursery practice, thinning, fertilising, establishment and site preparation, weed control, genetic improvement, and pest and disease control. The area of genetic improvement has particularly attracted a great deal of research. As a result, the Department of Primary Industries–Forestry now has genetically superior stock of several commercially important species (including Caribbean pine, slash pine, hoop pine and a Caribbean /slash hybrid). The techniques developed for nursery practice, site preparation, weed control, fertilising, thinning and residue management appear to be effective in enhancing softwood plantation productivity.

While the importance of practising ecologically sustainable forest management in both productive native forests and plantations has been now widely recognised, there is limited quantitative information on the relationship between the various silvicultural practices and their ecological effects. The limited ecological studies reviewed suggested that harvesting, thinning and prescribed burning could reduce the number of habitat trees and the range of food sources available to a number of species, change microclimates and cause habitat fragmentation.

The ecological studies reviewed also indicated that the adverse effect of harvesting can be reduced by a number of forest management practices. It is considered essential by many scientists that hollow-bearing trees be retained during harvesting in order to ensure the conservation of hollow-dependent fauna in logged forests. It is also considered important that seed trees be retained for regeneration of tree species required for foragers. In order to address the issue of habitat tree retention requirements, the Queensland Department of Natural Resources has developed a schedule “Trees to be retained for wildlife conservation” in the “Code of Practice for Native Forest Timber Production”.

This review suggests that forest management strategies should include a continuing commitment both to long-term ecological studies and to maintaining the flexibility required to improve the current silviculture practices as more scientific information becomes available. Priorities for research into the ecological effects of silviculture techniques should include well-designed, long-term, comprehensive and large-scale biodiversity studies in south-east Queensland, covering both flora and fauna. These studies should involve a commitment to the establishment of permanent plots and to long-term environmental and biodiversity monitoring and auditing. Such studies should span at least the term of one rotation or cutting cycle. It is also important that experimental studies be conducted in areas that are currently being harvested to quantify and evaluate the effects of different management practices and silvicultural treatments. This approach offers the immediate advantage of linking the management commitment and research focus to the issues most in need of resolution, namely, the effects of harvesting on biodiversity.

The review of published research undertaken in the native forests shows that few studies examined the cost effectiveness of the various specific silvicultural practices studied. The conclusions drawn from the financial analyses of early studies must be regarded with caution in view of the changes in costs and log price stumpage schedules that have occurred in the interim. The economic feasibility of silvicultural practices remains an important consideration and requires continual re-evaluation in the light of changing markets for timber products, changing utilisation standards (for example, the ability of industry to utilise smaller and lower quality logs), and changes in the pricing structure for those products.

It is recommended that while more studies are needed to develop silvicultural techniques that will enhance the productivity of the native forests and plantations in the south-east Queensland region, such techniques must be consistent with the principles of ecologically sustainable forest management. This means that future silviculture studies should also examine the short and long-term ecological effects of the techniques being evaluated.

It is recommended that priority be given to research into the following aspects:

For native forests

- Silvicultural systems that optimise the value of timber production. This research should also examine ecological effects, and impacts on conservation values. In particular it should consider further development of:
  - harvesting and thinning regimes combined with an evaluation of their financial viability
  - post-harvesting burning with the aim of identifying a frequency and intensity that maximises the potential for regeneration.

For hardwood plantations

- Silvicultural systems for sawlog production (most studies reviewed dealt with silviculture for pulpwood)
- Economics of various production regimes including consideration of greenhouse issues

- Development of effective weed control techniques (no studies dealing with weed control specific to south-east Queensland were found in the review)
- Genetic improvement focussing on potentially commercial species
- Spacing and thinning regimes for different end products
- Site preparation
- Nutrition regimes for different soil conditions
- Pest and disease control.

Most recent softwood plantation research carried out by forestry-related agencies is considered commercially sensitive. It is, therefore, difficult to make specific recommendations for research in relation to forest resource enhancement, in that ‘gaps’ apparent in the published research may nevertheless have been the subject of internal unpublished research. However, from the literature reviewed it appears that in south-east Queensland further studies in the following two key areas may offer opportunities to improve plantation productivity: developing fertiliser schedules to suit a wider range of atypical soil and site types, and improving pest and disease control in broad-scale softwood plantation activities. Given the commercial importance softwood plantations of in the south-east Queensland region, research into minimising or preventing threats from these sources may be required.

6.1 REFERENCES

Allen, P.J. 1985, *Estimation of genetic parameters for wood properties in slash pine in south eastern Queensland*, Research Note No. 41, Department of Primary Industries, Forest Service, Queensland, 14 pp. + app.

Allen, P.J. 1992, 'Selection indices for the genetic improvement of Caribbean pine to increase sawn timber production', *Australian Forestry*, vol. 55, pp. 90-95.

Allen Taylor & Co. Ltd, Hyne & Son Pty Ltd, Queensland Timber Board 1990, *Joint Submission to the Commission of Inquiry into the conservation, management and use of Fraser Island and the Great Sandy Region, in reply to the second submission to the Commission of Inquiry of 6th August 1990 fro the Australian Heritage Commission*, Allen Taylor & Co. Ltd, Hyne & Son Pty Ltd, Qld Timber Board, Brisbane.

Aitchison, J. (ed.) 1994, 'Getting the dirt on fertilisation', *Between the Leaves*, Summer, 1994.

Anderson, T.M., Bacon, G.J. & Shea, G.M. 1981, *Thinning strategies for Honduras Caribbean pine in plantations: an analysis of precommercial and commercial thinnings.* Technical Paper No. 25, Department of Forestry, Queensland, 17 pp.

Anderson, M.W. 1983a, 'Treemarking in areas to be enrichment planted', *Treemarking and treatment in Queensland native forests* in *Proceedings of the 1982 Routine-Research Conference*, ed. T.M. Anderson, Department of Forestry, Queensland, Gypmpie, 16-20 Aug., 1982, pp. 62-63.

Anderson, M.W. 1983b, *Growth of eucalypts planted on the coastal lowlands of southern Queensland,* Unpublished Report No. 9, Department of Forestry, Queensland, 13 pp.

Australian Heritage Commission 1990, *Second submission to the Commission of Inquiry into the conservation, management and use of Fraser Island and the Great Sandy Region*, Australian Heritage Commission, Brisbane.

Australian Weed Society 1988, *Australian weed control handbook*, 8th edn, Incata Press, Melbourne.

Bacon, G.J., Hawkins, P.J. & Jermyn, D. 1977, 'Root dip evaluation and short term storage trials with 1-0 slash pine seedlings', *Australian Forestry*, vol. 40, no. 3, pp. 167-172.

Bacon, G.J., & Hawkins, P.J. 1977, 'Studies on the establishment of open root Caribbean pine planting stock in southern Queensland', *Australian Forestry*, vol. 40, no. 3, pp. 173-191.

