An Australian Government Initiative

Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

Forest & Wood Products Research & Development Corporation

Land & Water Australia

Murray-Darling Basin Commission

Rainforest CRC

Reforestation in the Tropics and Subtropics of Australia

Using Rainforest Tree Species

Edited by
Peter D. Erskine,
David Lamb
and Mila Bristow

Joint Venture Agroforestry Program

Publication No 05/087

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A report for the RIRDC/Land & Water Australia/FWPRDC/MDBC *Joint Venture Agroforestry Program*, together with the Rainforest Cooperative Research Centre

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July 2005

Rainforest CRC

RIRDC Publication No 05/087
RIRDC Project No. WS023-20

ISBN 1 74151 150 X
ISSN 1440-6845

Reforestation in the Tropics and Subtropics of Australia Using Rainforest Tree Species
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Project No. WS023-20

The papers in this book are peer reviewed and edited. This book should be cited as: Erskine, P.D., Lamb, D. and Bristow, M. (Eds.) 2005. *Reforestation in the Tropics and Subtropics of Australia Using Rainforest Tree Species.* RIRDC Publication No 05/087, Rural Industries Research and Development Corporation, Canberra.

In submitting this report, the researchers have agreed to RIRDC publishing this material in its edited form.

Publication of this proceedings was jointly funded by the Joint Venture Agroforestry Program & the Rainforest CRC. Copies of the publication can be obtained from Rural Industries Research and Development Corporation.

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6272 4539
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au.
Website: http://www.rirdc.gov.au

Rainforest Cooperative Research Centre Contact Details
Rainforest CRC
PO Box 6811
CAIRNS, QLD 4870

Phone: 07 4042 1246
Fax: 07 4042 1247
Email: rainforestcrc@jcu.edu.au
Website: http://www.rainforest-crc.jcu.edu.au

Published in July 2005
Printed on environmentally friendly paper by Union Offset

Foreword

In the late 1980's nearly all of the state-controlled subtropical and tropical rainforests in New South Wales and Queensland were placed on the World Heritage register and timber extraction from these forests ceased. Although there had been attempts to grow rainforest trees in plantations in the early 1900's the silviculture and management requirements of most tropical and subtropical Australian rainforest trees, apart from *Araucaria cunninghamii* (hoop pine), were relatively unknown. With the loss of the natural forest timber resource there appeared to be an opportunity for growing rainforest trees in farm forestry systems to supply high-value wood and restore diversity to cleared rainforest landscapes. In north Queensland a great deal of support for this was provided by the Community Rainforest Reforestation Program (CRRP), while a variety of landholders and organisations throughout the tropics and subtropics also reforested land for production, biodiversity and/or other conservation reasons. The reforestation has been an opportunity for novel and integrative research by a range of organisations, in particular the Rainforest CRC since 1993. Several international workshops (e.g. IUFRO, IUCN) have also been held with a focus on this research.

A technical workshop was convened in June 2003 to review what we have learned in the past ten or so years of reforesting with rainforest and tropical species. The workshop was attended by many of those who have been involved in the reforestation effort in both Queensland and northern New South Wales. This peer-reviewed book documents the lessons learned as a result of their experiences. It covers some of the history of rainforest reforestation and planting schemes, and the methods that have been used to propagate and establish rainforest tree species. It also presents growth rates for a wide variety of species planted in different regions, knowledge about the pests and diseases found in rainforest plantations and discusses the management challenges of mixed species stands. As the planting of rainforest trees has occurred in some of the most biodiverse regions of Australia the book also examines some of the ecological consequences of plantation design and the emerging issues facing forest growers who desire production and biodiversity. A portion of the book also evaluates some of the socio-economic issues which arose from reforestation schemes. Finally the book offers future directions for rainforest plantation research and insights into how our Australian experience can be applied more widely throughout the altered rainforest landscapes of the tropical world.

