



An Australian Government Initiative



Mixed-species Plantations: Extending the Science

by Geoff Dickinson, Mila Bristow and John Huth

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Foreword

In sub-tropical and tropical eastern Australia, mixed species plantations are most common in small-scale farm forestry situations. In this region, private landowners are mainly interested in tree establishment for multiple purposes including economics, environmental and personal values. Mixed species plantations are generally considered by landowners to be more effective at fulfilling these values, compared with monocultures. Unfortunately the technology for growing mixed species plantations is complex, poorly understood and is largely fragmented between a large number of sources throughout this wide geographic region

The goal of this project was to rebuild, maintain and enhance communication networks with the main stakeholder groups involved with mixed species plantations in Queensland and New South Wales. Through network development and analysis of key DPI&F and other trials, improved technologies for species by site productivity assessment and best-bet mixed species configurations were identified. These were communicated, via a diverse range of extension strategies, to interested growers and stakeholders throughout this wide region.

The research ranked performance of more than 32 species across a large number of north and central Queensland sites, and 17 species from a range of sites in southeast Queensland. Simple and more complex designs for multi-species plantations are discussed, with the recommendation that harvest access and management of species competition are carefully considered in future designs. A key role of the project was to provide contact details for local extension and consultancy services. It is hoped that the various stakeholders will continue to seek information to best- manage the plantations and their development in the region.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations — Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia, and Forest and Wood Products Research and Development Corporation (FWPRDC). The Murray-Darling Basin Commission (MDBC) also contributed to the program during this time. The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

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We would like to acknowledge that the section of this report on north Queensland tree growth results draws heavily from a chapter written by Mila Bristow, Peter Erskine, Sean McNamara and Mark Annandale, titled 'Species performance and site relationships for rainforest timber species in plantations in the humid tropics of Queensland', published in *Reforestation in the tropics and sub-tropics of Australia using rainforest tree species* (2005, Eds. Erskine, P.D., Lamb, D. and Bristow, M., RIRDC publication No. 05/087, Rural Industries Research and Development Corporation). Considerable reference has been made to this, and other chapters of this book. We would like acknowledge the University of Queensland, the Rainforest CRC, DPI&F and JVAP for supporting the research which went into that publication, and to thank the authors, editors, and JVAP for supporting the workshop (WS023-20) from whence the publication came.

We would like to thank Susan House and John Simpson from the DPI&F, for conducting the internal review of this report, and Rosemary Lott for compiling the species list and editing the report into final form. Finally, the significant inputs of technical and extension expertise from DPI&F, Horticulture and Forestry Science research officers Nick Kelly, Alan Ward, Ken Robson and Glenn Bailey who supervised the measurement, maintenance and management of field trials and the coordination of a number of the public workshops is also acknowledged.

Abbreviations

AFG	Australian Forest Growers
BA	Basal Area
ARC	Australian Research Council
CQ	Central Queensland
CQFA	Central Queensland Forest Association
CRRP	Community Rainforest Reforestation Program
DBH	Diameter at Breast Height (cm)
DPI&F	Department of Primary Industries and Fisheries (Queensland)
DNRM	Department of Natural Resources and Mines (Queensland)
GU	Griffith University
ICM	Integrated Catchment Management
JCU	James Cook University
JVAP	Joint Venture Agroforestry Program
NA	Not Available
NNSW	Northern New South Wales
NQ	North Queensland
NRPF	Northern Rivers Private Forestry
PCH	<i>Pinus caribea</i> var. <i>hondurensis</i>
PFDC	Private Forestry Development Committee
PFNQ	Private Forestry North Queensland
PFSQ	Private Forestry Southern Queensland
QTP	Queensland Timber Plantations
RIRDC	Rural Industries Research and Development Corporation
SCU	Southern Cross University
SFFA	Subtropical Farm Forestry Association
SQ	Southern Queensland
UQ	University of Queensland

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Executive summary

What the report is about

This report presents new data on growth of high value tropical timber species in southeastern and north Queensland, and discusses best-bet configurations for mixed-species plantations. The project measured key trial sites in southeastern and north Queensland, and used this and previous data to analyse species by site productivity, and mixed-species designs. The project presented these results and recommendations via a range of extension activities – the report summarises a series of workshops attended by growers, extension staff and researchers in north, central and southeastern Queensland and northern New South Wales.

Who is the report targeted at?

This report is for researchers, extension staff and tree growers and others interested in the growth performance and management of high value tropical timber mixed-species plantations in eastern Queensland and northern New South Wales.

Background

In tropical and sub-tropical eastern Australia, mixed-species timber plantations primarily involve the establishment of high-value, rainforest cabinetwood plantations, although there is also a growing number of plantations involving mixed eucalypts, bush-tucker species and sandalwood species and their hosts. At present, the current technologies for growing mixed species plantations are highly complex and not well-known. Much of the available information is also fragmented between a large number of sources in this wide geographic region. This is further complicated by the large number of potential commercial timber species available to be planted on a particular site or across a particular region of interest.

Aims and objectives

The goal of this project was to rebuild, maintain and enhance communication networks with the main stakeholders involved with mixed-species plantations in Queensland and New South Wales. By working with these groups and individuals, information on the latest management practices was identified, collated and summarised. Combined with DPI&F resources, this information was communicated to interested growers and stakeholders to improve the understanding of mixed species plantation technologies throughout the region. The project objectives had three broad components: (1) species to site productivity assessment; (2) best-bet mixed-species configurations; and (3) extension of information.

Methods

Species to site productivity assessment was conducted for north and central Queensland by examining a number of key Queensland Department of Primary Industries & Fisheries (DPI&F) trials and over 110 growth plots in existing operational plantings. In southern Queensland, site productivity assessment was conducted through the establishment and monitoring of new growth plots in a number of existing private plantations managed by the two consultants, Jack Mitchell and John Steele.

In order to identify the latest best-bet mixed-species configurations across this region, various existing plantings were examined. These included a number of key DPI&F research trials and operational mixed-species plantations established by the Community Rainforest Reforestation Program, private growers and consultants.

Communicating information about mixed-species technologies across tropical and sub-tropical eastern Australia was facilitated by establishing and maintaining communication networks between the wide range of stakeholders groups. Relevant, existing technical literature was identified (including JVAP publications). New technical and scientific summaries were produced based on the latest information and presented at a range of public seminars, community meetings, workshops and conferences.

Results

Trial assessment results identified a number of cabinetwood and eucalypt species with good productivity and potential for particular regions and particular site types. Species performance was ranked for 32 top species in northeastern and central Queensland, and measured for 17 species in southeast Queensland. Two broad groups were identified: sun-loving fast growers and intermediate to slow growers with high value timber.

The range of plantations examined clearly demonstrated the gradual improvements in the understanding of inter-specific competition and operational factors such as harvest management. This evolution from random to quite complex designs, provided good information to guide the development of more effective and economic mixed-species plantation designs.

The project used field days, seminars, workshops and hard-copy and electronic publications to communicate generic recommendations on species selection and silvicultural management, to stakeholders throughout this diverse region. Thirteen workshops were conducted in eastern Queensland and northern New South Wales, attended by a total of approximately 400 people, primarily landowners with plantations or interest in planting. The project culminated in a final workshop where project outcomes and latest mixed-species plantation technologies were presented (attended by 45 people). The workshop participants provided information on their attitudes and motivations for planting mixed species plantations – most private landowners in tropical and sub-tropical eastern Australia prefer the concept of mixed-species plantations over monocultures. These designs best meet their expectations of commercial returns, personal satisfaction, conservation and sustainability values for their property.

Implications

Data showed variability in species growth across different site types, climatic conditions, management techniques and temporal variations; and often unpredictable inter-specific relationships which can affect growth on any specific site type. Nevertheless, the examination of a large range of operational plantings and research trials yielded some useful information on the most successful species across a range of site types. This has improved the capacity to recommend suitable species for planting.

It is hoped that the extension activities, the communication tools provided, and the momentum generated during the project have assisted researchers, extension providers, consultants and private landowners to implement more efficient and effective mixed-species plantations in this region. An important role of the workshops was to provide contact details for local extension support and consulting services, so that participants could continue to find information after the project and workshops finished.

Recommendations

Generic species recommendations and design configurations, such as those outlined in this project, need to be locally modified and adapted to suit each individual landowner's situation and expectations, and the complexity of mixed species plantations.

The design of mixed-species plantation configurations must consider inter-specific competition and harvesting access. Tree species should be planted in rows to allow efficient harvest operations, and some strategic non-commercial thinning will be required to manage inter-tree competition. The mix of fast-growing sun-loving species and the slower growing shade-tolerant species must also be considered.

Introduction

Operational mixed-species plantations

In tropical and sub-tropical eastern Australia, mixed-species timber plantations are often taken as synonymous with the establishment of high-value, rainforest cabinetwood plantations. While this is generally true, there is also a growing number of mixed-species plantations involving mixed-eucalypts, bush-tucker species as well as sandalwood species and their hosts.

The area established to mixed-species plantations in Australia is very small, with the majority of industrial plantations established as either *Pinus* or *Eucalyptus* monocultures. This is mainly attributable to economic reasons, as mixed species plantations are considered more expensive to establish, manage, harvest and market due to increased complexity and the difficulty in managing or predicting the interactions of multiple species across a range of site types. Mixed-species plantations are however, much more common in small-scale farm forestry situations. Herbohn *et al.* (2005) reported that the main reasons for planting trees by private landowners in Queensland were for non-commercial values, such as conservation and personal satisfaction. Mixed-species plantations are generally considered by landowners as more effective at fulfilling these values, compared to monoculture plantations.

While it is recognised that mixed-species plantation management is more complex and expensive, a number of authors (Keenan *et al.* 1995; Lamb *et al.* 2005; Nichols *et al.* 1999) have indicated that mixed-species plantations may have improved productivity. Productivity may be increased through the effects of complementarity, nitrogen-fixation, reduced pest and disease damage and a more diverse range of timber products to meet changing and lucrative niche markets. For rainforest sites where site resources such as moisture or sunlight can be under-utilised, complementarity where different species utilise site resources from different parts of the environment, may provide some large benefits (Kelty 1992). For example a shallow rooted *Elaeocarpus grandis* and a deep rooted *Grevillea robusta* could more efficiently utilise moisture and nutrients within the soil profile.

Mixed-species plantations utilising high-value rainforest cabinet-timbers, are the most common form of plantation polyculture utilised in eastern Australia. In north and central Queensland, approximately 1780 hectares of mixed species plantations were established for cabinetwood timber production, under the government-assisted Community Rainforest Reforestation Program (CRRP) which operated from 1992-1998 (Erskine *et al.* 2005a). The justification for establishing rainforest cabinetwoods in mixed-species plantations is due to the perceived greater market value of this timber which can offset the higher management costs and the suggestion that these species grow more successfully in a mixed species configuration (Lamb *et al.* 2005; Vize *et al.* 2005). For certain species, this mimics natural rainforest conditions, with successional species benefiting from the reduced light levels, lower temperatures and higher humidity that come when established with faster-growing pioneer species (Kooyman 1994). Additionally, in these regions, establishing rainforest species in mixtures is also seen to have greater environmental benefits, by increasing biodiversity (Kanowski *et al.* 2003; Catterall *et al.* 2005), returning greater personal satisfaction to the landowner (Emtage *et al.* 2001; Herbohn *et al.* 2005) and by producing a forest more closely resembling the original vegetation cover.

For semi-parasitic species such as the highly valuable, oil-producing *Santalum*, mixed-species plantations are essential, as sandalwood trees are dependent on nutrients and water from host plants to survive and grow. In the dry tropics of northern Australia, a number of large sandalwood plantations have been established in the past 10 years, and much work has been conducted to identify host species which are effective, but may also have some commercial value of their own (as recently summarised by Done *et al.* 2004).

In non-rainforest areas, where eucalypt species are usually best adapted, mixed-species timber plantations are relatively uncommon. This may be due to numerous factors including the highly competitive nature of eucalypts which can make them difficult to mix with other species, including other eucalypts. In addition, eucalypt timbers are of generally lower value, thus making it difficult to offset the higher management inputs associated with mixed-species plantations. Successful examples of mixed-eucalypt plantations have been observed, on sites using simple species mixes (two or three species) which have comparable growth rates (e.g. *E. cloeziana* and *E. pilularis*). Other cases where mixed-eucalypt plantations have demonstrated some advantage, have been on difficult sites such as waterlogged areas (Gary Clarke *pers. comm.*). On these sites species choices are more difficult and the establishment of a wider range of species can improve the chances of establishing a reasonable tree stocking in these areas.

Mixed species plantation technologies

The complex technology of growing mixed-species plantations is generally not well-known, excluding current research that focuses on the interactions between adjacent species, species to site suitability and plantation silvicultural management (Binkley *et al.* 1992; Kelty 1992; Lamb and Lawrence 1993; Khanna 1998). This is further complicated by the large number of species available for planting on sites or across particular regions of interest, that have the potential to produce commercial timber. As a result, much of the early species selection and establishment techniques were developed by numerous individuals across a wide geographic region, through a 'trial and error' approach. The 1780 hectare CRRP in north and central Queensland, has been described (by researchers) as one large research trial including over 175 species across 646 properties from Cooktown to Sarina (Erskine *et al.* 2005a).

The existing technological knowledge of growing mixed-species plantations in tropical and sub-tropical, eastern Australia is fragmented across a large number of sources in this wide geographic region. The Queensland Department of Primary Industries and Fisheries (DPI&F) through its Horticulture and Forestry Science group is custodian of a proportion of this information, through long-term databases and the establishment of field trials since the mid 1980s in north Queensland. Community forestry groups, forestry consultants and private forest growers also have a great deal of information but are dispersed widely throughout eastern Queensland and northern New South Wales. A number of universities including Southern Cross University, University of Queensland, Griffith University and James Cook University, have conducted post-graduate research studies in mixed-species technologies. The CSIRO has also conducted research activity, primarily in the study of the nutrition of mixed-species and cabinetwood plantations.

As may be expected, the delivery of this complexity in guidelines which permit the successful establishment of mixed-species plantations by interested growers across this wide geographic area, is a difficult task. In recent years, numerous government-assisted farm forestry schemes, extension services and research programs have been either terminated or scaled-down. This has resulted in the loss of substantial information and individual expertise in mixed-species plantation technologies. Much of the information held within research organisations is also difficult to access by private growers and the previously strong links between research groups and the community, have been eroding slowly over time (Erskine *et al.* 2005b). In this new climate of reduced funding and greater competition, some groups have become quite isolated and in certain cases competitive rivalries and inter-group antagonisms have emerged. At the same time however, there has been resurgence in public interest in growing mixed-species plantations in the coastal regions of Queensland and northern New South Wales and the public need for this information is increasing.

Objectives

The goal of this project was to rebuild, maintain and enhance technological communication networks between the main stakeholders involved with mixed-species plantations in Queensland and New South Wales. By working with these groups and individuals, information on the latest technologies was identified, collated and summarised. This information was combined with DPI&F information resources, and communicated to interested growers and stakeholders to improve the regional understanding of mixed-species plantation technologies in Queensland and northern New South Wales.

The six main project objectives were as follows.

- To improve understanding of high-value tropical timber mixed-species plantations through extension with growers, extension officers, and research staff in north eastern Australia (eastern Queensland and northern New South Wales).
- To collate and summarise the results of key trials and develop productivity models of best-bet species and species mix configurations. Specifically to measure and maintain existing experiments in north Queensland and establish and measure growth plots in key mixed-species plantings across the regions.
- To collect, collate and analyse data from these trials and to use current productivity models and financial viability models to match key species-site relationships.
- To hold a series of (12-16) one-day workshops in target regions (5 in NQ, 1-3 in CQ, 5-7 in SQ and 1 in NNSW) to present results and extend management prescriptions for establishment and management, including spacing, thinning and pruning in single and mixed-species plantations of high value tropical timber species.
- To develop effective communication and provide extension services to growers of mixed-species plantations in north-eastern Australia through field based activities on-line and hard copy publications and extension material.
- To contribute to a final mixed-species plantations project workshop with key researchers, extension staff and tree growers to summarise and present the project results. Discussions from this project will form part of the final project report.

In order to effectively deliver the project objectives across the target area of tropical and sub-tropical, eastern Australia, it was essential to initiate, develop and maintain strong linkages with the fragmented and often isolated sources of mixed-species plantation technologies in this region. The main collaborators who contributed to the delivery of project objectives are indicated in Table 1.

Utilising these networks, information on mixed-species plantation technologies was gradually identified and collated to deliver the six project outcomes to interested stakeholders throughout Queensland and northern New South Wales. The six project objectives have three main project components: (1) species to site productivity assessment (2), best-bet mixed species configurations and (3) extension of information.

Table 1:List of key organisations and contacts who collaborated with this project.