Bacon, G.J. & Bachelard, E.P. 1978, 'The influence of nursery conditioning treatments on some physiological responses of recently transplanted seedlings of P. caribaea Mor. var. hondurensis B & G', *Australian Forest Research*, vol. 8, pp. 171-83.

Bacon, G.J., Hawkins, P.J. & Ward, J.P. 1982, 'Productivity of commercial thinning operations in Queensland plantations: Influence of alternative silvicultural options', *New Zealand Journal of Forestry Science*, vol. 12, no. 2, pp. 308-322.

Barnett, J.L., How R.A., Humphries, W.F 1976, 'Mammals of Clouds Creek, north east NSW and their distribution in pine and native forest', *Australian Zoologist*, vol. 19, no. 1, pp. 23-34.

Bevege, D.I. 1972, *Girth and basal area growth of slash pine P. elliottii var. elliottii Engl. and their significance to plantation management in Queensland*, Research Paper No. 2, Department of Forestry, Queensland, 69 pp.

Bevege, D.I. & Simpson, J.A. 1981, 'Salinity associated with exotic pine plantation management in coastal Queensland', *Proceedings of a Symposium Held at Darling Downs Institute of Advance Education*, eds. A.J. Rixon & R.J. Smith, Toowoomba, Queensland, Australia, Aug. 1980.

Birk, E.M. & Turner, J. 1992, 'Response of flooded gum to intensive silvicultural treatments: Biomass and nutrient content of eucalypt plantations and native forests', *Forest Ecology and Management*, no. 47, pp. 1-28.

Bolland, L. 1984, 'Cause of a significant root-rot in Queensland hoop pine plantations', *Australian Forestry*, vol. 47, no. 1, pp. 2-10.

Bolland, L. 1985, Significance of root rot and options for control in Queensland second rotation pine plantations, paper presented to Second Rotation Establishment Conference, Gympie, Apr. 1985, pp. 17

Bonny, L. 1991, *Growth of a Eucalyptus grandis plantation following intensive silvicultural treatments applied in the first six years*, Research Paper No. 12, Forestry Commission of NSW, Sydney, 13 pp. + app.

Borg, H., Hordacre, A. & Batini, F. 1988, 'Effects of logging in stream and river buffers on watercourses and water quality in the southern forests of Western Australia', *Australian Forestry*, vol. 51, no. 2, pp. 98-105.

Borsboom, A. 1993, *An assessment of the land care program's shelter belts and forest blocks as wildlife refuges, at the DPI Animal Genetics Centre, Warrill View: Stage 1: Initial fauna survey and evaluation*, Department of Primary Industries, Forest Ecology and Conservation Section, Brisbane.

Brimblecombe, A.R. 1945, 'The biology, economic importance and control of the pine bark weevil, Aesiotes notabilis Pasc.', *Queensland Journal of Agricultural Science*, vol. 2, no. 1, 1-88.

Bubb, K.A., Simpson, J.A. & Xu, Z.H. 1995, 'Nutrient cycling in hoop pine plantations and implications for managing a sustainable plantation system', *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

Bunn, S.E., Davies, P.M. & Mosisch, T.D. (in press), Ecosystem measures of river health and their response to riparian and catchment degradation, submitted to *Freshwater Biology*.

Burnett, S.E. 1992, 'Effects of a rainforest road on the movements of small mammals: Mechanisms and implications', *Wildlife Research*, vol. 19, pp. 95-104.

Bragg, A.L. 1979, *Planting trials with klinki pine in Queensland*, Technical Note No. 3, Department of Forestry, Queensland, 3 pp. + app.

Campbell, I.C. & Doeg, T.J. 1989, 'Impact of timber harvesting and production on streams: a review', *Australian Journal of Marine and Freshwater Research*, vol. 40, no. 5, pp. 519-539.

Carne, P.B., Greaves, R.T.G., & McInnes, R.S. 1974, 'Insect damage to plantation-grown eucalypts in north coastal New South Wales, with particular reference to Christmas beetles (Coleoptera: Scarabaeaidae)', *Journal of the Australian Entomological Society*, vol. 13, pp. 189-206.

Carron, L. T. 1985, *History of Forestry in Australia*, ANU Press, Canberra.

Cassells D.S. 1984, *Erosion and stream sedimentation research in forested catchments in Queensland*, Queensland Department of Forestry, Gympie.

Cassells, D.S., Gilmour, D.A. & Gordon, P. 1982, The impact of plantation forestry on stream sedimentation in tropical and sub-tropical Queensland - An initial assessment, paper presented to Conference on Agricultural Engineering, Armidale, NSW, 22-24 Aug. 1882, pp. 22-24

Catterall, C. P. & Kingston, M. 1993a, 'Human populations, bushland distribution in south east Queensland and the implications for birds', in *Birds and their Habitats: Status and Conservation in Queensland*, eds C. P. Catterall, P. V. Driscoll, K. Hulsman, D. Muir, & A. Taplin, Queensland Ornithological Society Inc., Brisbane.

Catterall, C.P. & Kingston, M. 1993b, *Remnant bushland of south-east Queensland in the 1990's: its distribution, loss, ecological consequences and future prospects*, Institute of Environmental Research, Griffith University, & Brisbane City Council, Australia.

Chapman, W. (1975). 'Method of planting'. In *Queensland Department of Forestry Routine Research Conference on Exotic Pines*, unpublished report, Apr. 1975.

Clinnick, P.F. 1985, 'Buffer strip management in forest operations: A review', *Australian Forestry*, vol. 48, no. 1, pp. 34-45.

Cornish, P.M. 1989, *The effects of Radiata Pine plantation establishment and management on water yields and water quality - a review*, Technical Paper No. 49, Forestry Commission of NSW.

Costantini, A., Grimmett, J.L., & Dunn, G.M. 1997, 'Towards sustainable management of forest plantations in south-east Queensland. I: Logging and understorey residue management between rotations in steep country Araucaria cunninghamii plantations', *Australian Forestry*, vol. 60, no. 4, pp. 218-225

Costantini, A. & Grimmett, J. 1994, 'Site preparation requirements for Pinus plantations on the coastal lowlands of south eastern Queensland', *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Costantini, A., Dawes, W., O'Loughlin, E. & Vertessy, R. 1993a, 'Hoop pine plantation management: I. Gully erosion hazard prediction and watercourse classification', *Australian Journal of Soil and Water Conservation*, vol. 6, no. 1, pp. 35-39.

Costantini, A., Hiley, G., Last, I. & West, D. 1993b, 'Hoop pine plantation management in Queensland: II. Watercourse protection', *Australian Journal of Soil and Water Conservation*, vol. 6, no. 1, pp. 40-42.