Publication of this book was funded by the Joint Venture Agroforestry Program (JVAP) and the Rainforest CRC. The JVAP is supported by three R&D corporations—Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia, Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

This book, a new addition to RIRDC's diverse range of over 1200 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integratre sustainable and productive agroforestry within Australian farming systems. Most of the RIRDC publications are available for viewing, downloading or purchasing online through the RIRDC web site:

• downloads at www.rirdc.gov.au/fullreports
• purchases at www.rirdc.gov.au/eshop

CRC publications can be downloaded at:
• www.rainforest-crc.jcu.edu.au/publications/publications.htm

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

Nigel Stork
Chief Executive Officer
Rainforest Cooperative Research Centre

Acknowledgements

Research on growing Australian rainforest species has been carried out over many years. Many people have been involved in this, particularly in the former Queensland Forest Service (now part of the Department of Primary Industries). The result of much of this earlier work was summarized by David Cameron and David Jermyn in their seminal monograph published by the Australian Center for International Agricultural Research (Cameron, D. and Jermyn, D. 1991. *Review of plantation performance of high value rainforest species.* Australian Center for International Agricultural Research, ACIAR Working Paper, No. 36).

In recent years a more diverse range of researchers has become involved in reforestation work with rainforest species. These people have worked in government agencies and Departments such as the former Queensland Forestry Research Institute, the Queensland Department of Primary Industries, the Department of Natural Resources and Mines, and the Rainforest Cooperative Research Centre, as well as in universities and a number of other non-government organizations. All the authors in this book have depended in some way or other on the efforts of those people before them, and the book is an attempt to permanently document the knowledge they helped generate. Many of the authors of this book are members or former members of the Cooperative Research Centre for Tropical Rainforest Ecology and Management (the “Rainforest CRC”), which has facilitated much of the recent work reported here, and has acted as a valuable bridge linking many researchers and managers interested in reforestation.

The Joint Venture Agroforestry Program is gratefully acknowledged for providing funds to help run the workshop held to organise this project and to publish this volume.

This book could not have been completed without the input of the people who were willing to peer review the book chapters. Many thanks to Matt Armstrong, Joseph Baker, Adrian Borsboom, Peter Byrne, David Doley, Jim Donaldson, Peter Green, Keith Gould, Mark Hunt, Rod Keenan, Rosemary Lott, Helen Nahrung, Doland Nichols, Digby Race, Murray Keys, Susanne Schmidt, John Simpson, Jerry Vanclay, Peter Volker, Mal Wagner, David Westcott, Ross Wylie and Myron Zalucki for their insightful peer reviews. We thank Rosemary Lott for review and editorial comment on several chapters.

For supplying project information, growth data and maps, the following people and organisations are gratefully acknowledged: David Skelton, Bill Leggate, Gary Hopewell and Daryle Green. Photos in the section pages were provided by the following people: John Kanowski - Section I and restoration planting in Section IV; Terry Reis - vertebrate animals in Section IV; Heather Proctor - the rainforest mite in Section IV; Mila Bristow - Section II and V and tree care research in Section VI; and, Peter Erskine - Section III and the old-timers in Section VI.

Finally, we would like to acknowledge the considerable assistance we have had from Rachel Greenfield who has helped us review the various texts and assemble the final volume.

Contents

Contributors

Mark Annandale
Department of State Development and Innovation, Cairns, Qld 4810.

Mila Bristow
School of Environmental Science and Management, Southern Cross University, Lismore, NSW, 2480.
and
Department of Primary Industries and Fisheries, Walkamin, Qld, 4872.

Carla P. Catterall
Environmental Sciences, Griffith University, Nathan, Qld, 4111.

David Doley
School of Integrative Biology, University of Queensland, Brisbane, Qld, 4072.

Peter D. Erskine
School of Integrative Biology, University of Queensland, Brisbane, Qld, 4072.

Nick Emtage
School of Natural and Rural Systems Management, The University of Queensland, Gatton, Qld, 4343.

Kevin Glencross*
Forestry Program, School of Environmental Science and Management, Southern Cross University, Lismore, NSW, 2480.