Description	Location	Key contact
<i>Private Forestry Development Committees</i>		
Private Forestry North Queensland	NQ (Kairi)	David Skelton
Central Queensland Forest Association	CQ (Rockhampton)	Bruce Williams
Private Forestry South Queensland	SQ (Gympie)	Cliff Radattz
Northern Rivers Private Forestry	NNSW (Tweed)	J. McGregor Skinner
<i>Community Groups</i>		
AFG – Mossman	NQ (Mossman)	Bob Goodsell
AFG – Atherton Tablelands	NQ (Tablelands)	Bood Hickson
AFG – Charters Towers	NQ (C. Towers)	Diane Walker
AFG – Mackay-Whitsunday	CQ (Mackay)	G. McKenzie
Island Coast Agroforestry	NQ (Tully)	Mick Taifalos
Whitsunday Rivers ICM Association	NQ(Proserpine)	Leigh Scott
Noosa Landcare	SQ (Pomona)	Gary Clarke
Barung Landcare	SQ (Maleny)	Mim Coulstock
Forest Farmers Association	SQ (Brisbane)	Phil Wilson
Sub-tropical Farm Forestry Association	NNSW (Lismore)	Martin Novak
<i>Forestry Consultants</i>		
Northern Skills Alliance	NQ (Tully)	B. Vollemaere
Northern Resource Management	NQ (Cardwell)	Max Bell
Rod Collins Consulting	NQ (Ingham)	Rod Collins
Queensland Timber Plantations	SQ (Yandina)	John Steele
Roseash Consultants	SQ (Landsborough)	Ashley J Sewell
Jack Mitchell Forest Farming System	SQ (Samford)	Jack Mitchell
<i>Universities</i>		
James Cook University	NQ (Cairns)	Roger Leakey
University of Queensland	SQ (Brisbane)	Peter Erskine
Griffith University	SQ (Brisbane)	John Kanowski
Southern Cross University	NNSW (Lismore)	Kevin Glencross

Species by site productivity assessment

Introduction

To determine the species suitability and productivity that may be achieved on a particular site type (within a particular climatic region), it is necessary to establish and monitor taxa-evaluation trials or superimpose growth inventory plots, across the most representative site types within the region. While short-term growth data (< 3 years) is useful and can be quickly generated, it should be treated with some caution as early species performance can be misleading. Steady growth trends and long-term survival rates generally regulate after this period and consequently, plantation growth data of > 3 years are generally the greatest value in assessing medium to long-term plantation productivity on a particular site. An important factor influencing a species' performance on a particular site type, is plantation management (Dickinson *et al.* 1998). The level of management inputs (e.g. establishment and stand management techniques) can often override site factors such as soil type, greatly complicating the interpretation of species to site productivity. Consequently, plantings which had not been managed well (particularly those with poor weed control) were not included in this study.

In this study, a species to site productivity assessment was conducted for north and central Queensland sites by examining a number of key DPI&F trials and over 90 growth plots in existing CRRP plantings. In southern Queensland, where older, mixed-species plantations are scarce, site productivity assessment was conducted through the establishment and monitoring of new growth plots in a number of existing private plantations managed by the two consultants, Mr. Jack Mitchell and Mr. John Steele.

Methodology

North Queensland DPI&F trials

In north Queensland, DPI&F has established or collaborated with the establishment of numerous mixed-species or cabinetwood plantation experiments since the late 1980's. Over time, however, a number of these plantings have failed or been compromised in some way due to species/site incompatibility, incorrect management (e.g. weed control), fire, climate (e.g. cyclones, frost, drought), or animal damage (e.g. wild pigs, cattle). Nevertheless, a number of useful plantings remain and as many of these are now well established, they contain much useful information on species to site productivity and best-bet mixed-species configurations. A list of these pre-existing experiments selected for management and re-measurement within this project is shown in Table 2.

Most of these trials were re-measured for the general growth parameters of height, diameter at breast height (DBH), stem straightness and survival. More detailed growth and physiological measurements were conducted for selected experiments (756 ATH, 757 ATH, 785 ATH) via doctoral studies funded by an ARC-Linkage project (LP0349299), between DPI&F and Southern Cross University, undertaken by Ms Mila Bristow. This project is titled '*Mixed-species plantations; does diversity help tropical eucalypts grow faster, better, longer?*' Additional log measurements were also conducted for Experiments 785 ATH and 802 ATH as part of a concurrent JVAP Project (USC-7A) '*Wood-quality analysis from high value mixed-species agroforestry systems*' which formed the major component of another Southern Cross University PhD study being undertaken by Mr Kevin Glencross.

This chapter reports the two older experiments 708 ATH and 802 ATH under the heading 'DPI&F trials', and experiment 799 ATH which measured the CRRP growth plots. The results from a number of other DPI&F trials are discussed in the following chapter (Best-bet mixed species

configurations) of this report. A list of species scientific and common names is provided in Appendix 5.

The two older experiments 708 ATH and 802 ATH, which were measured at ages 18 and 13.5 years respectively, yielded particularly useful information on long-term species to site productivity. Experiment 708 ATH is a species evaluation trial and investigated 11 native and exotic tropical timber species for plantation suitability at Innisfail (described at age 10 years by Annandale and Keenan (2000) and cited in Bristow *et al.* 2005a). Most plots were 8 rows x 8 trees, with 1–3 treatment replicates. The initial stocking was 1234 stems/ha, however plots were thinned to 612 trees/ha at age 4 years. Experiment 802 ATH is a *Grevillea robusta* provenance trial at Kairi on the Atherton Tablelands and investigated the performance of 12 provenances from Queensland and New South Wales. Plots were established as 5-tree line plots and treatments were replicated 10 times. Trees were thinned from 1000 to 600 trees/ha at age 3 years.

To maintain experimental integrity for future years and allow future long-term monitoring, experimental management was also conducted for both the existing and new trials. This included maintenance activities such as refilling, herbicide weed control, slashing, tree marking, thinning, pruning and regular liaison with collaborating landowners and plantation managers.

Table 2: Existing north Queensland DPI&F experiments measured and maintained in this project.

Exp. No.	Location	Description	Tree age at last measurement
799 ATH	Cooktown - Sarina	112 CRRP growth plots	5.5-10.5 years
708 ATH	Innisfail	Species evaluation	18 years
747 ATH	Various NQ sites	Vegetative propagation	8 years
756 ATH	Mena Creek	Eucalypt, acacia taxa trial	9 years
757 ATH	Danbulla	Eucalypt x acacia mix trial	10 years
785 ATH	Babinda	Species pairwise mixtures	7 years
802 ATH	Kairi	<i>Grevillea robusta</i> provenances	13.5 years
863 ATH	Mossman	Species pairwise mixtures	2 years
861 ATH	Walkamin	<i>Santalum</i> species/host trial	2 years

CRRP growth plots

The Community Rainforest Reforestation Program (CRRP) was a joint commonwealth, state and local government initiative, which ran from 1992–1998, and extended from Cooktown in north Queensland to Sarina in central Queensland. Over the life of this program, approximately 1780 hectares of mixed-species plantations were established across 646 properties and included over 175 tree species (Erskine *et al.* 2005a). Over time, approximately 112 growth inventory plots were established and monitored within the most successful plantations from Ingham – Cooktown, as experiment 799 ATH (Table 2). Growth plots were established using standard DPI&F plantation yield plot methods (Department of Forestry 1979) and aimed to include 60 trees in plots 6 rows x 10 trees in size. Further experimental details, plot establishment and measurement methodology is fully described in Keenan and Annandale (1999), McNamara (2003) and Bristow *et al.* (2005b). Within this current project, the majority of existing growth plots was re-measured and eight new growth plots (Table 3) were established in CRRP plantations in the previously unstudied Sarina-Mackay-Proserpine region, to provide species to site information for a new productivity assessment.

A total of 90 growth measure plots within these existing CRRP plantations, was re-measured for the parameters of height and diameter at breast height. Forty-eight (48) growth measure plots were measured for straightness (scale 1–5, where 1 = poor) to determine short-medium-term species growth performance and site to species relationships. At the time of measurement, these plantations

varied in age from 6–11 years of age and included a total of 40 tropical rainforest and eucalypt tree species. These sites were distributed from Cooktown in the north (15° 26') to Sarina in the south (21° 27'), ranging from 5 to 1660 m above sea level, with annual rainfall from 800 mm to 4300 mm, on a range of basaltic, metamorphic, alluvial and granitic soils (Bristow *et al.* 2005b).

The measurement results were analysed and summarised by Ms Mila Bristow (and others, see Bristow *et al.* 2005b) as part of ARC-Linkage project (LP0349299), and presented as a chapter in the edited publication “*Reforestation in the tropics and sub-tropics of Australia using rainforest tree species*”, published by RIRDC and the Rainforest CRC (see Erskine *et al.* 2005).

South Queensland growth plots

In southern Queensland, there have been fewer government subsidised tree-establishment programs for private landowners, with most mixed-species plantations established independently and with much individuality by private landowners. In this region there have emerged two large private forestry establishment consultants, who have developed their own technologies and have been contracted to establish numerous plantations since the 1980s. Mr Jack Mitchell, a private consultant and the architect of the ‘Jack Mitchell Forest Farming System’ has been operating in southern Queensland since 1983 and has now established many mixed-species cabinetwood plantings throughout southern Queensland (Figure 1). Discussions were held with Mr Mitchell, and his collaboration secured with the establishment of 10 growth monitoring plots in four existing plantings, aged from 1–11 years (Experiments 659 a-d HWD, Table 3). The newer plantings reflect his improvement in planting design, with continued modification to species configurations and silvicultural management in each planting year.

Figure 1 Jack Mitchell (left) and landowner beside mixed-species planting at Imbil, age 1.5 years.



‘Queensland Timber Plantations’ (QTP) is owned and operated by Mr John Steele and has been operating in the Sunshine Coast hinterland since 2001. Originally this group utilised the ‘Jack Mitchell Forest Farming System’. However in recent years this company has progressively developed its own techniques for mixed-species cabinetwood plantation design and management. Mr Steele’s company is well known in local farm forestry networks in this region with numerous plantings in the Sunshine Coast and Brisbane valley regions. This company was also enthusiastic about collaborating and consequently eight growth monitoring plots were established in three plantations, aged 2–3 years in the Sunshine Coast Region (Experiments 657a-c HWD, Table 3).

Table 3: New DPI&F experiments and growth inventory plots established in this project.

Exp. No.	Location	Description	Tree age at last measurement
654a HWD	Dayboro, SQ.	Mixed-species configurations	1 month
654b HWD	Montville, SQ.	Mixed-species configurations	1 month
654c HWD	Finch Hatton, CQ	Mixed-species configurations	12 months
657a HWD	Yandina, SQ	QTP design, 4 growth plots	3.3 years
657b HWD	Eudlo, SQ	QTP design, 2 growth plots	3.3 years
657c HWD	Mooloolah, SQ	QTP design, 2 growth plots	3.1 years
659a HWD	Silkwood, NQ	Mitchell design, 6 growth plots	1.8 years
659b HWD	Mt Sampson, SQ	Mitchell design, 2 growth plots	8.3 years
659c HWD	Camp Mountain, SQ	Mitchell design, 1 growth plot	3.9 years
659d HWD	Bunya, SQ	Mitchell design, 1 growth plot	10.9 years
799-106 ATH	Koumala, CQ	CRRP design, 1 growth plot	8 years
799-107 ATH	Sarina, CQ	CRRP design, 1 growth plot	7 years
799-108 ATH	Eton, CQ	CRRP design, 1 growth plot	8 years
799-109 ATH	Mirani, CQ	CRRP design, 1 growth plot	10 years
799-110 ATH	Mirani, CQ	CRRP design, 1 growth plot	9 years
799-111 ATH	Mirani, CQ	CRRP design, 1 growth plot	8 years
799-112 ATH	Calen, CQ	CRRP design, 1 growth plot	8 years
799-113 ATH	Calen, CQ	CRRP design, 1 growth plot	7 years

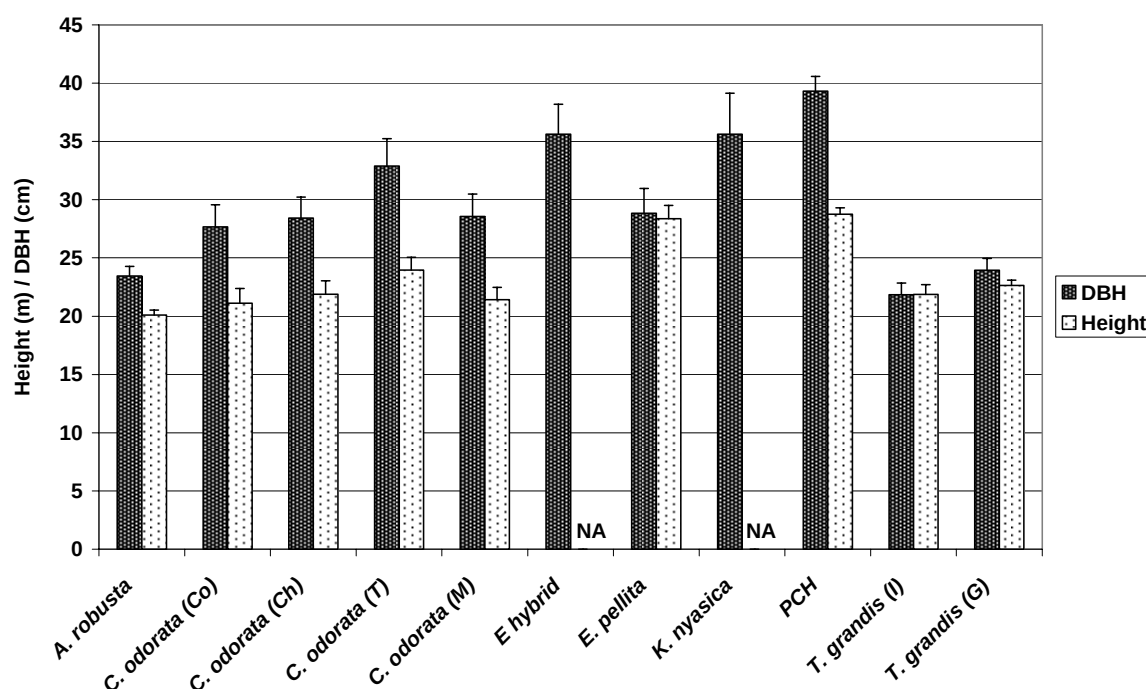
Discussion of results

North Queensland DPI&F trials

708 ATH: Cabinetwood species trial

The height and DBH growth of the 11 tropical timber species grown as monocultures and measured in this trial at age 18 years are illustrated in Figure 2. These results are a good indication of longer-term species potential on this fertile soil, a red Ferrosol (Isbel 1996) in tropical north Queensland, with this experiment experiencing a number of cyclones, low-intensity fires and many years of competition with vigorous, shade tolerant tropical grasses. Best growth was measured for *Pinus caribea* var. *hondurensis* (PCH), a low-value timber species but also the species most commonly grown in DPI&F timber plantations in tropical Queensland (DPI&F 2005). Other species which performed well on this site with growth rates of > 2 cm DBH increment / year were *Khaya nyasica* and the *E. grandis* x *E. tereticornis* hybrid. The four provenances of *Cedrela odorata* (three from Honduras; Coyote, Taulabe and Chaelecon and one from Nicaragua; Matagalpa) also performed well, although there was considerable variability within and between provenances. This indicates that there is substantial potential for productivity gains through the genetic improvement of this species. *Eucalyptus pellita*, from the Kuranda provenance, had good height and moderate DBH growth. Growth was slowest in *Agathis robusta* and the two provenances of *Tectona grandis* (Ingham and Gordonvale) however this is often characteristic of these species and may be offset by the high timber values that these species return.

Figure 2 Taxa development within experiment 708 ATH measured at age 18 years, with standard error bars.