Costantini, A., Nester, M.R. & Barnes, D.S. 1993c, *Erosion pin research studies in the hoop pine plantations of south-east Queensland*, Research Note No. 48, Department of Primary Industry-Forest Service, Indooroopilly, Australia, 11 pp.

Costantini, A. 1989, 'Definition of a plant zone for weed management during the establishment of Araucaria cunninghamii plantations', *Forest Ecology and Management*, vol. 29, pp. 15-27.

Costantini, A., Podberscek, M. & Baxter, A.G.M. 1989, *Directed glyphosate applications in Pinus caribaea* var*. hondurensis nursery weed management*, Research Note No. 42, Department of Primary Industries, Forest Service, 7 pp.

Costantini, A. 1988, Soil bulk density and soil strength: factors in the management of Pinus caribaea var. hondurensis plantations, PhD thesis, University of Queensland.

Costantini, A. & Foster, P.G. 1987, Review of recent findings in first rotation site preparation research in Queensland: 1987, paper presented to Australian Forestry Council Research Working Group No. 5 Workshop - Interactions of Silviculture with Genetics, Physiology, & Nutrition, Gympie, 1987.

Costermans, L. 1985, *Native trees and shrubs of south-eastern Australia*, Rigby, Adelaide.

Cromer, R.N. 1996, 'Silviculture of eucalypt plantations in Australia', in *Nutrition of Eucalypts*, eds. P.M. Attiwill & M.A. Adams, CSIRO Publishing, Melbourne.

Cromer, R.N., Cameron, D., Cameron J.N., Flinn, D.W., Neilson, W.A., Raupach, M., Snowdon, P. & Waring, H.D. 1981, 'Response of eucalypt species to fertiliser applied soon after planting at several sites', *Australian Forestry*, vol. 44, no. 1, pp. 3-13.

Cromer, R.N., Cameron, D.M., Rance, S.J., Ryan, P.A., & Brown, M. 1993a, 'Response to nutrients in Eucalyptus grandis: 1. Biomass accumulation', *Forest Ecology and Management*, no. 62, pp. 211-230.

Cromer, R.N., Cameron, D.M., Rance, S.J., Ryan, P.A., & Brown, M. 1993b, 'Response to nutrients in Eucalyptus grandis: 2. Nitrogen accumulation', *Forest Ecology and Management*, no. 62, pp. 231-243.

Cromer, R.N. & Jarvis, P.G. 1990, 'Growth and biomass partitioning in Eucalyptus grandis seedlings in response to nitrogen supply', *Australian Journal of Plant Physiology*, no. 17, pp. 503-15.

Cromer, R.N., Ryan, P.A., Booth, T.H., Cameron, D.M., & Rance, S.J. 1991, Limitations to productivity of Eucalyptus grandis plantations in sub-tropical Australia, paper presented to Third Australian Forest Soils and Nutrition Conference, Melbourne.

Curtin, R.A. 1963, 'Ideal stocking for maximum production in an irregular blackbutt forest', *Australian Forestry*, vol. 27, no. 2, pp. 121-127.

Curtin, R.A. 1970, 'Increasing the productivity of eucalypt forests in New South Wales', *Australian Forestry*, vol. 34, no. 2, pp. 98-106.

Dale, G. & Teasdale, B. 1993, 'Application of genetic markers to early selection of elite individuals in a clonal forestry program', *Proceedings of the Clonal Forestry Workshop*. Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Dale, J.A. & Johnson, G.T. 1987, 'Hoop pine forest management in Queensland' *Forest management in Australia in Proceedings of Conference of the Institute of Foresters of Australia*, Perth, Western Australia, 28 Sep.-2 Oct.

Dale, J.A. 1983, *Management studies in the escarpment rainforests of south-east Queensland*, Research Paper No. 14, Department of Forestry, Queensland, 90 pp.

de Oliveira, M.C., Smith, G.C. & Hogan, L.D. (in press), *Current limitations in the use of bat detectors to asses the impact of logging - a pilot study in south-east Queensland*.

Department of Forestry Queensland 1981, *Research Report 1981*, Department of Forestry, Brisbane.

Department of Natural Resources 1998, *Code of Practice for Native Forest Timber Production*, Department of Natural Resources, Brisbane.

Department of Primary Industries-Forestry 1998, *Wood production in the native forest estate - overview (Draft paper),* Department of Primary Industries, Brisbane.

Department of Primary Industries-Forestry 1993a, *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Department of Primary Industries-Forestry 1993b, *Proceedings of the Hoop Pine Nursery Workshop*, Department of Primary Industries-Forestry, Yarraman, Queensland, 27-28 Oct. 1993.

Department of Primary Industries-Forestry 1994, *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Department of Primary Industries-Forestry 1995, *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

Department of Primary Industries-Forestry, *Harvesting, marketing, and resource management manual*, Queensland Department of Primary Industries-Forestry, Brisbane.

Dieters, M.J. & Nikles, D.G. 1991, 'A multiple population structure for the continued genetic improvement of hoop pine (Araucaria cunninghamii) in Queensland', *Proceedings of the 11th Meeting of the Australian Forestry Council Research Working Group Number 1 (Forest Genetics*), Coonawarra, South Australia, 1991.

Eyre, T.J. & Smith, A.P. 1997, 'Floristic and structural habitat preference of Yellow-bellied Gliders (Petaurus australis) and selective logging impacts in south-east Queensland', *Forest Ecology and Management*, vol. 98, pp. 281-295.

Fisher, W.J. 1980, 'Ecological sense and sensitive management: some points to consider in planning for long-term management of the hoop pine plantation environment', *Procedures of Fire Conference*, Gympie, Queensland.

Fisher, W.J. 1978, *Growth and production in some open forests of the Blackbutt Range, south Queensland*, Technical Paper No. 11, Department of Forestry, Queensland, 28 pp.

Fisher, W.J. 1978, *Spacing, branch size, branch longevity and wood quality in plantations of hoop pine at Yarraman*, Technical Paper No. 12, Department of Forestry, Queensland, 17 pp.

Fisher, W.J. 1975, 'A preliminary examination of the impact of hoop pine plantation management on the birds of the Yarraman Forestry District, Queensland', *Proceedings of a Workshop on Agriculture, Forestry and Wildlife-Conflict or Coexistence*, University of New England, Armidale, 17-19 Aug. 1975, pp. 101-115.

Fitzgerald, G.E. (chairman) 1991, Commission of Inquiry into the conservation, management and use of Fraser Island and the Great Sandy Region (1991) Report, The Commission, Brisbane.

Florence, R.G. 1996, *Ecology and silviculture of eucalypt forests*, CSIRO publishing, Collingwood, Victoria.

Florence, R.G. 1968, 'The role of blackbutt in east coast forests', *Australian Forestry*, vol. 32, no. 2, pp. 118-127.