Steve Harrison
School of Economics, The University of Queensland, Brisbane, Qld, 4072.

John Herbohn
School of Natural and Rural Systems Management, The University of Queensland, Gatton, Qld, 4343.

John Kanowski
Environmental Sciences, Griffith University, Nathan Qld, 4111.

Rodney J. Keenan
Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, PO Box 858, Canberra, ACT, 2600

Daryl Killin*
Pentarch Forest Products, Kings Garden Estate, Level 1, 99 Coventry St, South Melbourne, Vic, 3205

Judith King*
Department of Primary Industries and Fisheries, PO Box 631, Indooroopilly, Qld, 4068

David Lamb
School of Integrative Biology, University of Queensland, Brisbane, Qld, 4072.

Simon Lawson*
Department of Primary Industries and Fisheries, PO Box 631, Indooroopilly, Qld, 4068

Rosemary Lott
Joint Venture Agroforestry Program, Rural Industries Research & Development Corporation, P.O. Box 4776, Kingston, ACT 2604

Steven McKenna
Environmental Sciences, Griffith University, Nathan, Qld, 4111.

Sean McNamara
School of Integrative Biology, University of Queensland, Brisbane, Qld, 4072.

Huynh Duc Nhan
Forest Research Center, Phu Tho, Vietnam

J. Doland Nichols*
Forestry Program, School of Environmental Science and Management, Southern Cross University , Box 157, Lismore, NSW, 2480.

D. Garth Nikles*
Department of Primary Industries and Fisheries, Indooroopilly, Queensland, 4068.

Martin Novak*
Subtropical Farm Forestry Association,
P.O. Box 1320, Lismore, NSW, 2480.

Scott Piper
Environmental Sciences, Griffith University, Nathan, Qld, 4111.

Heather Proctor
Biological Sciences, University of Alberta, Edmonton, Alberta, Canada, T6G 2E9.

Paul Reddell
CSIRO Land and Water, Tropical Forest Research Centre, Atherton, Qld, 4883.

Terry Reis
Environmental Sciences, Griffith University, Nathan, Qld, 4111.

Ken J. Robson*
Department of Primary Industries and Fisheries, Walkamin, Qld, 4872.

Nalish Sam*
Papua New Guinea Forest Research Institute, Lae, Papua New Guinea

Gary Sexton*
Private Forestry North Queensland
PO Box 27, Kairi, Qld, 4872.

Geoff Slaughter
School of Natural and Rural Systems Management, The University of Queensland, Gatton, Qld, 4343

Dave Smorfitt
School of Business, James Cook University, Cairns, 4870

Jungho Suh
School of Economics, The University of Queensland, Brisbane, Qld, 4072

Nigel I.J. Tucker
Biotropica Australia Pty Ltd, PO Box 866, Malanda, Qld, 4885.

Sue Vize*
Murray-Darling Basin Commission,
15 Moore street,Canberra, ACT 2601.

Grant W. Wardell-Johnson
Natural and Rural Systems Management, The University of Queensland, Gatton, Qld, 4343.

Michael J. Webb
CSIRO Land and Water, Davies Laboratory, Townsville, Qld, 4810.

* All except those asterisked are members or former members of the Rainforest Cooperative Research Centre