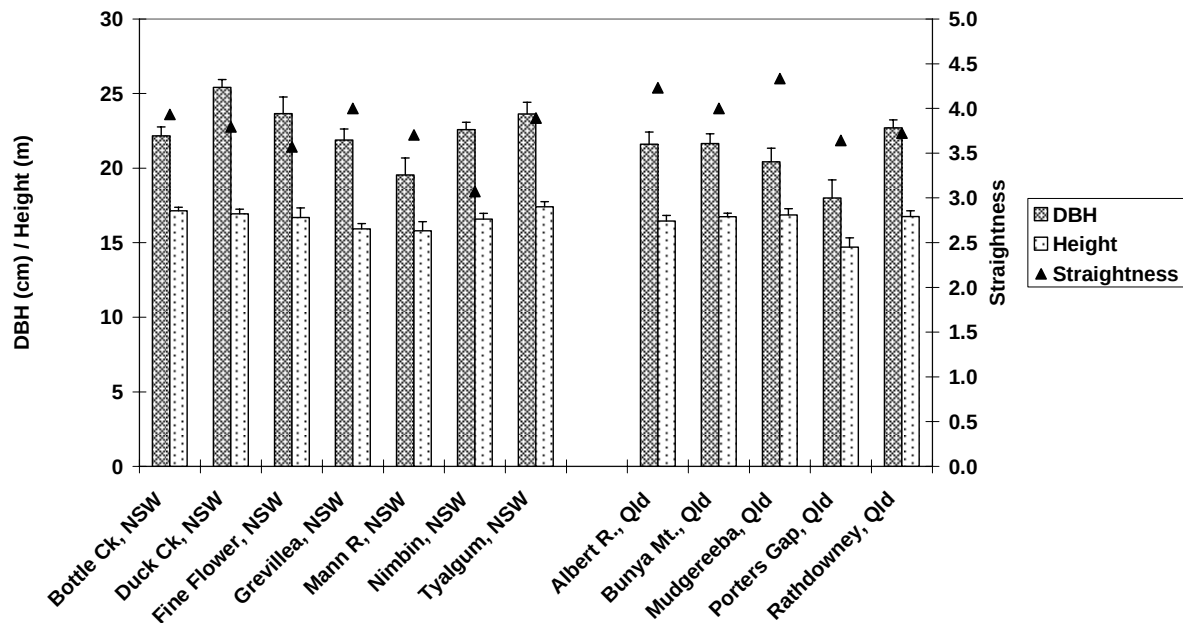


802 ATH: *Grevillea robusta* provenance trial

The measurements of DBH, height and stem straightness (scale 1–6, where 6 is best) collected at age 13.5 years for the 12 *G. robusta* provenances, are presented in Figure 3. Species growth on the fertile red Ferrosol soil type has been quite good, and there has been substantial variability between and within provenances. The best provenances were from NSW, with average DBH growth up to 25 cm for the Duck Creek, Tyalgum and Fine Flower provenances. The best Queensland provenance was Rathdowney, which is situated on the Qld/NSW border. It is interesting to note that provenance rankings in this trial are much the same at age 13.5 years as that recorded by Sun *et al.* (1995) at age 3.3 years. Stem straightness was variable between provenances, but may be better within the slower growing Queensland provenances. While *G. robusta* is often not considered suited to monoculture plantings due to allelopathic effects (Webb *et al.* 1967), the trees in this trial appeared quite healthy and would be considered one of the best examples of *G. robusta* plantation growth in this region.

The tree stocking within this trial at age 13.5 years was still relatively high, at approximately 500 trees/ha. This high density is likely to have slowed growth among a number of individuals. Consequently the trial was thinned to approximately 250 trees/ha after measurement and a number of timber samples collected for wood quality analysis within a concurrent JVAP project (USC-7A). This has removed many of the poorest individuals, particularly in the poorer performing provenances and it is anticipated that this trial will be a useful future seed production area for *G. robusta* in this region.

Figure 3 Provenance development within experiment 802 ATH, measured at age 13.5 years, with standard error bars.



CRRP growth plots

Results from the last measurement of CRRP growth inventory plots (2002), established as mixed-species plantings, were comprehensively analysed and summarised by Bristow *et al.* (2005b). The authors found that due to variability of growth-determining factors including climate, soils, plantation designs and silvicultural management between growth inventory plots, it was difficult to produce reliable species to site productivity assessments (Bristow *et al.* 2005b). After analysis of the accumulated data, these authors considered it was most useful to present the growth measurements by a ranking of average species growth for the most common 32 species (where $n > 10$ in each soil and rainfall class), at age eight years, as measured across all site types. These results, as presented in Table 4 are taken from Table 3 from Bristow *et al.* (2005b). Species which were limited to only a few site types, have been marked with an asterix (*).

As reported in Bristow *et al.* (2005b), the results in Table 4 identify several eucalypts and some rainforest cabinetwood species with very good, early growth rates and a wide variability in species to site suitability across the range of soil types and climatic zones (rainfall) examined in north Queensland. The best growth rates (> 2 cm per year on one or more site types) among eucalypts were recorded for *E. urophylla*, *E. dunnii*, *E. resinifera*, *E. pellita*, *E. and cloeziana*, and for rainforest cabinetwoods was recorded for *Acacia mangium*, *Grevillea robusta*, *Melia azedarach*, *Elaeocarpus grandis*, and *Nauclea orientalis* (Bristow *et al.* 2005b). These species are recognised fast-growing and sun-loving species and have performed very well on particular sites.

The remaining species measured in this study have exhibited slow to moderate growth rates on the range of site types investigated (Bristow *et al.* 2005b). For some species growth was correlated with climatic variables (McNamara 2003; Bristow *et al.* 2005b), however, these results may be due to the species' natural growth characteristics (e.g. slow-growing, shade tolerant species), but also incorrect site matching (e.g. not all species were trialled on all site types), improper plantation design (e.g. may have been suppressed by other dominant species) and inappropriate silvicultural management (poor weed control, plant nutrition, thinning). In a number of later CRRP plantations, a common plantation design for the high rainfall, coastal basalt sites involved alternate rows of *E. pellita* with a row of

mixed cabinetwoods such as *F. brayleyana*, *F. schottiana*, *Agathis robusta* and *Castanospermum australe*. Throughout the life of these plantations (e.g. eight years), *E. pellita* has had the greatest and most sustained growth. In contrast, the growth of the rainforest cabinetwoods was often slow to begin with, but generally began to accelerate after about two years. As was often the case however, on-going stand management (thinning) was not conducted as planned (at about age four years), and eventually the dominant *E. pellita* has suppressed the growth of all other species (Bristow *et al.* 2005b).

Table 4: Species development in mixed plantations at age 8 years, averaged across CRRP growth inventory plots in north and central Queensland (from Bristow *et al.* 2005b). (*n* is number of trees measured.)

Rank	Species	DBH (cm)	Ht (m)	Form	<i>n</i>
1	<i>Eucalyptus urophylla</i> *	26.86	21.57	4.3	11
2	<i>Acacia mangium</i>	26.03	15.69	3.0	93
3	<i>Eucalyptus dunnii</i> *	19.90	16.81	4.5	21
4	<i>Eucalyptus resinifera</i>	18.51	13.69	3.5	71
5	<i>Eucalyptus pellita</i>	17.76	14.58	4.0	565
6	<i>Grevillea robusta</i>	17.74	12.00	3.8	46
7	<i>Melia azedarach</i>	17.74	13.15	3.2	25
8	<i>Elaeocarpus grandis</i>	17.63	13.02	4.2	248
9	<i>Nauclea orientalis</i>	17.00	9.79	4.1	38
10	<i>Eucalyptus cloeziana</i>	16.88	15.32	3.9	409
11	<i>Eucalyptus camaldulensis</i>	15.64	14.03	3.5	135
12	<i>Alphitonia petrei</i>	15.02	9.90	3.4	27
13	<i>Eucalyptus acmeniodes</i> *	14.97	10.03	3.2	46
14	<i>Flindersia brayleyana</i>	14.66	12.05	4.0	393
15	<i>Cedrela odorata</i>	14.17	9.20	3.2	57
16	<i>Eucalyptus tereticornis</i>	13.87	12.34	3.5	194
17	<i>Eucalyptus drepanophylla</i>	13.30	12.50	3.7	58
18	<i>Araucaria cunninghamii</i>	12.54	8.26	4.2	307
19	<i>Cardwellia sublimis</i>	12.45	9.58	3.8	13
20	<i>Terminalia sericocarpa</i>	12.05	8.78	3.6	53
21	<i>Corymbia torelliana</i> *	11.77	8.30	3.3	78
22	<i>Corymbia citriodora</i> subsp. <i>citriodora</i> *	11.32	12.84	3.7	57
23	<i>Eucalyptus tetradonta</i>	10.79	8.48	3.9	20
24	<i>Khaya nyasica</i>	10.63	9.22	4.1	48
25	<i>Blepharocarya involucrigera</i>	10.62	6.99	3.3	31
26	<i>Agathis robusta</i>	9.23	6.62	4.1	291
27	<i>Flindersia schottiana</i>	9.15	7.36	3.7	74
28	<i>Tectona grandis</i> *	9.14	7.76	4.3	10
29	<i>Paraserianthes toona</i> *	8.11	5.85	2.7	80
30	<i>Khaya senegalensis</i> *	7.80	5.34	3.5	55
31	<i>Castanospermum australe</i> *	7.55	7.40	3.5	134
32	<i>Flindersia pimentelliana</i> *	7.49	7.00	3.5	21

* species in limited planting or few site types

Within CRRP plantings in the Mackay/Whitsunday region, a number of rainforest species such as *Elaeocarpus grandis* and *Flindersia brayleyana* have not performed as well as they have in the north Queensland plantings (Graham McKenzie, *pers. comm.*). The climate in this region, is generally drier than the wet tropics of north Queensland with most sites receiving between 1000 – 2000 mm mean annual rainfall, over a shorter wet season, with high annual rainfall variation.

It is unfortunate that the cabinetwood species *Trema orientalis* (peach cedar) was only included in very small numbers within the CRRP in central Queensland, and consequently has not been measured within the CRRP growth inventory plots. In the few cases where it was planted however, it has performed exceptionally well (Figure 4) and has become a high priority cabinetwood species for recent mixed species plantations in the central Queensland region (Graham McKenzie, *pers. comm.*).

Figure 4 Measurement of DBH (40 cm) on *Trema orientalis*, aged seven years at Sarina.



South Queensland growth plots

The measurements of tree height and DBH growth for three Jack Mitchell plantings and three QTP plantings are given in Tables 5 and 6 respectively. Within these mixed-species plantations, a total of 17 cabinetwood species were measured (n = number of trees measured), in plantations varying from 3.1 to 10.9 years of age.

Results from these six plantations indicate that moderate to high growth rates can be achieved by rainforest cabinetwoods in sub-tropical southern Queensland. Four species in particular, *Aleurites moluccana*, *Elaeocarpus grandis*, *Grevillea robusta* and *Melia azedarach* demonstrated very good growth rates across the range of sites investigated. Three species, *Flindersia brayleyana*, *F. schottiana* and *F. xanthoxyla* were more variable, but generally demonstrated moderate-good growth rates across the sites where they were included. The potential for these species in sub-tropical mixed species plantations was recognised by the two consultants many years ago, and it is not surprising that these seven species are the most common in each of the six plantations studied. While species such as *Castanospermum australe*, *Gmelina leichhardtii* and *F. australis* have exhibited slower growth rates across the sites where they were included, they are recognised for their high timber value and are a small, but important component of each consultant's designs, for the long-term production of high quality and high value timbers.

When these measurements were taken, none of the six plantations had been heavily thinned. The original plantation tree stockings of approximately 1111 trees/ha, had only been reduced over time by tree mortalities and some minor culling to a minimum of 720 trees/ha. In the two older Jack Mitchell plantations (8.3 and 10.9 years), this high plantation stocking would be inducing strong inter-tree competition, slowing tree growth of many individuals and possibly resulting in the complete suppression of weaker individuals or less competitive species. It is understood that both of these plantations are due for commercial thinning soon, which should reduce these inter-tree competition effects and allow individual tree growth rates to continue or possibly increase.

Table 5: Tree development for three Jack Mitchell mixed-species plantations.

Tree species	Camp Mountain (age 3.1 years)			Mt Sampson (age 8.3 years)			Bunya (age 10.9 years)		
	DBH (cm)	Ht (m)	<i>n</i>	DBH (cm)	Ht (m)	<i>n</i>	DBH (cm)	Ht (m)	<i>n</i>
<i>Aleurites moluccana</i>	11.4	6.1	11	-	-	-	-	-	-
<i>Castanospermum australe</i>	3.9	4.6	3	7.7	8.0	4	7.0	9.9	1
<i>Dysoxylum muelleri</i>	-	-	-	-	-	-	7.8	9.3	2
<i>Elaeocarpus grandis</i>	7.7	7.2	24	14.6	12.1	54	17.9	14.7	31
<i>Euroshinus falcata</i>	1.6	2.3	5	-	-	-	8.2	8.2	3
<i>Flindersia australis</i>	2.7	2.9	18	5.0	4.7	1	-	-	-
<i>Flindersia brayleyana</i>	-	-	-	-	-	-	15.3	13.8	4
<i>Flindersia schottiana</i>	-	-	-	8.7	9.6	20	12.6	13.9	16
<i>Flindersia xanthoxyla</i>	7.2	4.7	13	10.2	7.7	9	10.3	8.8	10
<i>Gmelina leichhardtii</i>	6.7	5.3	12	9.5	9.1	5	-	-	-
<i>Grevillea robusta</i>	7.9	7.3	11	14.2	12.6	7	13.3	14.6	1
<i>Harpullia pendula</i>	-	-	-	5.01	6.0	16	5.9	7.3	3
<i>Melia azedarach</i>	7.3	7.7	38	12.7	9.6	65	12.7	11.8	21
<i>Polyscias elegans</i>	-	-	-	17.7	11.6	1	-	-	-
<i>Rhodosphaera rhodanthema</i>	2.4	2.9	7	9.0	6.4	15	-	-	-
<i>Toona ciliata</i>	4.5	3.1	2	-	-	-	10.5	8.3	1

Table 6: Tree development for three QTP mixed-species plantations.

Tree species	Yandina (Age 3.1 years)			Eudlo (Age 3.3 years)			Mooloolah (Age 30.3 years)		
	DBH (cm)	Ht (m)	<i>n</i>	DBH (cm)	Ht (m)	<i>n</i>	DBH (cm)	Ht (m)	<i>n</i>
<i>Aleurites moluccana</i>	11.4	6.6	8	12.4	7.2	4	14.0	8.4	3
<i>Elaeocarpus grandis</i>	10.5	10.0	12 2	8.0	8.2	84	10.9	10.0	62
<i>Dysoxylum fraserianum</i>	-	-	-	3.8	5.5	1	-	-	-
<i>Flindersia australis</i>	-	-	-	5.8	5.1	2	-	-	-
<i>Flindersia brayleyana</i>	6.9	7.3	11	3.6	3.9	5	7.5	7.8	6
<i>Flindersia schottiana</i>	4.9	4.7	2	-	-	-	5.5	5.7	1
<i>Flindersia xanthoxyla</i>	2.7	4.0	1	-	-	-	-	-	-
<i>Gmelina leichhardtii</i>	4.5	4.0	4	4.1	4.4	2	3.7	4.1	4
<i>Grevillea robusta</i>	8.1	6.8	28	9.5	7.7	16	10.3	8.3	15
<i>Melia azedarach</i>	10.9	8.7	8	13.2	9.0	4	11.5	7.7	4
<i>Toona ciliata</i>	9.8	5.8	2	5.3	7.3	1	5.2	3.7	1

Best-bet mixed species configurations

Introduction

Once the most appropriate tree species for a particular site have been identified, the next challenge for mixed-species plantation growers is to develop an appropriate design for their plantation. In the early CRRP plantings, and in some recent restoration, environmental, and amenity plantings, species configuration is usually random, with little consideration for future, inter-specific competition or plantation management. Consequently, in random designs, fast-growing, sun-loving species can quickly dominate the plantation, resulting in suppression and even death of the slower-growing species (Lamb *et al.* 2005). Plantation management is also complicated, particularly in relation to thinning and harvest operations (see Keenan *et al.* 2005 for an example with *Flindersia brayleyana*). It can be very difficult to remove the larger trees in a plantation without damaging the remaining slower-growing species, which have not yet reached a commercial size.

Managing inter-specific competition and conducting efficient harvest operations are the two main factors which have impeded the use of mixed-species plantations on a larger scale. In Queensland, semi-operational plantings of *Araucaria cunninghamiana* mixed with exotic pine species including *Pinus elliotii* and PCH were trialled by the Queensland government in the 1960 and 70's, however were not adopted for these reasons (Simpson and Osborne 2004). In recent times, the advances in mixed-species plantations designs throughout sub-tropical and tropical eastern Australia have focused on developing suitable configurations to address these two main issues.

To simplify species selection, it is easiest to group plantation species into two categories (1) fast-growing and sun-loving (e.g. *Elaeocarpus grandis*, *Trema orientalis*, *Acacia mangium* and most eucalypts) and (2) slow-growing and/or shade tolerant (e.g. *Flindersia brayleyana*, *Flindersia schottiana* and *Castanospermum australe*). Advanced mixed-species design configurations can take this into account and basically allow two strategies. The first is to plant species with similar growth rates and light tolerance together. The block can then be able to be managed in a similar way to a monoculture, although it is not always easy to predict an individual species performance on a particular site. The second and more popular option is to plant species from each of these groups in a strategic design (usually in rows) which reduces inter-specific competition and will allow safer harvesting of the faster growing species at an earlier age (Nagle 1994).

To identify the latest best-bet mixed-species configurations for the region, various examples were examined. These included a number of key DPI&F research trials and operational mixed-species plantations established by the CRRP, private growers and consultants. In addition, three new mixed-species configuration trials were established in southern and central Queensland, with assistance from local community groups, to compare the latest range of techniques, with a number of monoculture control plots.

Methodology

Existing DPI&F research trials

In north Queensland, several existing middle-aged DPI&F research trials were re-measured (Table 2). Trials examining mixed-species configurations, included a number of pairwise mixtures trials (756, 757, 785 and 863 ATH) and a *Santalum* species x host interaction trial (861 ATH). Pairwise mixtures are a simple mixed species plantation concept, involving only two species planted in alternate rows. Experimental variability, as seen in the *ad hoc* design of earlier CRRP plantings, is minimised in pairwise mixtures, allowing the easier interpretation of species interactions. After inspection, measurement and analysis, the data from these five DPI&F trials were examined and the results from 757 ATH, 785 ATH and 861 ATH considered reliable enough for further summary.