Florence, R.G. 1970, 'Conservative silvicultural practice in irregular blackbutt forest', *Commonwealth Forestry Review*, vol. 49, no. 1, pp. 86-94.

Florence, R.G. & McWilliam, J.R. 1954, *The influence of spacing on seed production: its application to forest tree improvement*, Research Note No. 2(1), Department of Forestry, Queensland, 19 pp. + app.

Florence, R.G., Shea, G.M., & Pegg, R.E. 1970, 'Development of a logging schedule for spotted gum forest', *Commonwealth Forestry Review*, vol. 49, no. 3, pp. 235-244.

Florence, R.G. & Phillis, K.J. 1971, Development of a logging and treatment schedule for an irregular blackbutt forest, *Australian Forestry*, vol. 35, pp. 43-53.

Flower, P., Hamley, T., Smith, G.C., Corben, C., Hobcroft, D. & Kehl, J. 1995, *The Black-Breasted Button-quail Turnix melanogaster (Gould) in Queensland*, QFRI Unpublished Report.

Ford, H. 1993, 'The role of birds in ecosystems: risks from eucalypt forest fragmentation and degradation', in *Birds and their Habitats: Status and Conservation in Queensland,* eds. C. P. Catterall, P. V. Driscoll, K. Hulsman, D. Muir, & A. Taplin, Queensland Ornithological Society Inc., Brisbane.

Forestman & Assoc. 1997, '*The basis of code of practice watercourse prescriptions'*, report prepared for Queensland Department of Natural Resources.

Foster, P.G. & Costantini, A. 1991a, 'Pinus plantation establishment in Queensland: I. Field surveys for site preparation planning and site design', *Australian Forestry*, vol. 54, no. 1 & 2, pp. 75-82.

Foster, P.G. & Costantini, A. 1991b, 'Pinus plantation establishment in Queensland: II. Site preparation classes', *Australian Forestry*, vol. 54, no. 1 & 2, pp. 83-89.

Foster, P.G. & Costantini, A. 1991c, 'Pinus plantation establishment in Queensland: III. Site preparation design', *Australian Forestry*, vol. 54, no. 1 & 2, pp. 90-94.

Francis, P. 1984, 'Early development of an F1 hybrid of Honduras Caribbean pine and Ocote pine in Queensland', *Commonwealth Forestry Review*, vol. 63, no. 4, pp. 279-284.

Francis, P.J. & Shea, G.M. 1991, 'Management of tropical and sub-tropical pines in Queensland', in *Forest management in Australia*, eds. F.H. McKinnell, E.R. Hopkins & J.E.D. Fox, Surrey, Beatty and Sons, Chipping Norton, NSW, in association with the Institute of Foresters of Australia, Western Australian Division.

Francis, P.J. 1983, *Growth of exotic pine on Wongi State Forest*, Unpublished Report No. 12, Department of Forestry, Queensland, 20 pp. + app.

Francis, P.J. 1984, 'The role of cultivation in plantation establishment in subtropical eastern Australia', *Symposium on Site and Productivity of Fast Growing Plantations*, Vol. 2, Pretoria and Pietermaritzberg, South Africa, 1984.

Francis, P.J. & Bacon, G.J. 1983, *Ripping trials in coastal south Queensland Pinus plantations*, Research Paper No. 15, Department of Forestry, Queensland, 16 pp.

Francis, P.J., Bacon, G.J. & Gordon, P. 1984, 'Effect of ripping and nitrogen fertiliser on the growth and windfirmness of slash pine on a shallow soil on the Queensland lowlands', *Australian Forestry*, vol. 47, no. 32, pp. 90-94.

Friend, G.R. 1980, 'Wildlife conservation and softwood forestry in Australia : some considerations', *Australian Forestry*, vol. 43, no. 4, pp. 217-225.

Garthe, R.J. 1983a, 'Growth and yield in treemarking experiments', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 30-51.

Garthe, R.J. 1983b, 'Logging and natural regeneration', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 163-170.

Garthe, R.J. 1983c, 'Growth of enrichment planting stock', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 171-175.

Garthe, R.J. 1983d, 'Problems associated with enrichment planting', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 176-179.

Grenning, V. 1957, Production of quality wood in coniferous plantations in Queensland, paper presented to Seventh British Commonwealth Forestry Conference, Queensland Department of Forestry, Brisbane, Australia, 14 pp.

Greve, D.M. 1983a, 'An economic analysis of enrichment planting and natural regeneration treatment of blackbutt stands', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 180-182.

Greve, D.M. 1983b, 'Economics of natural regeneration treatment of spotted gum stands', in *Treemarking and treatment in Queensland native Forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 183-184.

Greve, D.M. & Garthe, R.J. 1983, 'Economics of planting Gympie messmate for long-term future pole supplies', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 192-198

Grimes, R.F. & Pegg, R.E. 1979, *Growth data for a spotted gum-ironbark forest in south-east Queensland*, Technical Paper No. 17, Department of Forestry, Queensland, 30 pp.

Grimmett, J. & Podberscek, M. 1994, 'Alternatives to chemical weed control', *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Guinto, D.F. 1997, Soil fertility, tree growth and nitrogen fixation in repeatedly burnt eucalypt forests of south-east Queensland, Abstract from unpublished PhD Thesis, Griffith University.

Guinto, D.F., House, A.P.N., Xu, Z.H. & Saffigna, P.G. (1997a). *Changes in soil fertility under repeated prescribed burning in two native eucalypt forests of south east Queensland. I. Soil and forest floor nutrient pools*. Submitted to *Australian Journal of Soil Research.*

Guinto, D.F., Saffigna, P.G., Xu, Z.H., House, A.P.N., & Perera, M.C.S. (1997b). *Changes in soil fertility under repeated prescribed burning in two native eucalypt forests of south east*

Queensland. II. Nitrogen mineralization and organic matter composition measured by ^{13}C NMR spectroscopy. Submitted to *Australian Journal of Soil Research.*

Haines, R.J. 1992, *Mass propagation by cuttings, biotechnologies and the capture of genetic gain,* in *Mass Production Technology for Genetically Improved Fast Growing Tree Species*. IUFRO/AFOCEL.

Haines, R.J. 1993, 'Clonal Forestry-Definition, Record, & Rationale', *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Haines, R.J. & Walker, S.M. 1993, 'Propagation of hoop pine by cuttings: current status and future directions', *Proceedings of the Hoop Pine Nursery Workshop*, Department of Primary Industries-Forestry, Yarraman, Queensland, 27-28 Oct. 1993.

Hannah, D.S. & Smith, G.C., 1995, 'The effects of prescribed burning on herptiles in south-eastern Queensland', *Memoirs of the Queensland Museum*, vol. 38, no. 2, pp. 529-531.