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ACTFM	Australian Cabinet Timbers Financial Model
AFFA	Agriculture, Fisheries and Forestry Australia
ANPWS	Australian National Park and Wildlife Service
ANU	Australian National University
ARFCT	Australian Rainforest Cabinet Timbers
ASL	Above Sea Level
ANOVA	Analysis of variance
BRS	Bureau of Rural Sciences
Ca	Calcium
CD	Crown Diameter
CEC	Cation exchange capacity
CR	Crown Ratio
CRC	Cooperative Research Centre
CRC-TREM	Cooperative Research Centre for Tropical Rainforest Ecology & Management
CRRP	Community Rainforest Reforestation Program
CRRPMC	Community Rainforest Reforestation Program Management Committee
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	Clonal Seed Orchard
Cu	Copper
DAFF	Department of Agriculture, Fisheries and Forestry (previously Agriculture, Fisheries and Forestry Australia AFFA)
DAP	Diammonium Phosphate
DBH	Diameter at Breast Height (stem diameter at 1.3m from the ground)
DBHOB	Diameter at Breast Height Over Bark
DNR	Department of Natural Resources Queensland (now NRM&E Natural Resources Mines and Energy)
DPI	Department of Primary Industries Queensland
DPI&F	Department of Primary Industries & Fisheries Queensland (previously Queensland Department of Primary Industries (DPI))
DPI Forestry	Department of Primary Industries Forestry (this group manages commercial forestry activities on behalf of the State of Queensland)
Dq	Quadratic mean diameter
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
FNQ	Far north Queensland
Ht	Height
ITTO	International Tropical Timber Organisation
JVAP	Joint Venture Agroforestry Program
JVS	Joint Venture scheme
K	Potassium
LEAP	Landcare and Environment Action Program
LSD	Least significant difference
MAI	Mean Annual Increment
MAR	Mean Annual Rainfall
MDS	Multidimensional Scaling
Mg	Magnesium
NHT	Natural Heritage Trust
n	Number of individuals
N	Nitrogen
NPV	Net Present Value
NQAA	North Queensland Afforestation Association

NQTC	North Queensland Timber Cooperative
NRM	Natural resource management
NSW	New South Wales
OC	Organic carbon
p	probability
P	Phosphorus
PFNQ	Private Forestry North Queensland
PMAI	Periodic Mean Annual Increment
QDPI	Queensland Department of Primary Industries
QFRI	Queensland Forestry Research Institute (part of DPI), this group is now referred to as Department of Primary Industries & Fisheries, Horticulture and Forestry Science
RCB	Randomised Complete Block
RD	Relative Density
REEP	Regional Environment Employment Projects
RIRDC	Rural Industries Research and Development Corporation
S	Sulphur
SDI	Stand Density Index
SEQ	South-east Queensland
SEQFA	South East Queensland Forest Agreement
SFFA	Subtropical Farm Forestry Association
SSO	Seedling Seed Orchards
TAS	Tree Assistance Scheme
TPH	Tree stocking Per Hectare
TREAT	Trees for the Evelyn and Atherton Tablelands
VP	Vegetative Propagation
WTQWHA	Wet Tropics of Queensland World Heritage Area
WTTPS	Wet Tropics Tree Planting Scheme
Zn	Zinc

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The Beginnings of Rainforest Reforestation

1. Reforestation with rainforest timber trees in the tropics and subtropics of Australia: A brief overview

David Lamb, Peter D. Erskine and Mila Bristow

Introduction

In the last 100 years the world's tropical forests have dramatically decreased in area. A recent survey by the Food and Agriculture Organisation of the United Nations, for example, found 14.2 million ha had been lost from the world's tropical forests between 1990 and 2000 (FAO 2002). Some of this formerly forested land has been used for permanent agriculture but large areas have been cleared, used briefly for agriculture, and then abandoned. Reforestation has occurred on some of this abandoned land but much remains degraded or in an under-utilized state. Estimates of just how much cleared and then abandoned lands that now exist are difficult to find but ITTO (2002) estimate there are around 350 million ha of deforested and degraded land scattered across the world's tropics. They also estimate there could be a further 500 million ha of partially deforested land.

This loss has had several consequences. One consequence has been that, globally, food production has kept pace with rising human populations. But another has been that the various goods and services once supplied by tropical forests are no longer available. This loss particularly affects rural people who have traditionally depended on forests for a variety of forest-derived resources. Many of these people have not benefited at all from the loss of forests in their regions and they continue to live in rural poverty.