757 ATH: *Acacia x eucalypt* trial

The trial is a simple randomised complete block, testing 5 treatments, replicated twice. Treatments one and five are monocultures of *E. pellita* (100 E) and *A. aulacocarpa* (100 A) respectively, treatment three consists of alternate rows of the two species (50E:50A), while treatments two and four consist of one row of pure species adjacent to an alternating mix of the two species within the row, (75E:25A) and (25E:75A) respectively. The trees were established in February and March 1995 at an initial stocking of 1000 stems per hectare. Although this trial was damaged by cyclones in March 1997 and March 1998, resulting in > 50% mortality, average species composition remained relatively unchanged within treatments. As a result, average tree stocking/treatment was reduced to 430, 500, 450, 300 and 480 trees/ha for treatments one, two, three, four and five respectively. All treatments were measured for height and DBH at age 10 years.

785 ATH: *Pairwise cabinetwood mixtures* trial

Experiment 785 ATH, located at Babinda, is a randomised complete block design, investigating 10 treatments including pairwise combinations of *Eucalyptus pellita*, *Eleocarpus grandis*, *Flindersia brayleyana* and *Acacia aulacocarpa*, and single species monocultures of each species. Treatments were established in plots of 8 rows x 14 trees and were replicated three times. The initial planting density was 2 m x 2 m = 2500 trees/ha which was progressively thinned to approximately 650 trees/ha by age seven years. Establishment methodology and early results of this trial are presented in Bristow *et al.* 2005a. Measurements of tree height, diameter and survival were conducted in March 2004, at a tree age of seven years.

This trial experienced some cyclone damage in 1998 and 1999, prior to the last thinning operation. Consequently tree stockings were reduced across most plots, with a few plots severely compromised. For most plots, these effects were largely rectified within the last thinning operation, however some species stocking variations remain. Over the seven years, a number of plots in the north-eastern corner of the trial (mainly replicate one) had poor growth and treatment performance was quite different from other replicates. It is probable that this is due to greater soil degradation (loss of most topsoil) from previous land uses. In order to remove this additional variability from the trial results, these plots with severe cyclone damage or poor growth rate were removed from the analysis, hence the results presented here are based on means of either two or three replicates.

861 ATH: *Santalum species x host* trial

Experiment 861ATH, located at Walkamin, investigated nine provenances of *Santalum album*, two provenances of *S. lanceolatum*, three provenances of *S. macgregorii* and one provenance of *S. austrocaledonicum* planted with seven host treatments. The host treatments were *Khaya senegalensis*, *Citrus limon*, *Casuarina cunninghamiana*, *Acacia victoriae*, *A. crassicaarpa* and mixed treatments (alternating within a row) of *C. cunninghamiana*/ *Citrus limon* and *C. cunninghamiana*/*A. crassicaarpa*. Host treatments were established as 20-tree line plots, with trees 4 m apart. Sandalwood treatments were established in a method described by Robson (2003), one year later as single tree plots within the host treatment rows, midway (2 m) between two long-term hosts. At the time of sandalwood establishment, an intermediate host (*Sesbania*) was planted approximately 30 cm from the sandalwood tree, to provide early host benefit, until the sandalwood root system could reach the more distant longer-term hosts. All trees were measured in early 2005, at a tree age of two years (*Santalum* treatments) and three years (host treatments).

New DPI&F research trials

Most DPI&F research activity in mixed-species plantations has been focused in north Queensland. It was recognised that while there was increasing interest in mixed-species plantations in other areas of the state, there was little supporting research activity. To meet this need, three new trials were designed in southern and central Queensland. These were located at Dayboro, southern Queensland (654a HWD), Montville, southern Queensland (654b HWD) and Finch Hatton, central Queensland (654c HWD). Each trial examined local species of interest and incorporated a range of tree planting designs as experimental treatments (Table 7). Initial tree stocking at all sites was approximately 1111 trees/ha. The three trials were established in March 2003 (654a HWD), April 2003 (654c HWD) and July 2003 (654b HWD).

Table 7: Experimental treatments in mixed-species configuration trials, 654a/b/c HWD.

Description	Species used	654a	654b	654c
Monocultures	<i>Eleocarpus grandis</i> (EG)	X	X	-
"	<i>Grevillea robusta</i> (GR)	X	X	-
"	<i>Flindersia brayleyana</i> (FB)	X	X	-
"	<i>Flindersia schottiana</i> (FS)	X	-	-
Single species/row	EG & GR	X	-	X
"	EG, GR & FB	X	X	-
"	EG, GR, FB & FS	X	-	-
"	EG & <i>Acacia mangium</i> (AM)	-	-	X
"	EG & <i>Trema orientalis</i> (TO)	-	-	X
"	AM & GR	-	-	X
"	AM & <i>Melia azedarach</i> (MA)	-	-	X
"	AM & TO	-	-	X
"	TO & MA	-	-	X
"	TO & GR	-	-	X
Completely randomised	EG, GR, FB & FS	X	X	-
Primarily EG, with mixtures of other species	EG, GR, FB, FS, MA, <i>Araucaria cunninghamiana</i> , <i>Agathis robusta</i> & <i>Castanospermum australe</i>	X	X	-
Primarily FB, with mixtures of other species	FB, EG, TO, MA, GR, AM	-	-	X
Primarily FS, with mixtures of other species	FS, EG, TO, MA, GR, AM	-	-	X

Initially, all three trials established well, however severe frosts in late July 2003, caused significant deaths amongst most species (except *G. robusta*) in experiment 654a HWD at Dayboro. The landowner considered that severe frosts were uncommon on this site, and that these were the most severe frosts he had observed on his property in 20 years. Vacant tree positions were refilled with more frost hardy species (*Araucaria bidwillii*, *Araucaria cunninghamii* and *G. robusta*) in November 2003 however this site was no longer useful for further monitoring. Growth and survival was also poor in experiment 654b HWD at Montville, with this site experiencing light frosts, poor weed management and frequent mammal browsing over the 2 years to 2005. This site has also not been measured since establishment.

Experiment 654c HWD at Finch Hatton (average rainfall 1663 mm), west of Mackay, has exhibited the best growth and survival of the three new trials. Moderate frosts (the worst on record for this region) were recorded in late July 2003 and damaged some species particularly *Eleocarpus grandis* and *F. brayleyana*, however overall trial health has been good. Rainfall over the first 16 months, has also been considerably lower than average for this site. Measurement of tree height and survival for all species was conducted at age 1.3 years.

Operational plantations

The wide variety of operational plantings established over the past 15 years are a good demonstration of the gradual development and improvements in mixed-species planting configurations. These include the range of mixed-species designs developed over the life of the CRRP from 1992–1998. In southern Queensland, continued refinements have led to the development of some quite complex designs as developed by individuals, consultants and community groups. In the more complex designs, considerable intellectual property is associated with these advancements, and some groups were reluctant to share the finer details of individual species placement. Where possible, the main designs adopted by these groups were studied and summarised in this project.

Discussion of results

DPI&F research trials

757 ATH: *Eucalyptus* x *Acacia* trial

Measurements of average tree height and basal area for individuals of *E. pellita* and *A. aulacocarpa* and the total plot are presented in Table 8. There is little difference in average tree height or basal area for either species in any of the five treatments. The slight increase in individual tree basal area in the 25E:75A treatment is most likely due to the benefits of the lower tree stocking (300 trees/ha) in this plot as compared with the other treatments (430–500 trees/ha). This preliminary analysis indicates that on this site that the greatest effect on tree growth is stocking. The growth of *E. pellita* has been much better than that of the *A. aulacocarpa* trees. This is demonstrated in the results for total plot basal area, which takes into account stocking/ha, with increasing plot BA with increasing percentage of *E. pellita* within the mix.

Table 8: Stand development at age 10 years, for the five eucalypt/acacia mix treatments.

Treatment	Eucalypt			Acacia			TOTAL
	Ht (m)	Mean stem BA (m ²)	Plot BA (m ² /ha)	Ht (m)	Mean stem BA (m ²)	Plot BA (m ² /ha)	Plot BA (m ² /ha)*
100E	20.5	0.06	23.50				23.50 a
75E:25A	20.8	0.06	21.90	10.0	0.02	1.41	23.32 a
50E:50A	19.9	0.06	10.40	12.8	0.02	5.37	15.76 b
25E:75A	20.7	0.07	8.42	11.7	0.03	5.36	13.78 b
100A				12.0	0.02	10.76	10.76 b

* Treatments followed by the same letter are not significantly different from each other ($p < 0.05$).

785 ATH: *Cabinetwood* pairwise mixtures trial

Stand development for the various pair-wise and monoculture combinations at age seven years are summarised in Table 9.

Table 9: Stand development at age seven years for four timber species grown as monocultures or as pairwise mixtures in experiment 785 ATH.

Companion species	<i>E. pellita</i>		<i>F. brayleyana</i>		<i>Ela. grandis</i>		<i>A. aulacocarpa</i>	
	DBH (cm)	H (m)	DBH (cm)	H (m)	DBH (cm)	H (m)	DBH (cm)	H (m)
<i>E. pellita</i>	22.3	23.5	12.7	12.4	14.0	14.9	10.5	10.7
<i>F. brayleyana</i>	26.3	23.2	17.0	16.2	19.0	16.5	14.1	13.3
<i>Elaeocarpus grandis</i>	22.5	21.6	11.9	12.2	18.2	17.3	12.1	11.7
<i>A. aulacocarpa</i>	22.0	19.9	16.4	16.2	21.1	17.4	14.1	12.4

E. pellita has performed very well on this site with exceptional height and diameter growth across all treatments (Table 9). Best growth was however achieved in the mixtures with *Flindersia brayleyana*. Two potential explanations for this are, firstly that intra-specific competition within the vigorous *E. pellita* was reduced by having only about half the stocking of the *E. pellita* monoculture treatments. The slower-growing *F. brayleyana* trees would have little competitive effect on the larger *E. pellita* trees at this age. The second explanation is that *E. pellita* is noted for its thin and narrow crown which limits its ability to shade out weeds and hence minimize long-term weed competition. Heavy weed growth was observed in all *E. pellita* treatments, except the pairwise mixture with *F. brayleyana*, where the denser canopy of the companion species had greatly reduced weed growth/competition and potentially improved the growth of the *E. pellita* trees.

F. brayleyana has performed well on this site (Table 9), with good growth rates recorded in the monoculture treatment. In this treatment there is almost complete canopy cover, with virtually no weeds. Growth of *F. brayleyana* was also good in the *A. aulacocarpa* mixture treatments, which could be attributed to less inter-specific competition due to the poorer performance of the acacia or possibly some benefits from N fixation (although this was not identified in earlier N fixation studies in this trial, see Huynh Duc Nhan (2001)). At this age, the poorest growth was measured in the very competitive *E. pellita* and *Elaeocarpus grandis* mixtures.

Elaeocarpus grandis achieved very good growth rates across most treatments (Table 9) except in the *E. pellita* pairwise mixture where inter-specific competition appears to have greatly reduced growth. Growth in the *A. aulacocarpa* and *F. brayleyana* mixtures was similar or slightly better than that in the *E. grandis* monoculture. In these treatments, the improved growth of individuals of *Elaeocarpus grandis* is likely to be attributed to its greater competitiveness over these other species, and the reduced intra-specific competition from a lower number of *Elaeocarpus grandis* trees in this treatment.

A. aulacocarpa was the poorest performer on this site (Table 9). While growth was moderate, form was very poor and survival was variable with numerous losses to cyclones (particularly the bigger trees). Growth was best in one of the pairwise mixtures with *F. brayleyana*, where the denser canopy may have reduced weed competition. Growth was poorest in the *E. pellita* treatments where vigorous inter-specific competition is likely to have reduced growth rates.

In order to compare the relative productivity of each of the 10 configuration treatments, calculations of tree basal area and treatment basal area/ha were made for each species within the mix. These calculations are presented in Table 10.

Table 10: Mean tree basal area (TBA), mean number of individuals/plot (*n*) and plot basal area (PBA) for individual species (y axis) within the 10 configuration treatments (x axis) in experiment 785 ATH at 7 years of age.

Treatment *	<i>E. pellita</i>			<i>F. brayleyana</i>			<i>Ela. grandis</i>			<i>A. aulacocarpa</i>			Total
	TBA m ²	<i>n</i>	PBA m ² /ha	TB A m ²	<i>n</i>	PBA m ² /ha	TBA m ²	<i>n</i>	PBA m ² /ha	TBA m ²	<i>n</i>	PBA m ² /ha	PBA m ² /ha
EP/FB	0.054	11.3	21.3	0.013	10.7	4.7	-	-	-	-	-	-	26.0
EP	0.039	17.5	23.8	-	-	-	-	-	-	-	-	-	23.8
EG/AA	-	-	-	-	-	-	0.035	14.5	17.6	0.013	12	5.6	23.2
EG	-	-	-	-	-	-	0.026	24	22.1	-	-	-	22.1
EP/AA	0.038	13.5	17.9	-	-	-	-	-	-	0.009	13.5	4.1	22.0
EP/EG	0.040	9.7	13.4	-	-	-	0.014	15.7	7.4	-	-	-	20.8
EG/FB	-	-	-	0.011	12	4.6	0.029	14.5	14.7	-	-	-	19.3
FB	-	-	-	0.023	20.5	16.3	-	-	-	-	-	-	16.3
FB/AA	-	-	-	0.016	11	6.2	-	-	-	0.016	14	8.0	14.2
AA	-	-	-	-	-	-	-	-	-	0.016	19.5	10.2	10.2

(* AA = *Acacia aulacocarpa*, EP = *Eucalyptus pellita*, EG = *Elaeocarpus grandis*, FB = *Flindersia brayleyana*)

The measurements of mean tree basal area (m²) and plot basal area (m²/ha) give a good indication of the relative productivity of each of the mixed species design configurations. While cyclone damage has caused some variability in tree stocking/ha amongst plots, and the health of *A. aulacocarpa* has suffered from random but severe pest attack (Bristow *et al.* 2005a), there are still some obvious trends visible. From these results it can be seen that *Eucalyptus pellita* is the most productive species, followed by *Elaeocarpus grandis*, *Flindersia brayleyana* and *Acacia aulacocarpa*. Intra-specific and inter-specific competition seems to be the main factors driving relative species performance in each of the configuration mixes. Comparing the mean tree basal areas measured for each species within different configuration treatments, gives a good idea of these competitive relationships. Individuals of the competitive species *E. pellita* and *Elaeocarpus grandis* have generally performed better when mixed with less aggressive species such as *F. brayleyana* and *A. aulacocarpa*, than they have when mixed together or as higher-density monocultures. Not surprisingly, the best individual growth of the poorly competitive *F. brayleyana* and *A. aulacocarpa*, was achieved when they were planted as monocultures or as pairwise mixtures with each other.

861 ATH: *Santalum* species x host trial

Tree heights for the *Santalum* species and host treatments as measured at ages two and three years respectively are given in Figures 5 and 6. For the range of *Santalum* species tested, there is considerable variation in early growth across the range of host treatments. It is likely that at this young age, the long-term host treatment effects are yet to be fully expressed and that for the past two years, the sandalwood trees have been primarily parasitizing the nearby *Sesbania* intermediate host as well as possibly grass and broadleaf leaf weeds. Done *et al.* (2004) suggests that overly-competitive species such as *Khaya senegalensis* can have detrimental long-term effects and that nitrogen fixing species such as *Casuarina* and *Acacia* are the most successful long-term hosts. It is likely that the performance of these host species in this trial will be more apparent over the next 2–3 years.

Figure 5 Mean height growth of the four *Santalum* species at a tree age of 2 years, grown with seven host treatments in experiment 861 ATH, with standard error bars.