Hannah, D.S., Smith, G.C. & Agnew, G. 1998, Reptile and amphibian composition in prescribed burnt dry sclerophyll forest, southern Queensland. *Australian Forestry*, vol. 61, no. 1, pp. 34-39

Harvey, A.M. 1983, *Growth, volume and value production of patula pine in a free growth spacing trial*, Technical Paper No. 33, Department of Forestry, Queensland, 40 pp.

Hawkins, P.J. 1961, *Progress report on experimental tree planting on the black soil plains of the Darling Downs*, Research Note No. 12, Queensland Forest Service, Brisbane, 75 pp.

Hawkins, P.J. 1971, Premerchantable thinning in plantations of slash pine and Honduras Caribbean pine in Queensland, paper submitted to 15th IUFRO Congress, Gainesville, Florida, USA, March 1971.

Hawkins, P.J., Nikles, D.G. & Smith, W.J. 1978, *Management, wood properties and genetic improvement of Caribbean pine in Queensland*, Technical Paper No. 4, Department of Forestry, Queensland, 19 pp.

Hawkins, P.J. & Muir, J.D. 1987, Aspects of management of plantations in tropical and sub-tropical Queensland, Revised edition 1987, original paper presented by P.J. Hawkins and J.D. Muir to the Ninth Commonwealth Forestry Conference, India, 1968.

Henry, N.B. 1954, *Progress report on thinning in even-aged blackbutt* (*E. pilularis*), Research Note No. 2(2), Queensland Forest Service, Brisbane, 18 pp. + app.

Henry, N.B. 1960, 'Effect of silvicultural treatment on the production from native forests', *Australian Forestry*, vol. 24, no. 1, pp. 30-46.

Henry, N.B. 1961, *Complete protection versus burning in the Maryborough hardwoods*, Research Note No. 13, Queensland Forest Service, Brisbane, 32 pp. + app.

Henry, N.B. & Florence, R.G. 1966, 'Establishment and development of regeneration in spotted gum-ironbark forests', *Australian Forestry*, vol. 30, no. 4, pp. 304-317.

Hillis, W.E. 1978, 'Wood quality and utilisation', in *Eucalypts For Wood Production*, eds. W.E. Hillis & A.G. Brown, CSIRO, Melbourne, pp. 259-289.

Hood, I.A. 1995, 'Root pathogen & site preparation', *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

Hogg, B. & Nester, M. 1991, 'Productivity of direct thinning regimes in south-east Queensland hoop pine plantations', *Commonwealth Forestry Review*, vol. 70, no. 1/2, pp. 37-45.

Holzworth, P.V. 1980, *Some factors influencing site indices of hoop pine plantations in south east Queensland*, Technical Paper No. 22, Department of Forestry, Queensland, 13 pp.

Hood, I.A. & Wylie, F.R. 1993, 'Minimising disease & insect threats associated with clonal forestry', *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

House, A. 1995, 'Fire ecology research in Queensland native forests - current status and new directions', *Working Papers of the Sixth Queensland Fire Research Workshop*, Land Use Study Centre, University of Southern Queensland, Bargara, Queensland, 8-10 March, 1995.

Hug, L. 1993, *Birds, Butterflies and Odonata at Warrill View Farm. Final report*, Department of Primary Industries, Forest Ecology and Conservation Section, Brisbane.

Humphries, S. 1994, 'Weeds insidious threats to biodiversity', *Biolinks*, vol. 94, no. 7. 8 pp.

Huth, J.R. 1982, *Pinus radiata* var. *binata trial plantings in south east Queensland*, Research Note No. 37, Department of Forestry, Queensland, 8 pp.

Huth, J.R. & Baxter, A.G.M. 1994, 'Planting stock conditioning and handling', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Huth, J.R. & Robinson, M.J. 1994, 'Evaluation of soil moisture at planting', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Innis, G. J. 1989, 'Feeding ecology of fruit pigeons in subtropical rainforests of south-eastern Queensland', *Australian Wildlife Research*, vol. 16, pp. 365-94

Innis, G. J. & McEcoy, J. 1992, 'Feeding ecology of green catbirds (Ailoroedus crassirostris) in subtropical rainforests of south-eastern Queensland', *Wildlife Research*, vol. 19, pp. 317-29.

Joint Conservation Groups (1990*), A Submission from Joint Conservation Groups to the Commission of Inquiry into the conservation, management and use of Fraser Island and the Great Sandy Region* - Appendix A & B, Joint Conservation Groups, Bardon, Queensland.

Just, T.E. 1977, *Fire control problems of the Wallum with particular reference to Cooloola*, Technical Paper No. 3, Department of Forestry, Queensland, 15 pp.

Kehl, J.C. & Corben, C. 1991, *The fauna of the closed forest of the Conondale Ranges with particular reference to conservation and future land use*, Department of Primary Industries, Forest Service.

Kerruish, C.M. 1978, 'Harvesting', in *Eucalypts For Wood Production*, Eds. W.E. Hillis & A.G. Brown, CSIRO, Melbourne, pp. 229-255.

Keys, M.G. 1993, 'The basis of exotic pine weed control techniques', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Lamb, D., Loyn, R., Smith, A. & Wilkinson, G. 1998, *Habitat Tree Technical Advisory Group*, report to Forest Resources Division, Department of Natural Resources, Brisbane.

Langford, K.J. & O'Shaughnessy, P.J. 1977, 'Some effects of forest change on water values', *Australian Forestry*, vol. 40, no. 3, pp. 192-218.

Lewty, M.J. & Francis, P.J. 1982, 'Effects of cultivation and weed control on the early growth of Pinus caribaea var. hondurensis in Queensland', *Abstract on establishment of coniferous plantations, Workshop Proceedings*, Mt. Gambier, South Australia, 20-23 Sept., 1982.

Lewty, M.J. 1989, 'The major plantation species: their characteristics and site requirements ', paper presented to Department of Forestry Forest Development Workshop, Gympie, Queensland. 3-7 July, 16 pp.

Lewty, M.J. 1990, 'Effects of waterlogging on the growth of water relations of three Pinus taxa', *Forest Ecology and Management*, vol. 30, pp. 189-201.

Lewty, M.J. 1993, 'The use of physiological parameters in the early selection of clonal material', in *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Lewty, M.J., Nester, M.R., Huth, J.R. & Simpson, J.A. 1993, ‘The possible impact of clonal forestry on early silvicultural practices’, in *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Lewty, M.J., Huth, J.R., Nester, M.R & McKenna, D.J. 1993a, ‘Field performance of container hoop pine’, in *Proceedings of the Hoop Pine Nursery Workshop*, Department of Primary Industries-Forestry, Yarraman, Queensland. 27-28 Oct. 1993.