Reforestation has occurred in many tropical areas. FAO (2002) has reported an increase in tropical plantation cover of 1.9 million ha between 1990 and 2000. Most of these plantations have used a small number of species, often exotic to the regions they are planted, and an even smaller number of genera (primarily *Eucalyptus*, *Acacia* and *Pinus*). Most plantations have fast growing species and a large proportion are being grown as monocultures on short rotations (ca. 10 years) to supply pulpwood. The legacy of this history of deforestation and reforestation is that the most species-rich forests on earth have been replaced by comparatively simple agricultural or plantation systems, or by degraded landscapes.

Deforestation and reforestation in the wet tropics of Australia

Similar events have occurred in Australia. Clearing of tropical forests started over 100 years ago and continued until recently. Much of this land has been used for agriculture but there are now significant areas of formerly forested land in Queensland and northern New South Wales that were once used for agriculture but which are now under-utilised or have been abandoned. Again, estimates of just how much of this land might be available for reforestation are scarce. Shea (1992) suggested 47,150 ha of land in the wet tropics of northern Australia is 'unsuitable for sustainable agriculture… that would be suitable for tree establishment.' He goes on to suggest it would be composed of both private and public land, and that while not all landholders would want to plant trees, 'a net figure of 30,000 ha would be available for planting.' Subsequently a field-based survey of privately owned rural land within 200kms of Cairns in north Queensland (see Figure 1) by Annandale *et al*. (2003) identified approximately 86,000 ha of land with rainfall and slope conditions suitable for timber plantations.

The first attempts to grow rainforest trees in plantations began in the early 1900's but only *Araucaria cunninghamii* (hoop pine) was ever planted over significant areas (Lamb *et al*. 2001). Reforestation was never an attractive option while the demand for agricultural land was high and high-value timbers could be obtained by logging natural forests. The large areas of natural forest suggested the supply of high-value rainforest timbers was assured. This situation changed in 1988 when logging of tropical forests in north Queensland ceased (logging had ceased earlier in New South Wales and most of these rainforests had been placed on the World Heritage register in 1986). In this new situation it seemed there might be scope for growing rainforest trees in plantations to supply a high-value niche market and, at the same time, to restore some diversity to the cleared and simplified landscapes.

However, there were two problems. One was the political imperative to do something quickly. In particular, there was a need to begin the compensation program for former timber workers who had lost their jobs when logging ceased (see Vize *et al*. Chapter 2). The other problem was that the technical knowledge necessary to undertake a large reforestation program was lacking. The previous 100 years of logging had bequeathed some of the required knowledge. This included the identity of the most commercially attractive tree species, knowledge of the natural distribution of these and some limited information of their ecology and silviculture. The former Queensland Forest Service had also carried out trials with some of these species (summarized in Cameron and Jermyn 1991) but detailed knowledge of the seed sources, nursery systems and plantation silvicultural requirements for most species was extremely limited.

Problems in creating a new forest and timber resource

Establishing a new industry based on rainforest tree species is difficult. The problems include that:

- suitable land for growing rainforest timbers is restricted to the higher rainfall areas (see Figure 1) which generally have higher land values;
- there are many potential timber species and provenances to choose from;
- the ecology and silviculture of most of these species is unknown;
- most of these species are slow growing (meaning the rotation length of any commercial plantation will be long – possibly 30 to 60 years - and therefore financially problematic);
- the future timber markets over time scales such as these are uncertain; and
- many landowners have multiple objectives; many are interested in growing trees for timber production but are also interested in creating “conservation” benefits as well (such as providing wildlife habits and improving biodiversity on their properties).

On past occasions when a new industry has been developed the government has usually reduced the risk to landowners by undertaking the necessary research (usually at specialised research stations) or by creating farms or plantations of its own at which problems can be identified and solved over time. New industries often take a number of years to become self-sustaining so this support is usually long-lasting. The north Queensland sugar industry and the softwood plantations of south east Queensland are examples where support was provided over many years and allowed significant industries to develop. But an industry based on high-value rainforest trees was always destined to be a small one because the land available for such plantations is limited and mostly privately owned. This has meant that government support was always going to be modest.