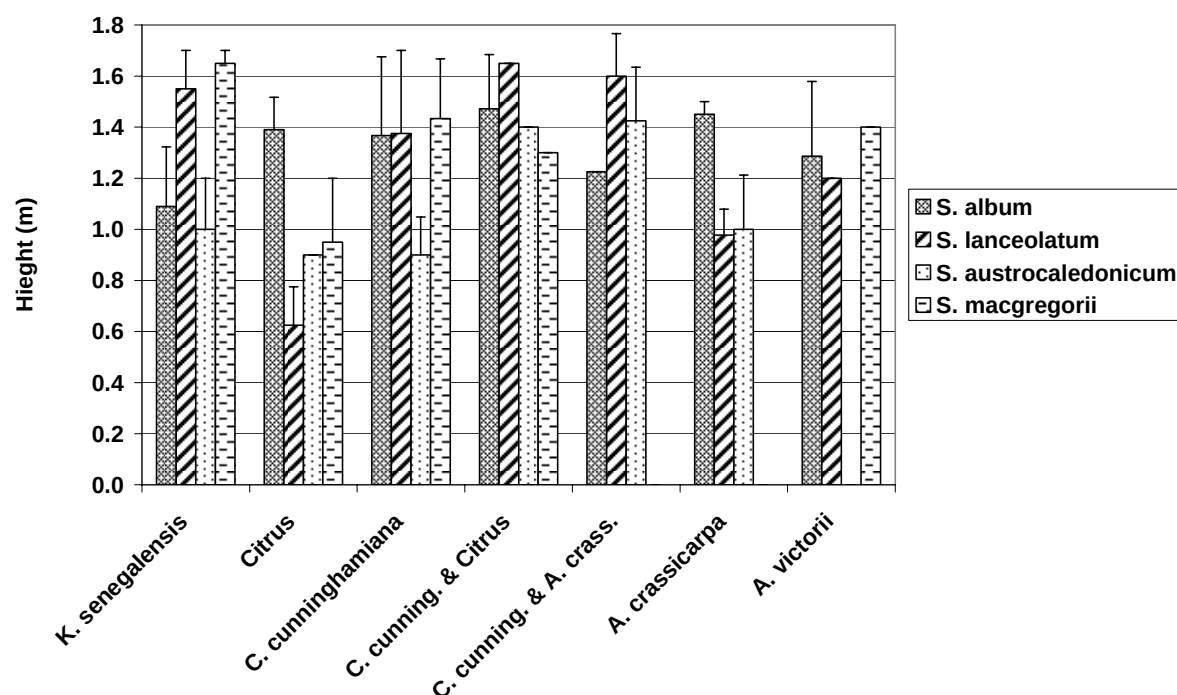
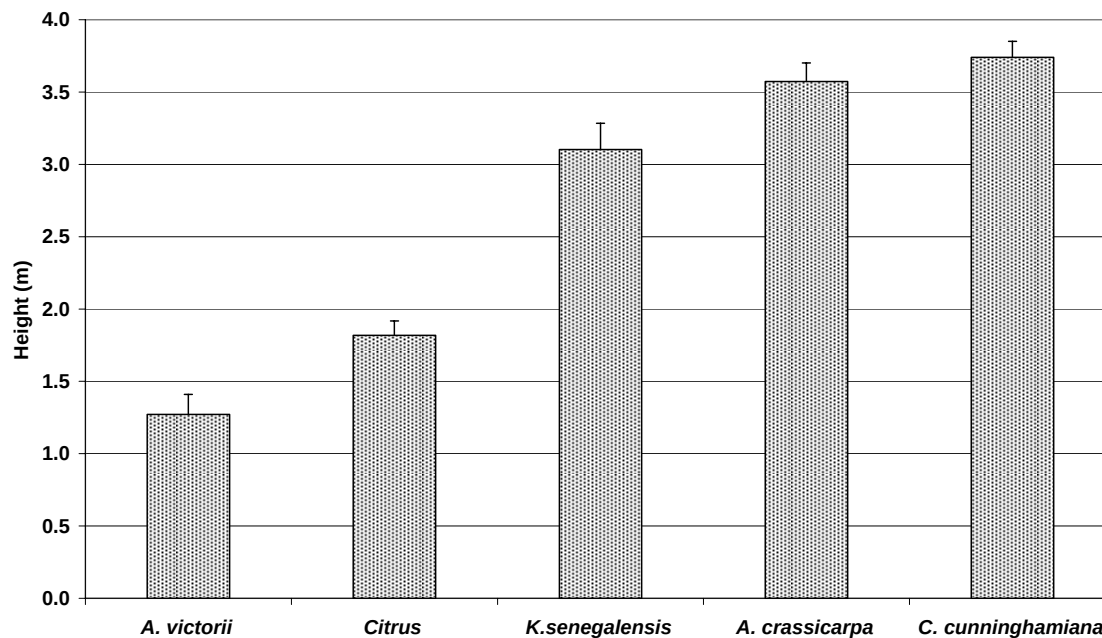


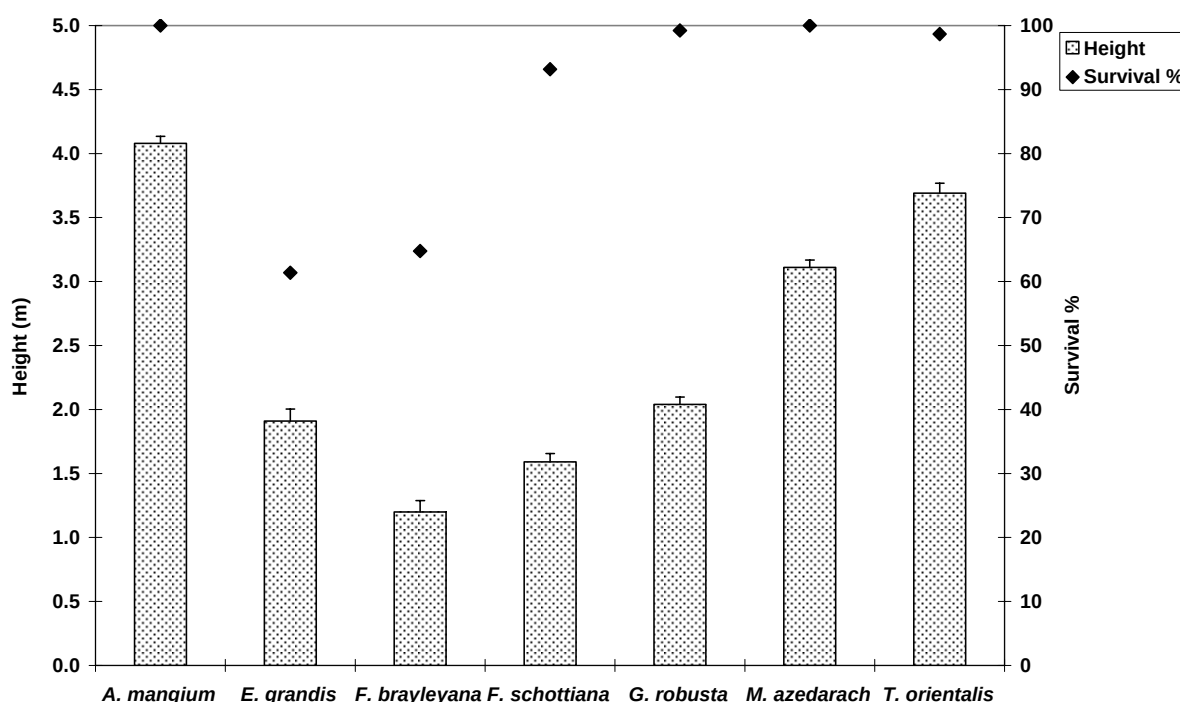
Figure 6 Mean height growth of the five host species at a tree age of 3 years in experiment 861 ATH with standard error bars.



654c HWD: Mixed species configuration trial

Stand development for the seven cabinetwood species at age 1.3 years are summarised in Figure 7. These results are presented on an individual species basis, rather than as configuration treatment, as there are no treatment effects at this early tree age.

Figure 7 Mean height growth of the seven cabinetwood species at a tree age of 1.3 years in experiment 654c HWD, with standard error bars.



These results, while still quite early, indicate the good potential for species such as *A. mangium*, *T. orientalis*, and *M. azedarach* for these higher rainfall sites in the central Queensland region. *Elaeocarpus grandis* and *Flindersia brayleyana* have not performed as well on this site, due to the early frosts in 2003 and below average rainfall over the first 16 months.

Operational plantations

CRRP plantations

The CRRP (1992–1998) provides a range of examples of early mixed species planting configurations (Erskine *et al.* 2005b; Lamb *et al.* 2005b). Originally plantings were random mixtures which included a diverse range of species and species growth characteristics. Initial plantation stockings were also low, with initial plantings established at 5m x 3m spacing (666 trees/ha). Irregular plantation growth, poor site capture and high tree mortalities, all contributed to problems with weed competition, which was a major cause of overall plantation failure. As experience grew and technologies were improved, tree stockings were increased, many of the poorer performing species were discarded and plantation configurations were developed to accommodate species' differential growth characteristics; although this was not reflected in better overall plantation success (Erskine *et al.* 2005b). Towards the end of the program the typical plantation design was to establish trees at a spacing of 4 m x 2.5 m (1000 trees/ha) and to alternate rows of fast-growing and slower growing species. Generally the faster growing row comprised a single or mixture of species such as *Acacia mangium*, *Eucalyptus pellita* or *Elaeocarpus grandis*, with the slower growing row usually mixtures of species such as *Flindersia brayleyana*, *F. schottiana*, *Castanospermum australe* and *Agathis robusta*. After the closure of this program in 1998, mixed species plantations continued to be planted on a small scale. Unfortunately without a coordinating body, much of the extension experience with mixed species technologies in this region has gradually been lost. New plantings are now generally established based on nursery advice, landowners experience, or from written information in a few key publications (e.g. Bristow *et al.* 2005).

South Queensland plantings

In southern Queensland, the development of design configurations for mixed-species plantations originally followed the same path as that experienced by the CRRP. However, since 2000 there has been sustained public interest in mixed species plantations encouraging the development of mixed species plantation technologies to continue through the activities of various consultants, individuals and community groups.

One of the simplest and most effective mixed species configurations to be developed and utilised by some southern Queensland community groups and Rose-ash consultants, has been to establish single alternate rows of best-bet species. In south Queensland, this is often *G. robusta*, *F. brayleyana*, *F. schottiana*, and *Elaeocarpus grandis*. This design has also been utilised for some mixed-eucalypt plantations, including *E. cloeziana*, *E. pilularis* and *Corymbia citriodora* subsp. *variegata*.

The most complex designs practiced in Queensland are those used by the consultants Jack Mitchell and Queensland Timber Plantations. In both systems, the design incorporates alternate rows of fast-growing species (often single rows of *Elaeocarpus grandis*), and a selection of slower-growing species, such as *F. brayleyana*, *F. schottiana*, *M. azedarach*, *Grevillea robusta*, *Gmelina leichardtii*, *Aleurites moluccana* and *T. ciliata*. In some examples, the fast-growing species may be included at wide intervals, in the slow-growing row (e.g. every 5th tree position). Trees are planted at close spacings, 3 m x 3m (1111 trees/ha) and are intensively managed. This involves complete weed control (rows and inter-rows) and close attention to form and branch pruning. The first commercial thinning in both systems is planned for age 8–12 years, and will achieve the removal of most or all of the trees in the fast-growing row. The remaining trees will then be allowed to continue to grow to commercial size, with selective harvesting occurring from age 20 years. Where present, coppice from harvested trees (e.g. *Elaeocarpus grandis*) will be managed for future harvests, thus allowing the concept of a continuous (perpetual) plantation with ongoing management and harvest operations.

Summary of key results from the mixed species trials

In more than one trial, the sun-loving or ‘sprinter’ species had a larger basal area when grown in monoculture than in mixes. These species may be better suited to monocultures.

Tree stocking rate is important for managing growth competition between species. High plantation stocking can be expected to induce strong inter-tree competition, slowing tree growth of many individuals and possibly resulting in the complete suppression of weaker individuals or less competitive species. This can affect the productivity and health of the plantation.

Sprinters with similar growth rates and high site demands should be managed for stocking and competition (as in monoculture), otherwise the growth of one or both species in a mix will be slowed (e.g. *Elaeocarpus grandis* and *Eucalyptus pellita* in experiment 785 ATH).

Frost and lack of weed control will limit the success of cabinet species plantings – planting times, sites and management should be chosen accordingly. In some cases, incorporating a species with a denser crown might help to shade out weeds (e.g. experiment 757 ATH). However this requires further testing, for example to verify the reason for the higher growth of *E. pellita* when planted with *Flindersia brayleyana* – this might be due to a weed-shading effect, or lower stocking and competition effects.

Earlier research indicates that nitrogen-fixing hosts may possibly be best for sandalwood, and fast growing hosts with strong competition may be detrimental to sandalwood in the long term. The sandalwood x host species trial (861 ATH) is too young to determine the best species mix. Hosts which are growing well at 3 years of age are *Casuarina cunninghamiana* and *Acacia crassicarpa*.

Extension activities

Introduction

In southern Queensland, a successful extension program for private eucalypt plantations was conducted from 1997–2003 using combinations of demonstration plantings, research trials, field days, seminars, extension literature and web-based research notes (Bailey *et al.* 2001). In order to communicate the collated and summarised information on mixed-species technologies across tropical and sub-tropical eastern Australia from this project, similar extension strategies were adopted. The project communication strategy was:

- a series of one-day workshops conducted throughout north, central and southeast Queensland and northern New South Wales
- the presentation and discussion of information summarised by DPI&F in the JVAP publication, ‘Growing Rainforest Timber Trees: A farm forestry manual for north Queensland’ (Bristow *et al.* 2005a), covering species and site selection, plantation design, establishment techniques, spacing, pruning, thinning and marketing;
- the production and distribution of new extension publications, to summarise the results of this study, through extension networks including regional plantation committees, Australian Forest Growers and other farm forestry groups, timber cooperatives, Landcare groups, State government extension services, and courses on farm forestry being developed by the academic institutions
- a final mixed-species plantations workshop where project outcomes and latest mixed species plantation technologies were presented
- presentation of results in peer-reviewed literature and at appropriate public seminars, community meetings, workshops and conferences.

Methodology

Publications and seminars

As the new and existing DPI&F experiments (Tables 2 and 3) were measured, analysed and summarised, the latest results were assessed for their suitability for various publication styles. Additional information about mixed-species technologies collected from individuals, community groups and consultants was also collated. This information was incorporated in extension handouts, pamphlets and field tour/workshop notes and distributed to workshop participants and interested stakeholders. Individual experiment or site summaries were summarised in the form of research updates and these were distributed as hard-copies or stored electronically for public access via the Queensland government web site www.dpi-qlld.gov.au/hardwoods/qlld. Articles were prepared for magazines such as Agroforestry News and Agroforestry Today. Where more detailed scientific information was collected, a number of key workshop and conference poster papers and presentations were prepared and published within the event proceedings.

Much of the work in this current JVAP project was an extension of activities conducted in the preceding JVAP project DAQ-240A ‘Silviculture of Rainforest Cabinetwoods’ that was managed by DPI&F from 1998–2002. A final milestone of the original project was the production of ‘Growing Rainforest Timber Trees: A farm forestry manual for north Queensland.’ (Bristow *et al.* 2005a). The communication strategy for this current project included to develop information in the JVAP manual and to present it to stakeholders through project workshops and seminars. Once published, ground truthing and extension of the manual was to form part of this current project’s activities. Unfortunately the manual was not printed until near the end of the current project; nevertheless the content of the manual, which was available to the authors, formed a major component of the presentations and discussions held at each regional workshop. The manual was available for

inspection and mail order purchases at the final two public workshops (Nambour and Lismore) and the final project workshop at Cairns.

Over the duration of this project, several public, mixed-species plantation presentations were given at workshops, seminars, conferences, community forums and community meetings by DPI&F researchers. The main events are summarised in Table 11.

Table 11: Details of public presentations and seminars conducted by this project.

Event	Location	Date	Presenter
James Cook Agroforestry Day	Cairns	04/02/03	M. Bristow
RIRDC Bio-Industries Workshop	Sth Johnstone	12/02/03	G. Dickinson
PFSQ General Meeting	Maleny	26/02/03	G. Bailey
Rural Innovation Expo	Yarraman	11/04/03	G. Bailey
Maleny Wood Expo	Maleny	3/05/03	G. Bailey
“What have we learnt from planting rainforest timber trees in Australia?” workshop (JVAP project WS023-20) supported by UQ/JVAP/Rainforest CRC/QDPI	Brisbane	16-17/06/03	M. Bristow G. Nikles J. King
Rainforest CRC Conference	Cairns	10/11/03	M. Hunt
Qld Landcare Conference/Workshop	Gympie	23/08/03	J. Huth
PFNQ General Meeting	Mareeba	30/01/04	G. Dickinson
Malanda EnviroForum	Malanda	21/03/04	G. Dickinson
Mareeba/Barron Catchment group	Mareeba	09/08/04	G. Dickinson

Public workshops

Seven mixed-species plantation workshops were conducted in north and central Queensland. In all cases, these workshops were conducted in close collaboration with local groups and individuals and in some cases formed a component of a larger farm forestry field day or workshop training events. Details of the seven workshops are included in Table 12.

Table 12: Details of workshops held in north and central Queensland.

Location	Date	Collaborating organisations	Description
Walkers property, Charters Towers.	April 2003	Charters Towers AFG, FNQ Training	Seminar and field tour of mixed-species & monoculture plantings.
Various properties, Mackay.	April 2003	Mackay-Whitsunday AFG	Seminar and field tour of mixed-species & monoculture plantings.
Various properties, Mossman.	May 2003	Mossman AFG, FNQ Training	Seminar and field tour of mixed-species plantings.
Taifalos property, Silkwood.	August 2003	Island Coast Agroforestry, FNQ Training	Seminar and field tour of mixed-species & monoculture plantings.
Marti Property, Atherton.	September 2004	Atherton Tablelands AFG, Southern Cross University	Seminars, stand management training & field tour of mixed-species planting.
Various properties, Ingham.	February 2005	Rod Collins Consulting, Taifalos nurseries.	Seminars, nursery display and field tour of mixed-species plantings.
Various properties, Proserpine.	February 2005	Mackay-Whitsunday AFG, Whitsunday Rivers ICM	Seminar and field tour of mixed-species & monoculture plantings.