Lewty, M.J., Huth, J.R. & McKenna, D.J. 1993b, ‘The container hoop pine nursery system: prescription & cost’, in *Proceedings of the Hoop Pine Nursery Workshop*, Department of Primary Industries-Forestry, Yarraman, Queensland. 27-28 Oct. 1993.

Lewty, M.J., Robinson, M.J., & Huth, J.R. 1994, ‘Season of planting: a review of research & development trials’, in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Lindner, S. 1984, ‘Potential and actual production in Australian forest stands’, in *Proceedings of a Conference on Research for Forest Management*, Division of Forest Research, CSIRO, Canberra, Australia, 21-25 May 1984

Mannion, E.G. 1977, *Quantitative assessment of aerial fertilization of young slash pine plantations in south east Queensland*, Research Paper No. 8, Department of Forestry, Queensland, 39 pp.

McEvoy, J.S., McDonald, K.R. & Searle, A.K. 1979, ‘Mammals, birds, reptiles and amphibians of the Kilcoy Shire, Queensland’, *Queensland Journal of Agricultural and Animal Sciences*, vol. 36, no. 2.

McIntyre, D.K. & Pryor, L.D. 1974, ‘Response of flooded gum in plantations to fertilisers’, *Australian Forestry*, vol. 37, no. 1, pp. 15-23.

McKinnell, F.H., Hopkins, E.R. & Fox, J.E.D.(eds) 1991, *Forest Management in Australia*, Surrey Beatty & Sons, Chipping Norton, NSW.

McIlroy, J.C. 1978, ‘The effects of forestry practices on wildlife in Australia: a review’, *Australian Forestry*, vol. 41, no. 2, pp. 78-94.

Moore, P.P. & Garthe, R.J. 1983, ‘Effect of treatment on pole yield in spotted gum forests’, in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 199-207.

Nicholson, D.I. & Bragg, A.L. 1980, *The performance of Pinus strobus L. var. chiapensis Martinez in Queensland*, Technical Paper No. 23, Department of Forestry, Queensland, 7 pp.

Nikles, D.G. 1964, ‘Cross progenies of P. elliottii X P. caribaea hybrids’, *Australian Forest Research*, vol. 1, no. 1, pp. 32-33.

Nikles, D.G. 1964, ‘P. caribaea X P. elliottii hybrid produced by 1960 pollination’, *Australian Forest Research*, vol. 1, no. 1, pp. 30-31.

Nikles, D.G. 1973, ‘Biology and improvement of Araucaria cunninghamii Ait. in Queensland, Australia’, in *Selection and breeding to improve some tropical conifers*, vol. 2, eds. Burley, J. & Nikles, D.G., Commonwealth Forestry Institute, Oxford, pp. 304-334

Nikles, D.G. & Newton, R.S. 1983, ‘Distribution, genetic variation, genetic improvement and conservation of Araucaria cunninghamii Aiton ex D.Don’, *Silvicultura* (Brazil).vol. 30, pp. 276-286.

Nikles, D.G. & Dieters, M.J. 1986, ‘Strategy and rationale of the breeding programme with Araucaria cunninghamii (hoop pine) in Queensland’, P*roceedings of IUFRO Conference - a joint meeting of working parties on breeding theory, progeny testing, & seed orchards*, Virginia, USA, October 13-17, 1986.

Norton, T.W. & May, S.A. 1993, *Integrated forestry harvesting in eastern Australia: ecological impacts and priorities for conservation Working Paper*, Centre for Resource & Environmental Studies, Australian National University, Canberra.

O'Brien, G. 1983, 'Treatment policy present and future: review paper', in *Treemarking and treatment in Queensland native forests,* in *Proceedings of the 1982 Routine Research Conference*, ed. T.M. Anderson, Department of Forestry, Gypmpie, Queensland, 16-20 August, 1982, pp. 143-157

Osborne, D.O., Simpson, J.A. & Xu, Z.H. 1994a, 'Overview of exotic pine nutritional disorders', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Osborne, D.O., Simpson, J.A. & Xu, Z.H. 1994b, 'Soil classification systems: the role in site design', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Palmer, G. 1993, 'Testing methods & preliminary results', in *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Pattemore, V.J. 1985, The rufous whistler in pine plantations: a study of niche shift, PhD thesis, University of Queensland.

Pegg, R.E. 1967, *Relation of slash pine site index to soil, vegetation and climate in south east Queensland*, Research Note 19, Department of Forestry, Queensland, 53 pp. + app.

Porter, J.W. 1993, Ecological and population studies of a flower-feeding specialist, the Rainbow Lorikeet, (Trichoglossus haemotodus moluccanus (Gmelin)) during the extensive clearing of a coastal ecosystem in south-east Queensland. Unpublished PhD thesis University of Queensland

Porter, J.W. & Henderson, R. 1983, 'Birds and burning histories of open forests at Gundiah, south-east Queensland', *The Sunbird*, vol. 13, no. 4, pp. 61-68.

Porter, J.W. 1980, Birds in Pine plantations at Gambubal and Passchendaele, south-eastern Queensland, report to the Department of Forestry, Brisbane.

Powell, M.B. & Nikles, D.G. 1996, 'Performance of Pinus elliottii var. elliottii and P. caribaea var. hondurensis, and their F1, F2 and backcross hybrids across a range of sites in Queensland', in *Proceedings of QFRI-IUFRO Conference on tree improvement for sustainable tropical forestry*, eds. Dieters, M.J., Matheson, A.C., Nikles, D.G. Harwood, C.E. & Walker, S.M., Caloundra, Queensland, 27 Oct.-1 Nov. 1996.

Preen, A.R. 1981, The effects of selective logging on the vertebrate fauna of a tropical rainforest in North East Queensland, unpublished BSc Hon thesis, James Cook University.

Queensland Department of Forestry 1974, *Forestry Inquiry - Softwood Timber Industry submission to the House of Representatives Standing Committee on Environment and Conservation*, Department of Forestry, Brisbane.

Queensland Department of Forestry 1983, *Rainforest research in North Queensland - A position paper issued by the Queensland Department of Forestry*, Queensland Department of Forestry.

Queensland Department of Forestry, 1984 *Forest Management in Queensland*, Parts 1 & 2, Queensland Department of Forestry, Brisbane.

Queensland Department of Forestry, 1987, Research Report No. 6 1986 & 1987 for the Department of Forestry, Queensland. Division of Technical Services (Research & Utilisation).

Queensland Department of Primary Industries 1990, *First Submission to the Commission of Inquiry into the conservation, management and use of Fraser Island and the Great Sandy Region Paper 3.4 (ii)*, Department of Primary Industries, Brisbane.

Queensland Department of Primary Industries-Forestry 1996, *Fire Management Manual*

Queensland Forest Service 1991, *The harvest of Queensland's state forests*, Information Brochure 31, Forest Advisory Branch, Brisbane.