In north Queensland, the main support provided to create a new timber resource came through the Community Rainforest Reforestation Program (CRRP) and the background to this is described in Vize *et al*. Chapter 2. There was also some interest in reforesting abandoned land for, largely, biodiversity and other “conservation” reasons. In central and southeast Queensland and in northern New South Wales, a variety of individual landholders, government and non-government groups have undertaken reforestation work (see Vize *et al*. Chapter 2 and Lott *et al*. Chapter 3). The outcome of these activities has been a flourishing of mostly rainforest tree plantings across the wet tropics of north Queensland as well as in southern Queensland and northern NSW.

Research to support this reforestation has been relatively recent, and modest in terms of silviculture. The Cooperative Research Centre for Tropical Rainforest Ecology and Management (the “Rainforest CRC”) has had a program working on rainforest reforestation research since 1993. Other reforestation research by universities and government agencies, with a range of funding including by the Joint Venture Agroforestry Program, has also been undertaken.

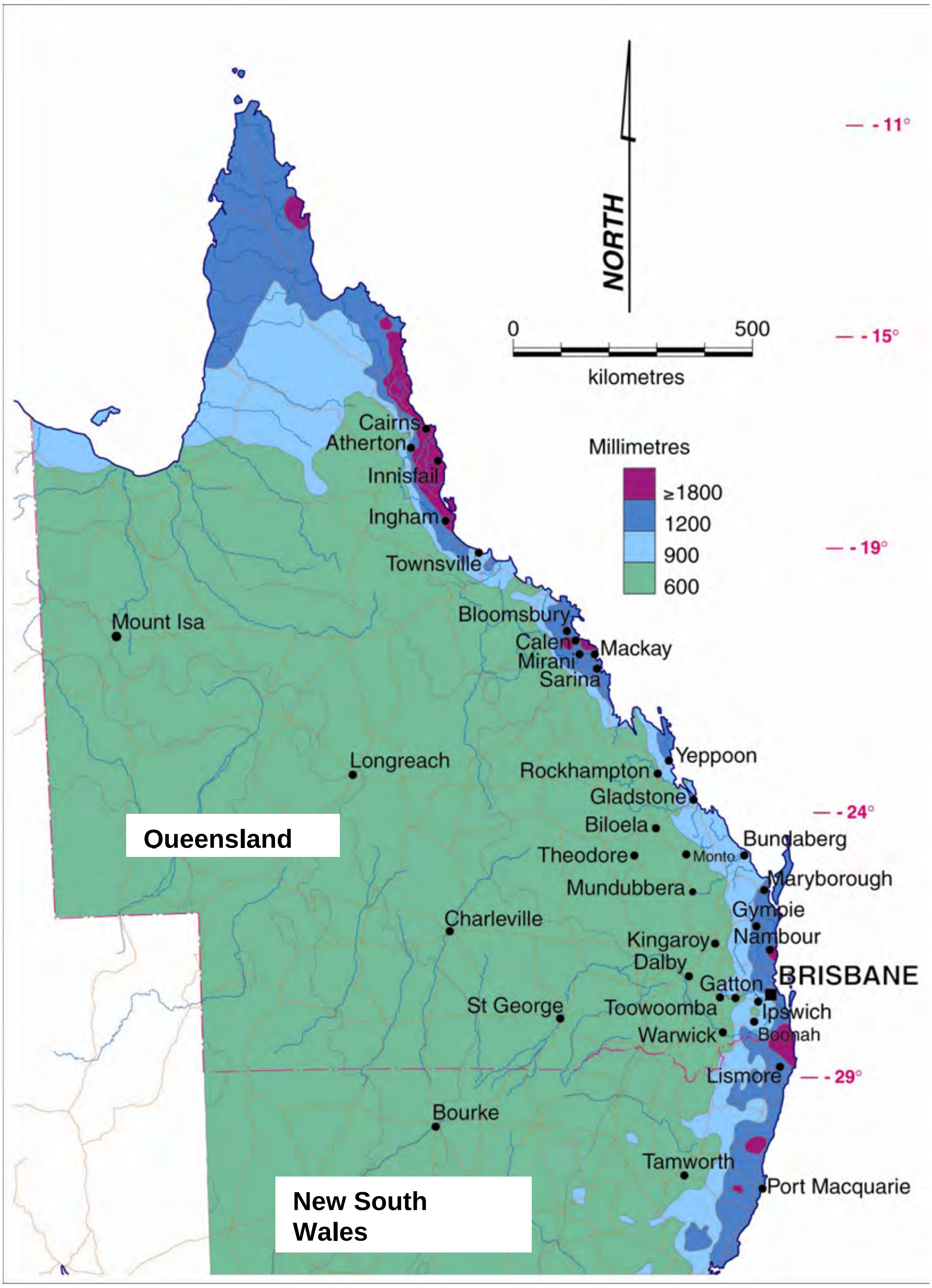

Figure 1 Rainfall zones in the tropics and subtropics of eastern Australia. Areas with average annual rainfall of greater than 1200 mm are generally capable of supporting rainforest timber species.

The objectives of this book

More than ten years have elapsed since many of these programs and plantings commenced. Some of the plantings are now well established and are growing well. Others have failed. It seemed timely to review what has been learned over this period.

A workshop was held at the University of Queensland in June 2003, attended by many of those who have been involved in this reforestation effort in both Queensland and New South Wales. The intention was to capture their experience and document the lessons learned. The organisers sought to included practitioners as well as researchers, foresters and ecologists. The focus of the meeting was primarily on the ecological and silvicultural issues rather than on the social, economic or policy issues. The latter are equally important of course, if reforestation is to actually take place, and two chapters in this book review some of the social and economic research that both complements and interacts with this biophysical research. It is expected that a more detailed treatment of these issues will be presented elsewhere.