Six mixed-species plantation workshops were conducted in southern Queensland and northern New South Wales. As in north Queensland, all workshops were conducted in close collaboration with

local groups and individuals and in some cases formed a component of a larger farm forestry field day or workshop training events. Details of the six workshops are included in Table 13.

Table 13: Details of workshops held in southern Queensland and northern New South Wales.

Location	Date	Collaborating organisations	Description
Various properties, Crows Nest	April 2003	Crows Nest Shire Council, DPI-Forestry, Jack Mitchell	Seminars and field tour of mixed-species & monoculture plantings.
Maleny Wood Expo	1 May 2004	Barung Landcare	Official major event sponsor, co-ordinated & presented key expo activities. Included morning mixed-species plantation seminars and afternoon bus tours of mixed-species & monoculture plantings.
Maleny Wood Expo	2 May 2004	Barung Landcare	
Maleny Wood Expo	3 May 2004	Barung Landcare	
Various properties, Sunshine Coast	March 2005	Barung Landcare, Noosa Landcare, PFSQ, Jack Mitchell, Qld Timber Plantations	Bus tour of mixed-species plantations and discussion of different goals, designs and species to site matching preferences used in this region by the main plantation groups.
Various properties, Lismore region	March 2005	Sub-tropical Farm Forestry Association, Northern Rivers Private Forestry, Southern Cross University.	Bus tour of mixed-species plantations and discussion of wood quality, plantation goals, designs and species to site matching preferences used in this region.

The information presented at the 13 regional workshops was largely based on the information in the JVAP publication 'Growing Rainforest Timber Trees: A farm forestry manual for north Queensland' (Bristow et al. 2005a). This publication had assembled much of the known information on mixed species plantations, collected from years of research trials and the experience of landowners and extension advisors. This information was complemented by some of the latest knowledge and results collected on mixed species configuration and species selection within the current project. Experienced local extension advisors and landowners in attendance at these workshops were also incorporated into the discussions to provide some of their valuable knowledge to the group. Where workshops were held in the field, existing mixed species plantations were used as valuable tools to demonstrate and discuss mixed species plantation design and management.

Mixed-species plantation workshop

A final Mixed-species Plantation Workshop was conducted on the 11th April 2005 at the James Cook University Campus at Smithfield Cairns. The objectives of the workshop were as follows;

- To present the results of this project, including latest mixed-species plantation technologies and their design, management, ecology, productivity estimates and timber quality.
- To provide a public forum to discuss these latest technologies and their importance for the future expansion of high-value plantations in eastern Australia.
- To promote the recent Joint Venture Agroforestry Program publication 'Growing Rainforest Timber Trees; A farm forestry manual' (Bristow *et al.* 2005a)

To achieve these project objectives a workshop agenda was developed (Table 14) and the workshop widely promoted through forestry e-mail networks, extensive industry contacts and the popular press. Mr Geoff Dickinson, the DPI&F principle investigator for this project, chaired and facilitated this workshop.

In the afternoon, the workshop component 'To mix or not to mix, that is the question?' was conducted. The group of approximately 40 participants was randomly divided into two. Each group was then asked to consider the following scenario.

“You have bought a 10 hectare property at Innisfail. It is a cleared ex-rainforest site, previously used for sugar-cane and is well suited to forestry with little slope and reasonable soils. It borders World Heritage rainforest. Which forestry option would you establish; a mixed-species cabinetwood plantation or a *Eucalyptus pellita* monoculture?”

The group was asked to identify the positive or negative characteristics for each plantation option under the three categories; (1) Commercial values, (2) Personal values and (3) Conservation and sustainability values. After an hour of facilitated group discussion, the participants were requested to present their findings and then for all participants in both groups to discuss and consider which option they found most appropriate for this example.

Table 14: Agenda for final Mixed-species Plantation Workshop at Cairns, 11/04/2005.

Start	Speaker	Topic	Finish
9:00	Mr. Geoff Dickinson, Scientist (Dept. Primary Industries & Fisheries)	Welcome and summary of JVAP project “Mixed-species plantations: Extending the Science” activities in Qld and NSW, 2002-05.	9:30
9:30	Dr. Peter Erskine, Research Fellow. (University of Queensland)	Mixed-species plantations principles and design	10:00
10:00	Ms. Mila Bristow, PhD candidate (Southern Cross University)	Measurements of growth and productivity of mixed-species plantations in north Queensland.	10:30
10:30	Dr. John Kanowski, Research Fellow & Dr. Carla Catterall, Assoc. Professor (Griffith University)	The comparative biodiversity value of mixed-species plantations vs. exotic and native species monocultures.	11:00
11:00		MORNING TEA	11:30
11:30	Mr. David Skelton, CEO (Private Forestry North Queensland)	Management of mixed-species plantations, experiences, lessons learnt and new directions.	12:00
12:00	Mr. Kevin Glencross, PhD candidate (Southern Cross University)	Assessment of wood characteristics and quality of plantation-grown rainforest cabinetwoods.	12:30
12:30		LUNCH	1:30
1:30	Workshop participants	Workshop: ‘Too mix or not to mix? That is the question!’ Participants will debate/discuss the benefits/disadvantages of mixed-species plantations based on the information presented in the morning talks and personal experiences.	3:30
3:30	Mr. Geoff Dickinson (DPI&F) & Ms Mila Bristow (Southern Cross Uni)	JVAP Book promotion ‘Growing Rainforest Timber Trees: A Farm Forestry Manual.’	3:45
3:45		Farewell & thanks	4:00
4:00		AFTERNOON TEA	4:30

Results and discussion

Publications and seminars

Project activities contributed to the data collection, analysis and/or preparation of several summary reports, popular press articles and workshop/conference proceedings (see below). For key experimental trials, the latest results were summarised in the form of research updates and were distributed as hard-copies or stored electronically for public access via the web site www.dpi-qld.gov.au/hardwoods/qld.

Articles which were published with support from this project are as follows:

- Bristow, M. Webb, M., Erskine, P., Brown, P. and McNamara, S. (2003). Queensland Maple: Growing prized cabinet timbers in Queensland's tropics. *Agroforestry News*. Winter 2003, Volume 12, Issue 2.
- Bristow, M., Brown, P. and Doley, D. (2003). Thinning Queensland maple: Promising results for farm forestry. *Australian Forest Grower*. Spring 2003, Vol. 26, No. 3.
- Department of Primary Industries and Fisheries (2005). **708 ATH/1. Evaluation of rainforest cabinetwood species for plantations at Innisfail**. DPI&F Hardwoods Research Update No. 708ATH/01.
- Department of Primary Industries and Fisheries (2005). **785 ATH/1. Mixed species design configurations in north Queensland**. DPI&F Hardwoods Research Update No. 785ATH/01.
- Department of Primary Industries and Fisheries (2005). **802 ATH/1. Grevillea robusta provenance evaluation trial on the Atherton Tablelands**. DPI&F Hardwoods Research Update No. 802ATH/01.
- Department of Primary Industries and Fisheries (2005). **861 ATH/1. Sandalwood species x host interactions in the dry tropics of Queensland**. DPI&F Hardwoods Research Update No. 861ATH/01.
- Huth, J.R and Dickinson, G.R. (2005). **A tour of mixed species plantations in northern New South Wales**. Tour notes, DPI&F, Gympie.
- Huth, J.R and Dickinson, G.R. (2005). **A tour of mixed species plantations in south-east Queensland**. Tour notes, DPI&F, Gympie.

Articles from independent yet complementary projects (indicated with an asterisk) which were used in the final workshops, field days and meetings included:

- *Bristow, M., Vanclay, J., Hunt, M. and Nichols, D. (2003). Mixed species plantations: Does diversity help tropical eucalypts grow faster, better, longer? Sustainable Tropical Forest Landscapes. In **Proceedings of the Rainforest CRC 10TH Annual Conference**, Cairns, 10-13 November, 2003. p 35.
- *Bristow, M., Vanclay, J., Hunt, M. and Nichols, D. (2004). North Queensland tropical eucalypt plantations, the advantages of mixes. **Pacific Islands Forests and Trees**, 02/04. pp 13-14.
- *Bristow, M., Erskine, P. McNamara, S. and Annandale, M. (2005). Species performance and site relationships for rainforest timber species in plantations in north and central Queensland. In **Reforestation in the tropics and sub-tropics of Australia using rainforest tree species** eds. Erskine, P.D., Lamb, D. and Bristow, M., RIRDC & Rainforest CRC, Canberra.
- *Hunt, M.A. (2003). Biodiversity versus production trade-offs: A production perspective. In **Production Versus Rainforest Biodiversity: Trade-offs or Synergies in Farm Forestry Systems?** Eds. Erskine, P.D. and Catterall, C.P., Rainforest CRC, Cairns, 41 pp.
- *King, J. and Lawson, S. (2005). Insect pests and diseases of rainforest timber species grown in plantations." In **Reforestation in the tropics and sub-tropics of Australia using rainforest tree species** eds. Erskine, P.D., Lamb, D. and Bristow, M., RIRDC & Rainforest CRC, Canberra.
- *Nikles, D.G. and Robson, K.J. (2005) Vegetative propagation and preliminary field performance

of sixteen rainforest tree species in north Queensland. *In Reforestation in the tropics and sub-tropics of Australia using rainforest tree species* eds. Erskine, P.D., Lamb, D. and Bristow, M., RIRDC & Rainforest CRC, Canberra.

The 11 public presentations and seminars (Table 11) were generally well received by the audience. Interest in mixed species plantations was greatest from private landowners and researchers. In most cases, large commercial forestry growers such as state governments or private forestry prospectus-based companies had little interest or involvement with these events.

Public workshops

A total of approximately 400 people attended the 13 workshops across eastern Queensland and northern New South Wales. The participants in these public workshops were primarily landowners with approximately half of these managing existing plantations and half interested in establishing new plantations on their properties. A small, but diverse range of community extension officers, researchers, students, consultants and government officials were other participants. All of these workshops were conducted with encouragement and support of the local farm forestry community groups in each of these regions. The format of these workshops varied widely depending on community interests in each region, the availability of resources, complementarity of the objectives of other regional extension groups and the recommendations of the collaborating community organisations.

In north Queensland, where many field days have been conducted in the past 10 years, local stakeholders were interested in events with multiple speakers and a range of equipment displays (e.g. Lucas mobile saw-mills, pruning equipment) and hands-on management demonstrations (e.g. pruning, tree selection). Copies of existing extension literature were made available and contact details for farm forestry extension/support were provided to interested participants. These types of workshops/field days were held at growers' properties at Charters Towers, Mossman, Silkwood and Ingham and included collaboration with groups such as FNQ Training, Private Forestry North Queensland, Rod Collins Consulting, Island Coast Agroforestry, AFG-Mossman, AFG-Atherton Tablelands and AFG-Charters Towers (Figure 8). Almost all mixed-species plantations visited in these workshops were established under the CRRP scheme or were DPI&F research trials.

Figure 8 Discussion of mixed species plantation technologies with landholders at the Ingham workshop.



In central Queensland, farm forestry extension is primarily conducted by one organisation, Australian Forest Growers (AFG) Mackay/Whitsunday, the largest AFG group in Australia. In this area, there are few complementary groups to work with apart from the local Private Forestry Development Committee (PFDC) and Central Queensland Forest Association (CQFA). The two workshops conducted in this region at Mackay and Proserpine, involved field tours and displays at grower's properties with existing CRRP mixed-species plantations of varying age classes (Figure 9).

Presentations were given at each site, which was then followed by an extensive field inspection, where mixed species technologies and general silvicultural questions were discussed with both existing and potential new plantation growers. Local extension literature was provided, as were contact details for future farm forestry extension/support services with the AFG-Mackay/Whitsunday group.

Figure 9 Presentation area at the Proserpine mixed species workshop (left) and field inspection and discussion of adjacent CRPP design and silvicultural management (right).



In southern Queensland, there is a strong plantation forestry culture and several farm forestry groups, consultants and individual landowners with good experience in private forestry including mixed species plantations. This allowed greater diversity in the workshop formats. At Crows Nest, a workshop similar to those in north Queensland was conducted involving numerous collaborators including Jack Mitchell, DPI Forestry and the Crows Nest Shire Council. On that day, there were several speakers, a number of plantations were inspected and several types of equipment and management techniques were demonstrated. In 2004, DPI&F played a major role in the co-ordination and presentation of some key activities at the Maleny Wood Expo. This event is held annually on the May Day weekend, attracts over 4000 visitors/year and is the largest farm forestry event in Queensland (Figure 10). For each of the three days, a mixed species seminar was presented in the morning, followed by a bus tour and inspection of mixed species plantations in the Maleny area in the afternoon with a range of expert guides.

Figure 10 View of some of the 2004 Maleny Wood Expo stalls and morning seminar facilities (left) and field inspection and discussion of mixed species plantation technologies on the afternoon field tours (right).



The last workshop held in southern Queensland in early March 2005, was a bus tour to inspect the latest plantation establishment and management techniques used in the region by the four main private forestry groups. Local interest was huge, with over 75 participants. The tour inspected plantations established by Barung Landcare, Noosa Landcare, Jack Mitchell and Queensland Timber Plantations where detailed presentations were given, equipment displays were provided and close group communication was encouraged (Figure 11). A common question asked by the participants was “After today, where can I go to find more information?” So, an important component of these workshops was to provide contact details for local extension support and consulting services.

Figure 11 South Queensland bus tour with demonstration of planting equipment by John Steele, QTP (left) and inspection of Noosa Landcare ‘whole property’ forestry establishment and management services (right).



In northern New South Wales, a bus tour (similar to the Nambour tour) was conducted at Lismore, in late March 2005. Strong collaboration was provided by the Sub-tropical Farm Forestry Association (SFFA), Southern Cross University and Northern Rivers Private Forestry groups. This tour had over 45 participants, visited a range of mixed-species plantations established with the SFFA and included scientific talks from university researchers on design configurations and wood quality (Figure 12). Project results on best-bet species for this region and options for various mixed species configurations were discussed at each site. In this region, there is a strong interest in the conservation values of mixed species plantations. As a result, additional effort was made to demonstrate the environmental benefits of these plantations and included a visit to plantations adjoining a nearby remnant of the ‘Big Scrub’. As a major component of this workshop, details of the local activities and services of the SFFA was discussed and contact addresses provided to the group.

Figure 12 Lismore bus tour with group inspecting a species configuration trial (left) and discussing timber quality of mixed species plantations with university researchers (right).



Mixed species plantation workshop

A total of 45 participants attended the final Mixed-species Workshop held at James Cook University on the 11th April 2005 (Figure 13). The participants represented a diverse range of stakeholder groups including landowners, contractors, consultants, nurserymen, researchers, community groups, forestry companies and government officials. The five invited speakers presented papers on a range of mixed species plantation technologies (Table 14). These included design concepts and configurations (Dr. Peter Erskine, UQ), productivity measurements (Ms. Mila Bristow, SCU), biodiversity values (Dr. John Kanowski and Dr. Carla Catterall, GU), management issues (Mr David Skelton, PFNQ) and wood quality (Mr. Kevin Glencross, SCU). Summaries of these presentations were provided by each of the authors (except Dr P. Erskine) and are included as Appendices 1-4. There was strong interest from the workshop participants in all presentations, with much discussion continuing into the morning tea and lunch-time breaks.

Figure 13 Morning seminar presentation of latest mixed species technologies.



The afternoon workshop was held with much enthusiasm and there was vigorous debate within groups, as individuals raised issues which were important to them (Figure 14). It was interesting to note that the two forestry options which were put before the group were recognised as the most viable options for this area. Alternatives such as monocultures of *Pinus caribea*, *Tectona grandis*, *Khaya nyasica* and some individual rainforest species such as *Flindersia brayleyana* were raised but were not pursued.

Figure 14 Group discussions in the afternoon workshop, ‘Too mix or not to mix? That is the question.’



After completing their discussions, workshop participants re-assembled and a representative of each group presented their findings. During these presentations, numerous topics were debated by the audience. A summary of the combined groups findings are summarised in Table 15.

Table 15: Positive and negative commercial, personal and conservation values for mixed-species and monoculture plantations identified by workshop participants.

	Mixed species	Monocultures
+ Commercial values	• Diversity of timber products • Greater flexibility for future timber fashions • Lower pest risks • Spread harvest income period • More options for value adding • High value, niche market potential • Greater scenic & consequent property value	• More predictable markets • May attract commercial investment • Less sovereign risk • Lower establishment, management and harvest costs • Easier marketing • Less damage to final crop when thinning • Supports other options (grazing) • Fewer resources (labour) required • Greater productivity / hectare • Faster growing, quicker returns • A more productive system • A more bullet-proof option
- Commercial values	• Higher establishment, management and harvest costs • More complex management and marketing • Right to harvest questionable in future • May lose plantation area to future buffer zones • Difficult to source skilled labour • Higher risks when thinning & harvesting • Lower critical mass, poorer markets	• Higher pest risks • Greater risk of fire or cyclone damage • Only one harvest, one market opportunity • Fewer product options • Lower scenic & consequent property value • Lower value of timber products
+ Personal values	• Greater aesthetics/scenic value • More liveable environment • Perception (feel-good) about biodiversity • Greater personal enjoyment/interest • High education values (ecology, biology)	• Looks like a commercial forest enterprise
- Personal values	• Can look unmanaged/scruffy • Poorer performing species reduce scenic value	• Lower scenic value • Looks barren, low biodiversity • Less interesting
+ Conservation values	• Greater biodiversity (flora & fauna) • Acts as a better wildlife corridor • Less run-off and site soil degradation • Selective harvesting, more sustainable • Better soils, water catchment quality • It may be formally recognised as high environmental, wildlife preservation value. • More resilient to climate change • Carbon usually remains stored in cabinetwood timbers longer than eucalypt products. • Returns the land to its original vegetation • May be easier to achieve plantation environmental certification	• Greater production thus greater carbon sink potential • Useful for koala food • Some soil enhancement/improvement
- Conservation values		• Soil degradation and depletion • Greater site damage with clear-fall harvesting • Greater potential to harbour weeds

After the group presentations were made, the following two questions were then asked:

- (1) In the described scenario would you establish a mixed-species cabinetwood plantation or a *Eucalyptus pellita* monoculture?
- (2) In the described scenario, would you prefer a mosaic design incorporating the two options?