Reilly, J.J. 1981, 'Economics of a hoop pine program', in *Planning, establishment and management of hoop pine plantations,* in *Proceedings of the 1979 Routine Research Conference*, vol. 1, eds. Fisher, W.J., Pegg, R.E. & Harvey, A.M., Yarraman 4 Apr. & 9-13 Jul. 1979, Division of Technical Services, Department of Forestry, Brisbane, pp. 1-17.

Richards, B.N. & Bevege, D.I. 1969, 'Critical foliage concentrations of nitrogen and phosphorus as a guide to the nutrient status of Araucaria interplanted to Pinus', *Plant and Soil*, vol. 31, pp. 328-336.

Robinson, W.M. 1969, Pruning and thinning practice in Queensland plantations, paper presented to Ninth Commonwealth Forestry Conference, India, 1968, 21 pp.

Robinson, W.M., Henry, N.B. & Schmidt, J.D.K. 1971, The influence of tree size on stand value in natural forests and plantations in Queensland, paper presented to 21st AUSTIS Conference, Port Moresby, 1971, 11 pp.

Ross, Y. 1998, *Hollow trees and habitat management in south-east Queensland*, *Draft report*, Queensland Department of Natural Resources.

Ross, D.J. & Thompson, C.H. 1991, *Soils at sites selected for eucalypt research in Toolara State Forest, Gympie, Queensland*, Divisional Report No. 111, CSIRO Division of Soils, 26 pp. + app.

Russell, M.J. & Roberts B.R. 1996, 'Effects of four low-intensity burns over 14 years on the floristics of a blackbutt (Eucalyptus pilularis) forest in southern Queensland', *Australian Journal of Botany*, vol. 44, no. 3, pp. 315-329.

Ryan, T. 1990, 'A Queensland pine plantation case study', in *Prospects for Australian forest plantations*, eds. J. Dargavel & N. Semple, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Ryan, P. 1993, Hardwood plantations in Queensland? Why not!, paper presented to internal QFRI seminar, Gympie, 13 Aug. 1993.

Ryan, P.A. & Bell, R.E. 1989, 'Growth, coppicing and flowering of Australian tree species in trials in southeast Queensland, Australia', in *Trees for the Tropics: Growing Australian Multipurpose Trees and Shrubs in Developing Countries*, ed. D.J. Boland, ACIAR Monograph Series No. 10, Australian Centre for International Agricultural Research, Canberra, 247 pp.

Schonau, A.P.G. 1984, 'Silvicultural considerations for high productivity of Eucalyptus grandis', *Forest Ecology and Management*, no. 9, pp. 295-344.

Schonau, A.P.G. & Herbert, M.A. 1989, 'Fertilizing eucalypts at plantation establishment', *Forest Ecology and Management*, no. 29, pp. 221-244.

Shea, G.M. & Armstrong, P.A. 1978, *Factors affecting survival in open-root plantings of Caribbean pine - coastal Queensland*, Technical Paper No. 8, Department of Forestry, Queensland, 18 pp.

Shea, G.M., Bacon, G.J. & Anderson, T.M. 1979, Growth of Araucaria cunninghamii Ait ex. D. Don plantations in Queensland, paper presented to IUFRO meeting on problems of the genus Araucaria, Curitiba, Brazil, 8 pp.

Shea, G.M., Harvey, A.M. & Anderson, T.M. 1984, 'Holistic evaluation of research findings in softwood plantations in Queensland', *Symposium on site and productivity of fast growing plantations*, vol. 2, Pretoria and Pietermaritzberg, South Africa, 1984.

Schulz, M. 1994, Preliminary investigation of fauna in watercourse protection zones within pine plantations Beerburrum State Forests, Fauna Conservation and Ecology Section, Department of Primary Industries - Forestry, Indooroopilly, Queensland.

Simpson, J.A. 1978, *Nursery nutrition studies with slash pine at Beerburrum*, Research Paper No. 9, Department of Forestry, Queensland, 32 pp.

Simpson, J.A. 1990, Site requirements for Pinus species planted in coastal south east Queensland, paper presented to Australian Forestry Council Research Working Group 3, Soils and Nutrition, 10th meeting, Adelaide, 26-29 Mar., 1990, 12 pp.

Simpson, J.A. & Grant, M.J. 1991, *Exotic pine fertilizer practice and its development in Queensland*, Technical Paper No. 49, Queensland Forest Service.

Simpson, J.A., Xu, Z.H. & Osborne, D.O. 1994, 'Fertilizing practices in exotic pines - principles of application', in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Simpson, J.A. 1995, 'An overview of soils and nutrition research in hoop pine plantations in Queensland', in *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

Slee, M.U. 1969, Height and girth growth of slash-Caribbean hybrids in south Queensland, paper presented to IUFRO Second World Consultation on Forest Tree Breeding, Washington, USA, 7-16 Aug.

Smith, G. C., Aridis, J. & Lees, N. (in press), Radio-tracking revealed home ranges of Black-Breasted Button-quail Turnix melanogaster in remnant vine scrub between hoop pine plantation and agriculture, *Emu*.

Stone, E.L. 1982, 'Observations on forest nutrition research in Australia', *Australian Forestry*, vol. 45, no. 3, pp. 181-192.

Suckling, G.C. 1982, 'Value of reserved habitat for mammal conservation in plantations' *Australian Forestry*, vol. 45, no. 1, pp. 19-27.

Taylor, D. W. 1997a The Implementation of Native Forest Silvicultural Systems in Queensland, paper presented to Research Working Group IV - Native Forest Silviculture, Hobart, March 11-13, 1997. Queensland Department of Primary Industries - Forestry, Queensland Forestry Research Institute.

Taylor, D. W. 1997b Current Native Forest Research Activities - Queensland, paper presented to Research Working Group IV - Native Forest Silviculture, Hobart, March 11-13, 1997. Queensland Department of Primary Industries - Forestry, Queensland Forestry Research Institute.

Taylor, P 1994, *Growing up - Forestry in Queensland*, Allen and Unwin, Brisbane.

Thomas, M., Bevege, D.I. & Lamb, D. 1980, A possible relationship between salinity and dieback of Cypress Pine in south-east Queensland, report by the Botany Department, University of Queensland, for the Department of Forestry, Queensland.

Turvey, N.D. & Poutsma, T. 1980, 'A forest soil survey: I. The provision of a factual framework for silvicultural management decisions', *Australian Forestry*, vol. 43, no. 3, pp. 165-171.

van Altena, A.C. 1979, *Growth comparisons of slash pine and Honduras Caribbean pine at Toolara*, Research Note No. 28, Department of Forestry, Queensland, 4 pp. + app.

Vanclay, J.K. 1992, Lessons from Queensland rainforests: a century striving for sustainability, paper presented to IUFRO Centennial meeting, Eberswalde, Berlin.