The participants responses are given below in Table 16.

Table 16: Percent responses from workshop participants to the two questions, with actual numbers in brackets.

Plantation options	Question 1	Question 2
Mixed species cabinetwood plantation	68% (27)	28% (11)
<i>E. pellita</i> monoculture	32% (13)	3% (1)
Mosaic of both options	–	69% (28)

The workshop participants' responses in Tables 15 and 16, confirm that in north Queensland, there is strong preference amongst stakeholders for the establishment of mixed-species plantations in this region. However, when given an option of a mosaic of both mixed-species and monoculture plantations, the majority of participants (69%) considered this would be most appropriate for the scenario in question.

When the participant responses for the three values (commercial, personal and conservation) are examined, it can be seen that there is a general understanding that monocultures may be more economic, although mixed-species plantations have greater conservation and personal values. This result is similar to past surveys conducted in Queensland, by Emtage *et al.* (2001) and Herbohn *et al.* (2005), who reported that most private landowners planted trees on their properties primarily for non-commercial reasons.

Summary of results

Species by site productivity

Trial assessment results identified a number of cabinetwood and eucalypt species with good productivity and potential for particular regions and particular site types:

In north Queensland, a number of cabinetwood species have performed well in regions with > 1500 mm rainfall, with DBH increments of > 2 cm/year. These include *Elaeocarpus grandis*, *Acacia mangium*, *Flindersia brayleyana*, *Grevillea robusta* and *Nauclea orientalis*. Many other cabinetwood species had slow-moderate growth rates, although often these species have very high quality timber (e.g. *Tectona grandis*, *Castanospermum australe*), which should be considered when developing species recommendations for a region. In the regions with < 1500 mm rainfall, mainly eucalypt species performed best with *Eucalyptus cloeziana*, *E. resinifera*, *E. pellita*, *E. camaldulensis* and *E. drepanophylla* demonstrating DBH growth rates of > 2cm/year. Bristow *et al.* (2005b) give more detailed coverage of the CRRP results in north and central Queensland, and species response to region and broad soil groups.

Four species occurred in the CRRP data and one of the older age DPI&F trials measured at 13.5 and 18 years. The best provenances of *Grevillea robusta* in the Atherton trial achieved 25 cm DBH and 17 m height at 13.5 years age, compared with 17 cm DBH and 12 m height averaged over the CRRP sites at 8 years of age. The *Grevillea robusta* trial showed some provenance variation on the single site tested; selection of provenances for improved planting material is worthy of further investigation. In the trial measured at 18 years of age, the exotics *P. caribaea* var *hondurensis* (PCH), *K. nyasica*, *C. odorata* and the native *E. pellita* had the largest growth, and give some indication of what can be achieved over a longer term on a fertile site (23-28 cm DBH and 20-28 m height). Species which were in common to experiment 708 ATH and the CRRP data are shown in Table 17, and give a rough comparison of average growth at 8 years, and good growth at 18 years.

Table 17: Growth of species in common to experiment 708 ATH and CRRP data for north Queensland

	<i>E. pellita</i>	<i>K. nyasica</i>	<i>Agathis robusta</i>
CRRP average (8 years of age)	18 cm DBH 15 m Ht	11 cm DBH 9 m Ht	9 cm DBH 7 m Ht
708 ATH (18 years of age)	28 cm DBH 28 m Ht	35 cm DBH	23 cm DBH 20 m Ht

Early results indicate that sandalwood plantations (particularly *Santalum album*) and their hosts may also have potential in northern Australia.

In central Queensland, where mean annual rainfall is lower (1000–2000 mm) and less reliable than in north Queensland, growth rates were generally lower. The cabinetwoods *Acacia mangium*, *Casuarina cunninghamiana*, *Grevillea robusta* and *Trema orientalis* all performed well in this region (DBH increment > 2 cm/year) and all species would be considered to be moderately drought tolerant. Less drought tolerant species such as *Elaeocarpus grandis* and *Flindersia brayleyana* often performed poorly here and some plantation failures were recorded for these species. A number of eucalypts performed well in this region, including *E. resinifera*, *E. cloeziana* and *E. acmeniodes*.

In southern Queensland and northern New South Wales, mean annual rainfall is similar to central Queensland, however the sub-tropical climate is more benign with less seasonality and variability of annual rainfall and lower temperatures. As a result, a number of cabinetwood species have performed

very well in this region (DBH increment > 2 cm/year) including *Elaeocarpus grandis*, *Aleurites moluccana*, *Grevillea robusta* and *Melia azedarach* (Glencross and Nichols 2005). Members of the *Flindersia* group are very popular in mixed species plantations in this region and species such as *F. brayleyana*, *F. schottiana* and *F. xanthoxyla* have also performed well on certain sites. Eucalypt species were not included in the growth monitoring plots in this study, however good growth rates of *E. cloeziana*, *Corymbia citriodora* subsp. *variegata*, *E. pilularis* and *E. grandis*, were observed in numerous private mixed species plantations in this region.

Best-bet plantation configurations

The range of plantations examined clearly demonstrated the gradual improvements in the understanding of inter-specific competition and operational factors such as harvest management. This evolution from random to quite complex designs, provided good information to guide the development of more effective and economic mixed-species plantation designs.

Extension

The project used field days, seminars, workshops and hard-copy and electronic publications to communicate generic recommendations on species selection and silvicultural management, to stakeholders throughout this diverse region. Thirteen project workshops were conducted in eastern Queensland and northern New South Wales, attended by a total of approximately 400 people. The participants in these public workshops were primarily landowners; approximately half of these had existing plantations and half were interested in establishing new plantations on their properties.

The project culminated in a final workshop where project outcomes and latest mixed-species plantation technologies were presented (attended by 45 people). The workshop participants provided information on their attitudes and motivations for planting mixed species plantations – most private landowners in tropical and sub-tropical eastern Australia prefer the concept of mixed-species plantations over monocultures. These designs best meet their expectations of commercial returns, personal satisfaction, conservation and sustainability values for their property.

Implications

The selection of the most suitable species or combination of species for particular sites is a complex and difficult task. Whilst productivity is in many cases an important consideration, frequently there are other landowner preferences to be taken into account. Species data showed the expected variability associated with comparing species growth across different site types, climatic conditions, management techniques and temporal variations, there are also often unpredictable inter-specific relationships which can affect growth on any specific site type. Nevertheless, in this study the examination of a large range of operational plantings and research trials has yielded some useful information on the most successful species across a range of site types. This has improved the research and extension capacity to recommend suitable species for planting.

Extension outcomes from this project, were the communication of generic recommendations on species selection and silvicultural management, to stakeholders throughout this diverse region, through field days, seminars, workshops and hard-copy and electronic publications. Over the duration of this project the momentum generated by project activities was highly successful in building, maintaining and re-establishing important communication networks between the wide range of stakeholders groups involved with mixed-species plantations.

It is hoped that the extension activities, the communication tools provided, and the momentum generated during the project have assisted researchers, extension providers, consultants and private landowners to implement more efficient and effective mixed-species plantations in this region. An important role of the workshops was to provide contact details for local extension support and consulting services, so that participants could continue to find information after the project and workshops finished. The future challenge for these stakeholders is to maintain this momentum

through the networks and communication resources which have been generated and to ensure the continued development and expansion of mixed-species plantations on suitable sites throughout tropical and sub-tropical eastern Australia.

Recommendations

Species-site productivity and species choice

Generic species recommendations and design configurations, such as those outlined in this project, need to be locally modified and adapted to suit each individual landowner's situation and expectations, and the complexity of mixed species plantations. Most private landowners in tropical and sub-tropical eastern Australia prefer the concept of mixed-species plantations over monocultures. These designs best meet their expectations of commercial returns, personal satisfaction, conservation and sustainability values for their property. However, multi-purpose objectives, the wide variation in species performance across site types and the greater complexity of mixed species plantations, results in a difficult extension challenge.

Best-bet mixed species configurations

The design of mixed-species plantation configurations is driven by two factors; inter-specific competition and harvesting access. From the results presented in this report, it can be generalised that there are two main groups of species, the fast-growing, sun-loving species and the slower-growing shade tolerant species.

- a) Fast growing species include *Elaeocarpus grandis*, *Acacia mangium*, *Aleurites moluccana*, *Trema orientalis* and most eucalypts. These species are highly competitive within themselves and with other species and will quickly capture surplus site resources, at the expense of weaker species. Many of these dominant species are well suited to monoculture designs.
- b) Slower-growing species include many of the cabinetwood species such as *Flindersia schottiana*, *Castanospermum australe* and *Gmelina leichardtii*. A few species such as *Araucaria cunninghamiana*, *Flindersia brayleyana*, *Melia azedarach* and *Grevillea robusta* form a small intermediate group, which can be quite fast growing on particular sites, but tend to be less competitive.

As most species exhibit variable growth across a site, the ability to harvest the larger trees without damaging the slower-growing trees is a major objective when designing mixed-species plantations. The simplest concept is to establish individual species in rows, which will more easily allow the partial or complete harvest of a particular species, minimising the damage to the remaining trees in the plantation. Some strategic non-commercial thinning will also be required to managed inter-tree competition.

Two practical mixed-species design options are:

Simple mixed species design

This concept has been used by some landowners, and often includes a small selection of best-bet species (usually between 2–4). Each individual species is established in rows. This is the most practical design for mixed-species plantations, but does not include a large number of timber species and does not result in a natural forest appearance, often desired by landowners.

More complex design

More complex mixed-species design configurations which incorporate practicality of management, a greater tree species number, and produce a more natural forest appearance, must pay special attention to inter-specific competitive relationships. Within these plantations, the design is still based on tree rows to allow efficient harvest operations. They also utilise knowledge of individual species growth characteristics on a particular site, to minimise inter-specific competition and maintain productivity of all species.

A typical design, is to plant alternate rows of fast-growing and slow-growing species of similar growth rates at an initial spacing of 3 m x 3 m. Common examples for the fast-growing row may include a single species row of either *Eucalyptus pellita* or *Elaeocarpus grandis* or a mixed species row with *Elaeocarpus grandis*, *Grevillea robusta*, *Melia azedarach* and *Aleurites moluccana*. The slower-growing row can include a wide range of species which may be locally adapted, however common examples include *Gmelina leichardtii*, *Castanospermum australe*, *Toona ciliata*, *Flindersia schottiana* and *Flindersia brayleyana*. Early plantation growth needs to be carefully monitored and some strategic non-commercial thinning will be required to manage inter-tree competition. Generally the fast-growing row may then be completely or partially harvested between ages 8–15 years, freeing site resources to allow the slower growing species to grow on to a merchantable size. In many cases the harvested trees will readily coppice and this can then be managed for future harvest as well, to provide a perpetual forest harvesting cycle.

Extension

Private forestry extension activities in Queensland and northern New South Wales have traditionally relied on direct contact between landowners and experienced advisors from various community groups, consultants and government organisations. However, the strength of these advisory services has gradually diminished over the past 10 years due to funding reductions, changes in group strategic direction and the loss of experienced advisors.

While this project was successful at rebuilding and enhancing technical communication networks between the existing main advisory groups, it is apparent that the provision of permanent records in the form of advisory manuals and research publications is the only way to ensure that valuable knowledge and technologies gained by years of experience are not lost. As new technologies are identified in the future, it is vital that this information is made widely-available to the public, through publication mechanisms such as electronic web-based reports, manuals and scientific papers.

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Appendix 1

Growing timber species in monocultures and mixed-species plantations in north Queensland

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Introduction

Timber plantations have been established in Queensland since the early 1900s. The majority of these are softwood plantations grown to produce high volume, low value commodity timber, much of it from exotic *Pinus* species. These plantations are almost exclusively monocultures; one species, grown using relatively simple, even-aged and uniform management.

Markets for high-value, appearance-grade timber, like that produced from native tropical rainforests, have changed since the cessation of harvesting from Queensland's publicly-owned forests following World Heritage (WH) listing in 1987 (Bristow *et al.* 2000, Herbohn and Harrison 2004). Prior to WH listing, the availability of timber from these forests led to a good knowledge of the identity of favoured timber species, but limited knowledge of how to grow these species in plantations (Lamb and Lawrence 1993, Bristow *et al.* 2000, Erskine *et al.* 2005a). This, coupled with the presumed long rotation length of growing rainforest species, led to the low importance of plantation research with native rainforest species (Lamb *et al.* 1997, Herbohn and Harrison 2004, Erskine *et al.* 2005).

Private sector (and community) interest in growing rainforest timbers in north Queensland was strengthened through the Community Rainforest Reforestation Program (CRRP) (Bristow *et al.* 2005b). When the CRRP began in 1992, species choice and plantation design were effectively *ad hoc* or based on relatively untested theories and methods (Erskine *et al.* 2005b). Through the CRRP and other similar farm forestry programs a series of publications are emerging presenting results and discussions about species to site matching in Queensland (Lamb and Borschmann 1998, McNamara 2003, Bristow *et al.* 2005, Erskine *et al.* 2005, Bristow *et al.* 2005, Nikles and Robson 2005), and New South Wales (Subtropical Farm Forestry Association 2001, Glencross and Nichols 2005 *In press*), early rainforest species plantation nutrition (Webb *et al.* 1997, Webb *et al.* 2000, Webb *et al.* 2005), and plantation design and management of these stands (Catterall *et al.* 2005, Keenan *et al.* 2005, Lamb *et al.* 2005).

If you are interested in this topic, I recommend you watch out for the forthcoming publication (currently in press) which includes the above chapters:

Erskine, P.D., Lamb, D. and Bristow, M. (Eds) 2005. *Reforestation in the tropics and sub-tropics of Australia using rainforest tree species*. RIRDC Publication No. 05/087, RIRDC and Rainforest CRC, Canberra.

North Queensland mixtures with *Eucalyptus pellita*

One common mixed-species design investigates the use of mixed-species plantings with N-fixing species (Binkley *et al.* 1992, Khanna 1997, Binkley *et al.* 2000, Montagnini 2000). Using a local example of this design, I am asking questions about growing *Eucalyptus pellita* in mixed stands with N-fixing trees as an essential component of the mixture. *E. pellita* is a key hardwood species planted in the high rainfall areas of northern Queensland (>1400 mm per annum) (Harwood *et al.* 1997). Generally the profitability of existing hardwood plantations as measured from plantings established >25 years ago has been quite poor. Productivity has been quite low, varying between 3 to 30m³/ha merchantable Mean Annual Increment (MAI), depending on species and site characteristics, but averaging approximately 10m³/ha MAI (Ryan 1993). *E. pellita* has dark-red timber with density from

natural stands about 960 kgm⁻³ (Bootle 1983), and 558 kgm⁻³ from young plantation-grown material (Muneri *et al.* in review).

In a DPI&F-managed trial *E. pellita* and *Acacia aulacocarpa* have been grown at five different proportions (100E, 75E:25A, 50E:50A, 25E:75A, 100A) on the wet tropics uplands, north Queensland.

Recent growth results from this trial are summarised in the final report, entitled 'Expt 757Ath: Species testing of tropical eucalypts and acacias'.

Furthermore in the mixed species trial mentioned by Geoff and Peter Erskine (Expt 785Ath), which includes row-by-row pairwise two species mixes *E. pellita* and *Flindersia brayleyana*, the growth of the eucalypt with this second species is significantly greater, than when grown in a monoculture (data not shown).

I am currently working on these mixed-species trials funded through an ARC-Linkage project with Southern Cross University and industry support from Queensland Department of Primary Industries & Fisheries. My results are not yet summarised, however so far indications are that growing *Eucalyptus pellita* with some other in mixed-species plantations can potentially:

- not impair the growth and possibly increase the growth of the eucalypt;
- save on thinning costs by establishing the eucalypt at final stocking;
- perhaps increase diversity (over that of a monoculture);
- improve soil nutrition (through the addition of diverse leaf litter);
- potentially produce two alternative timber products.

Please stay tuned for more results over the next 12 months.

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Appendix 2

Biodiversity values of mixed-species plantations in cleared rainforest landscapes.

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Introduction

Rainforests support a high proportion of Australia's biodiversity, but (especially on fertile soils) have been heavily cleared for agriculture. In recent years, there has been considerable interest in reforesting cleared land in former rainforest landscapes for a variety of purposes including nature conservation and timber production. Mixed species plantations are widely considered to have more value for biodiversity than monocultures, and this is a major factor motivating landholders to plant mixed species plots. In this paper, we summarise the results of current research on the biodiversity value of mixed species plantations and other types of reforestation. Most of the research has been conducted by the 'Quantifying biodiversity values of reforestation' project of the Rainforest CRC (see reference list).

Results and discussion

Plantations may have a range of impacts on biodiversity, both positive and negative, at a range of scales. Some of these impacts are associated with the species planted; others are associated with management regimes (e.g., thinning and pruning schedules, harvest protocols); others with landscape context (e.g., proximity to native forest), and so on. The presumed increase in value of mixed species plantations, compared with monocultures, arises from just two of these factors: first, the use of a variety of species rather than one; and second, the increased richness and diversity of resources associated with the use of a range of species, which are presumed to provide higher quality habitat for native biota.

However, the increase in species richness and habitat diversity of mixed species plantations compared with monocultures is marginal when contrasted with the diversity of plants and habitat complexity of native rainforest. For example, mixed species plantations established under the CRRP scheme in north Queensland typically used about 10 species of timber trees per site, whereas rainforests in the region may support hundreds of species in a few hectares.

Surveys in tropical and subtropical Australia have found that young mixed species plantations do not, on average, provide markedly better habitat for rainforest biota than monocultures of hoop pine. Even 'ecological restoration' plantings, which typically use 20 – 100 species to reforest a site, support only a proportion of the biota recorded in intact rainforest. The relatively poor biodiversity value of mixed species plantations can be attributed to their use of a limited range of species and their simple vegetation structure, compared with intact rainforest. An important caveat to these findings is that the value of mixed species plantations to rainforest biota may increase as plantations mature.

Conclusions

The biodiversity value of mixed species cabinet timber plantations is presently rather low. It is possible this value could be improved by various approaches, such as:

- changes to design and management to improve habitat quality: e.g., greater use of endemic, fleshy fruited species (see list in Tucker *et al.* 2004), greater structural complexity, strategic location in the landscape; and
- the reduction of negative impacts (e.g., reducing use of potentially weedy species and potentially invasive exotic genotypes, better control of weeds).

However, these changes may only produce modest improvements to the biodiversity value of mixed species plantations. Further, some of the approaches (e.g., increased habitat value) may be at the expense of timber production or management efficiency.

An alternative approach for landholders seeking multiple benefits from reforestation may be to manage different parts of an estate for nature conservation and timber production, e.g., by a mix of plantations and restoration plantings. This approach is likely to produce higher biodiversity values than mixed species plantations at a landscape scale, as well as simplifying management. For some designs (e.g., 75% hoop pine monocultures, 25% mixed species plantations), the establishment costs would be similar to mixed species plantations. While the allocation of land to restoration plantings would reduce timber production, this cost may be reduced by locating restoration plantings on non-productive/ legally constrained areas, such as steep slopes or riparian zones. While the marginal cost of restoration plantings might be borne by a plantation developer (e.g., to increase landholder involvement, or for public relations), there may also be a case for restoration plantings to be funded by government agencies that currently fund reforestation for nature conservation purposes. Optimal design of mixtures of plantations and restoration planting will require the integration of large-scale, long-term research into reforestation projects.

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Appendix 3

Management of mixed-species plantations; some practicalities and realities

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A rural land holder has the following options:

- Agriculture, forestry or agroforestry
- Native forestry or plantation forestry
- Commercial forestry or forest restoration/ rehabilitation
- Monoculture or mixed species forestry
- If mixed species, how many?

Forestry is usually the growing of wood. Other forest products may be harvested as ancillary ‘crops’, but when forest trees are used to primarily produce a crop other than timber (fruits, foliage, leaf oils), the enterprise tends to fall into the realm of horticulture. Growing wood (other than for pulp wood), particularly *quality* timber (and sandal wood from which an oil is extracted) is long term (15 to 40 years plus) and it is the general long term nature of growing wood that results in it being only the forestry profession that retains it as its primary focus.

Most ‘industrial’ plantations are a monoculture. If mixtures are planted at industrial scale, from experience they tend to be restricted to 2, occasionally 3 species. However under the Government funded Community Rainforest Reforestation Program (CRRP), that established up to 2000 ha of various sized forest stands (0.1 to over 20 ha) on private land from 1992 to 1998, plantation mixtures were extensively established, up to over 30 species in some cases. The success of these plantings has been variable, depending in most cases on the degree of management applied.

Simplicity, ease of management and minimising costs are essential in ensuring an acceptable financial return. Monoculture plantations, with their relative ease of control are therefore generally more efficient in producing timber than mixed species plantations.

At establishment, initial inputs, costs and operational practice are the same, whether trees are planted for commercial or non-commercial use (in fact more may well be spent on trees planted for forest restoration). It is the same for naturally regenerated trees.

However from then on, whereas trees in restoration areas may be left to grow, continued active management is required to trees regenerated for a commercial or potential commercial outcome.

In **planning** therefore, decisions are necessary on:

- End use or purpose;
- Biodiversity considerations;
- Wind abatement;
- Land stability and soil erosion (including land slip and gully control);
- Water quality (through percolation and run off)
- Integration into other farm/ land uses and operations, both on-farm and in the neighbourhood (vegetation mosaics).

Once a decision is made to grow commercial timber, further consideration is needed on the timber likely to be grown and its future market.

Different timbers have differing **properties**, that all have an influence on the end use, their value (price) and their market:

- Durability (resistance to decay in various environments);
- Strength (and suitability for poles);
- Log length (including suitability for poles);
- Colour (light/ dark, brown/ red/ pink/ yellow/ white);
- Weight/ density;
- Marine borer resistance;
- Straightness of grain (and timber workability);
- Grain figure/ feature (often highlighted by sawing in a particular way).

Generally, the greater the establishment success and early stand growth, the greater is the commercial success later on. To achieve this, good control is needed in:

- Weeding (or tending);
- Pruning;
- Thinning management;
- Thinning harvesting.

Forest management infers interference and the largest single factor to control in all silvicultural operations is **damage**; in:

- Weeding;
- Pruning;
- Thinning.

In plantations consisting of single species or mixtures of just one or two species, there is usually a single rotation and fixed pruning and thinning times.

In mixed species plantations, particularly complex mixtures, the following may all influence management:

- Light demanding or shade tolerant species differences;
- Differences in species' growth curve shape and length;
- Rooting depths, crown densities and shapes;
- Individual species rotations, thinning regimes and forest stand cutting cycles (polycyclic silvicultural systems);
- Change of species composition with time;
- More complex yield regulation of individual species within the stand (individual species basal areas and stand basal area at any particular time and their effect on thinning);
- Greater potential for damage as thinned trees are felled over and through the remaining crop (rather than underneath in traditional monoculture thinning);
- Effect of topography on harvesting 'grid planted' species mixtures;
- Economic, environmental and sovereign risk.

Overall it is a 'personal' choice. Monocultures are clearly simpler to manage and the preference of large scale enterprise. Large scale monoculture plantations can be impressive in their scale, but the undeniable scenic values and the perception that mixed species plantations are more bio-diverse and more 'natural' means that they are more desirable within the community than monocultures.

Given the very limited experience in mixed species plantations to date, the successful management of such plantations should be considered a challenge!

Appendix 4

Wood quality issues for rainforest agroforestry systems in subtropical and tropical Australia.

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Background

The high value of wood from Australia's rainforests has provided a strong incentive to investigate the plantation potential of some high value species (Keenan 1998). Research trials to test the growth of some of the premier rainforest timber species have been carried out for nearly a century in Australia (Cameron and Jermyn 1991). The result of these early trials was not very encouraging, and only one rainforest tree, hoop pine (*Araucaria cunninghamii*) has been used in large-scale commercial plantations (Russell et al. 1993). The cessation of logging in natural rainforests and concerns about regeneration has re-stimulated interest in growing some rainforest species in plantations in Australia over the last decade (Lamb 1998).

A number of reports have indicated excellent prospects for the growing of high value timbers as the harvest from the world's tropical rainforest inevitably declines over the coming years (Shea 1992, Russell et al. 1993, Mayhew and Newton 1998). This reduction in supply would be expected to increase market prices of rainforest timber. However, as pointed out by Bristow et al. (2001) cabinet timber prices have declined over the last decade in Queensland. This uncertainty over current and future prices has created some concern regarding the viability of rainforest cabinet timber production. However, Keenan (1998) sees the production of high quality timber products for niche markets, such as cabinet timbers, as having the highest potential for long term returns to forest growers.

The wood qualities of significance to end-users

Wood producers are well advised to be aware of the needs and expectations of end-users at all stages, from establishment through to harvesting of plantations. Managers can carry out the improvement of wood quality by careful pruning and thinning to remove unwanted characteristics such as defects and bends. Research has also shown that some wood qualities, tree form and growth characteristics are inherited; therefore breeding can be used to achieve significant gains (Zobel and Talbert 1984). The combination of management and breeding to improve wood quality are long-term strategies that will benefit all stakeholders. The important considerations for improvement of wood quality have been briefly presented to give wood producers some understanding of the requirements of end-users.

Uniformity

Uniformity is the most important criterion for end-users after cost (Hillis 1978). Uniformity is concerned with the similarity of wood properties such as density, colour, defect levels and mechanical properties. The consistency of a wood resource allows for better economies of scale, reduction of waste and better prediction of in-service performance. The development of uniformity provides a significant challenge, as there is a great deal of variation in wood qualities, both between trees (Zobel and van Buijtenen 1989) and within trees (Walker 1993).

Density

Density is the best indicator of appropriate end uses for a given wood raw material, although it is a characteristic that can vary within the tree and change significantly over time (Downes 1997). Density will give some idea of the mechanical properties of wood such as strength, hardness, penetrability and the degree of shrinkage (Bootle 1983). The rainforests of the Australia produce some very dense hardwoods, such as Crow's ash (945 kg/m³), to comparatively light hardwoods (red cedar 450kg/m³) (Sewell 1997). Generally, high value processes such as joinery favour species with

moderate density 450-600kg/m³, where the wood is sufficiently strong, yet easy to work and not too heavy.

Heartwood and juvenile wood.

The formation of mature heartwood is a process that is not well understood (Walker 1993). The properties of heartwood are what give many timbers their unique place in the market. Heartwood formation is related to the presence of extractives that influence properties such as colour and durability. Juvenile wood is generally not favoured in the marketplace as it is less stable and more susceptible to decay and insect attack (Bootle 1983).

Growth stresses

The assessment of wood properties from young hardwood (eucalypt) plantations show that Longitudinal Growth Stresses (LGS) significantly reduce the production of high value sawn products (Muneri *et al* 1999). LGS create problems in terms of distortion and stability of sawn products as well as difficulties in sawing and processing solid products.

Knots and defects

The downgrading of wood products on the basis of knots and defects will be a major concern for solid wood producers. Premium prices are paid for clear wood that is suitable for appearance grade products such as sliced veneers and panelling. Those raw materials that are relegated to structural or reconstituted processing streams will command much lower prices. Knots can lead to difficulties in shrinkage, degrade and machining. The pruning of stems at an early age will reduce the size of the knotty core and result in the production of clear, defect free wood.

Reaction wood

The wood of the highest commercial value comes from straight trees where there is an absence of stress in the wood as a result of bends and leaning stems (Hillis 1978). The additional loads on a bent tree stem leads to the production of reaction wood, which create higher internal stresses (Walker 1993). The formation of reaction wood can increase the shrinkage during drying and result in collapse (Bootle 1983).

Case Studies

The wood properties of a number of species included in the CRRP program were investigated in 1995 (Clause 1995) by the Wood Products Program, Queensland Forestry Research Institute (QFRI). This research focussed on the recovery and utilisation of a number of key species produced in fast grown rainforest plantations. The major assessment, from a wood quality perspective, was the sawn recovery rate and the percentage of Grade 1 boards produced. Some of the better performing species (less than 30 years of age) were *Khaya spp* (41% sawn recovery- 88% grade 1), *Swietenia spp* (40% sawn recovery- 82% grade 1), and *Flindersia brayleyana* (88% grade 1). In this analysis, recovery of *Elaeocarpus grandis* from natural stands was very good (40% recovery- 97% Grade 1) however; pinhole borer, blue stain and knots were noted as areas of concern.

A number of studies have identified *Elaeocarpus grandis* (F. Muell.) as potentially an excellent rainforest plantation species in terms of form, volume and height growth (Cameron and Jermyn 1991, Russell *et al* 1993, Specht *et al* 1999). According to Borshmann & Lamb (1996) the speed at which trees grow as well as the high value of the timber make this species an excellent forestry option on suitable sites. Over the last 10 years growth of *Elaeocarpus grandis* in mixed species rainforest plantings has been encouraging, yet we know very little about the nature of the wood produced.

A pilot study was undertaken at SCU with assistance from Queensland Forestry Research Institute (QFRI) to investigate the properties of young plantation grown *Elaeocarpus grandis* wood (Ibell *et al.* 2000). The preliminary study was undertaken to identify the wood properties of eight-year old Silver Quandong, and compare these results to the properties of mature wood as outlined by Bootle (1983). The young wood was similar in a number of ways to the mature wood of the Silver Quandong, being straw coloured, stable, easy to work (Bootle 1983, Sewell 1999). The density of the

young wood was close to that of mature wood, and the mechanical properties closely resembled those of mature wood sourced from native forests (Ibell et al. 2000). However, the results of the wood properties analysis should be considered only preliminary, due to the small number of samples tested. Currently a full and comprehensive study on the wood properties of high value timber species is being undertaken by RIRDC (JVAP) and SCU.

Conclusions

The growers of rainforest timber plantations can benefit from the consideration of wood quality issues at every stage of the production process. The current demands of the high value solid timber end-users are focussed on provision of a stable, uniform resource, free of defects. Rainforest plantation managers need to carefully select species and management systems that improve wood quality and meet the expectations of potential end users.

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Appendix 5 - Species list

Scientific name	Common name
<i>Acacia crassicarpa</i>	lancewood, northern wattle
<i>Acacia mangium</i>	sally wattle
<i>Acacia victorii</i>	
<i>Agathis robusta</i>	kauri pine
<i>Aleurites moluccana</i>	candelnut
<i>Alphitonia petrei</i>	pink ash
<i>Araucaria cunninghamii</i>	hoop pine
<i>Blepharocarya involucrigera</i>	rose butternut
<i>Cardwellia sublimis</i>	northern silky oak
<i>Castanospermum australe</i>	black bean
<i>Casuarina cunninghamiana</i>	river sheoak
<i>Cedrela odorata</i>	West Indian cedar
<i>Citrus limon</i>	lemon
<i>Corymbia citriodora</i> subsp. <i>citriodora</i> *	lemon-scented gum
<i>Corymbia torelliana</i> *	cadaghi
<i>Dysoxylum fraseranum</i>	rose mahogany
<i>Dysoxylum muelleri</i>	red bean
<i>Elaeocarpus grandis</i>	flooded gum
<i>Eucalyptus acmeniodes</i> *	white mahogany
<i>Eucalyptus camaldulensis</i>	river red gum
<i>Eucalyptus cloeziana</i>	Gympie messmate
<i>Eucalyptus drepanophylla</i>	grey ironbark
<i>Eucalyptus dunnei</i> *	Dunn's white gum
<i>Eucalyptus pellita</i>	red mahogany
<i>Eucalyptus resinifera</i>	red mahogany
<i>Eucalyptus tereticornis</i>	forest red gum
<i>Eucalyptus tetradonta</i>	Darwin stringybark
<i>Eucalyptus urophylla</i> *	Timor white gum
<i>Euroschinus falcata</i>	ribbonwood
<i>Flindersia australis</i>	crows ash, Australian teak
<i>Flindersia brayleyana</i>	Queensland maple
<i>Flindersia pimentelliana</i> *	maple silkwood
<i>Flindersia schottiana</i>	Queensland silver ash, cudgerie
<i>Flindersia xanthoxyla</i>	long jack
<i>Gmelina leichhardtii</i>	white beech
<i>Grevillea robusta</i>	southern silky oak
<i>Harpullia pendula</i>	tulipwood
<i>Khaya nyasica</i> (<i>anthotheca</i>)*	African mahogany
<i>Khaya senegalensis</i> *	African mahogany
<i>Melia azedarach</i>	white cedar

<i>Nauclea orientalis</i>	Leichhardt tree/cheesewood
<i>Paraserianthes toona</i> *	Mackay cedar / red siris
<i>Pinus caribaea</i> var <i>hondurensis</i> *	Caribbean pine
<i>Polyscias elegans</i>	celery wood
<i>Rhodosphaera rhodanthema</i>	deep yellow-wood
<i>Santalum album</i>	sandalwood
<i>Santalum lanceolatum</i>	northern sandalwood
<i>Santalum macgregorii</i>	
<i>Santalum austrocaledonicum</i>	
<i>Tectona grandis</i> *	teak
<i>Terminalia sericocarpa</i>	damson
<i>Toona ciliata</i>	red cedar