Vanclay, J.K. & Anderson, T.M. 1982, *Initial spacing effects on thinned stem volumes of slash pine in south east Queensland*, Research Note No. 34, Department of Forestry, Queensland, 9 pp.

Vanderwoude, C., Andersen, A.N. & House, A.P.N., 1997, 'Ant communities as bio-indicators in relation to fire management of Spotted Gum (Eucalyptus maculata. Hook) forests in south-east Queensland', *Memoirs of the Museum of Victoria*, vol. 56, no. 2, pp. 671 - 675.

Vanderwoude, C., Anderson, A.N. & House, A.P.N. (In press). *Community organisation, biogeography and seasonality of ants in an open forest of south-eastern Australia*, submitted to Australian Journal of Zoology.

Walker, S.M., Robinson, M.J. & Haines, R.J. 1993, ‘Propagation techniques for clonal forestry’, *Proceedings of the Clonal Forestry Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 30 Nov.-2 Dec. 1993.

Walker, S. 1994, ‘Performance of cuttings’, *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Ward, D.L., Huth, J.R. & Perkins, L.R. 1993, *Cold storage of Honduras Caribbean pine seedlings*, Research Note No. 47, Department of Primary Industries, Forest Service, 6 pp.

Ward, A., Murphy, J. & Dickens, J. 1995, ‘Hoop pine planting methods and practices’, *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

West, P. & Mattay, J.P. 1993, ‘Yield prediction models and comparative growth rates for six eucalypt species’, *Australian Forestry*, vol. 56, no. 3, pp. 211-225.

Xu, Z.H., Simpson, J.A. & Osborne, D.O. 1994, ‘Effective nutrient management for sustainable production of pine plantations’, in *Proceedings of the Exotic Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 12-15 Sep. 1994.

Xu, Z.H., Simpson, J.A., Osborne, D.O. & Bubb, K.A. 1995, ‘The role of fertilisation in improving the productivity of hoop pine plantations’, in *Proceedings of the Hoop Pine Establishment Workshop*, Department of Primary Industries-Forestry, Gympie, Queensland, 11-14 Sep. 1995.

7. APPENDICES

7.1 APPENDIX 1

CRA/RFA PROJECT SPECIFICATION

PROJECT NAME:	Forest resource enhancement opportunities
PROJECT IDENTIFIER:	SE 1.3
LOCATION/EXTENT:	South-east Queensland
ORGANISATION/S:	Bureau of Resource Sciences/QDPI-Forestry/DNR
CONTACT OFFICER/S:	Dan Sun, Senior Research Scientist Malcolm Taylor, Resource Officer Rebecca Williams
POSTAL ADDRESSES:	Dan Sun Bureau of Resource Sciences PO Box E11, Kingston, ACT 2604 Ph. (06) 272 5694 Fax (06) 272 3882 E-mail: dsun@mailpc.brs.gov.au Malcolm Taylor QDPI Forestry GPO Box 944, Q 4001 Ph. (07) 3234 0136 Fax (07) 3234 1200 E-mail: taylorm@dpi.gov.au Rebecca Williams DNR, 80 Meiers Rd, Indooroopilly, Qld 4068 Ph. (07) 3234 1383 Fax (07)

7.1.1 Linkages/Dependencies:

This project will complement other resource projects and wood industry development opportunities by providing information on opportunities for forest resource enhancement in the SEQ region.

7.1.2 Type of Study:

Collation and analysis of existing information through literature review and a workshop

7.1.2.1 1. OBJECTIVES OF THE PROJECT

To identify feasible options for improving timber yields of native forests and plantations (both hardwood and softwood) in south-east Queensland through silvicultural means and to identify priorities for future R&D through knowledge gap analysis. This project addresses clause 4 of the Scoping Agreement.

7.1.2.2 2. BACKGROUND

The majority of Queensland's native forests are of low timber yield productivity relative to other Australian forests used for commercial production. Studies aiming at increasing forest productivity through silvicultural treatments have been undertaken in the region. In order to find out what is known and to identify future opportunities and research and development priorities in this area, there is a need to review the results from these studies and evaluate any silvicultural techniques developed on the basis of their productivity gains, financial viability and ecological impacts. The information obtained from this project will assist the option development phase.

3. SCOPE OF THE PROJECT

This project will cover the following three major subjects:

- silvicultural techniques of forest resource enhancement for native forests and plantations (both hardwood and softwood) in south-east Queensland, focusing on: productivity gains, financial viability, ecological impacts, and strength and weakness;

- identification of feasible options in forest resource enhancement for native forests and plantations in south-east Queensland.

- identification of priorities for research and development through gap analysis.

4. METHODS

This project is to be undertaken by compiling existing information on silvicultural treatments in relation to resource enhancement for both native forests and plantations in south-east Queensland. The outcome will be a detailed documentation of the treatments developed in terms of productivity, financial viability, ecological impacts and strength and weakness.

A workshop is to be held to provide wider input from experts in the field.

The project is to be conducted through the following four? steps:

Collating and reviewing existing information from research reports and other available resources in relation to productivity enhancement projects undertaken in south-east Queensland or in other forests directly relevant to those in south-east Queensland. Document silvicultural techniques developed for forest resource enhancement focusing on:

- productivity gains
- financial viability
- ecological impacts

- strength and weakness

Organising a workshop with technical experts in the field to provide a wider input in current knowledge and practices and identification of priorities for future research and development;
Producing an assessment of the potential for productivity enhancement within the context of ecological sustainable forest management as defined for the south-east Queensland regional forest agreement, using the information collected and collated;
Compiling the final assessment report.

Any final conclusions from this project are subject to the outcomes of the ecologically sustainable forest management assessment process in south-east Queensland.

5. CRITICAL PATH

Outcomes/Outputs

The following are expected outcomes from the project:

- identification of scope and opportunities to increase productivity of native forests and plantations;
- review of financial viability and ecological implications of enhancement opportunities including limitations of the methodology;
- assessment report detailing possible forest resource enhancement opportunities for both native forests and plantations in SEQ under the context of ESFM;
- identification of priorities for future R&D in relation to forest resource enhancement for both native forests and plantations in the SEQ region.

Reporting

Progress reports will be prepared and submitted to the Social-Economic Technical Committee monthly. At the completion of the project, a final assessment report will be produced and submitted to the Steering-Committee. BRS is responsible for compiling the final report.

6. PERFORMANCE INDICATORS

Performance indicators for the project are:

- Information presented in the final report useable
- Most existing information is collated
- Completion of the project in timely manner

7. QUALITY CONTROL

The following measures will be applied to ensure the outcomes from the project are of the highest quality possible:

- the appointment of a highly qualified and experienced project officer to undertake the major tasks of the project;

- project manager to undertake periodic review of progress to ensure that the project will be completed on time within budget.