As the rainforests of eastern Australia are natural biodiversity hotspots the reforestation efforts discussed in this book are obviously concerned with retaining species and landscapes in cleared rainforest regions, and several methods of reforestation are compared in later chapters. One of the strengths of this book is the contrasting opinions on reforestation methods presented, or implied, by various authors. The editors believe that the competition for commercial returns from productive, agricultural land in these ex-rainforest landscapes, coupled with the current modest levels of investment in rainforest restoration, necessitate pragmatic approaches to reforestation. For private landholders to adopt and fund conservation efforts outside the existing reserves, on the scale that is needed to prevent further degradation of rainforest landscapes, will require planting systems that are 'profitable' to the landholder. It is unlikely that these efforts will be able to conserve everything and it may be necessary to consider trade-offs. Trade-offs between biodiversity and production in reforestation plantings have recently been discussed by Erskine and Catterall (2004) and are further discussed in this book. From a biodiversity perspective, the need to maintain or enhance structural complexity and floristic composition in disturbed ex-rainforest landscapes in order to increase the usefulness of these forests to a diverse range of wildlife was examined. From a primary industries or land productivity perspective (e.g. agricultural, horticultural, industrial timber plantation or farm forestry production), the need for better understanding of the functional consequences of biodiversity in order to satisfactorily resolve the contention that "increased biodiversity is good" was highlighted. Both standpoints agreed on the need to know more about what scale of reforestation is required in these ex-rainforest landscapes. Practical outcomes for forest growers will come from answers about how many fleshy-fruited rainforest trees should be added to production-focused monocultures to increase biodiversity, or how can timber plantations be made more useful to rainforest wildlife, or how does increased biodiversity affect the silviculture or ability to harvest plantations?

The workshop and this book that has emerged out of it have had a largely Australian focus. But the problems of how to reforest cleared or degraded land in Australia's tropics are problems being faced by foresters and ecologists in many other tropical regions. It is our hope that at least some of the lessons we have learned and the solutions we have found will have use in these other tropical situations as well.

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2. The Community Rainforest Reforestation Program and other farm forestry programs based around the utilisation of rainforest and tropical species

Sue Vize, Daryl Killin and Gary Sexton

Abstract

The Community Rainforest Reforestation Program commenced in 1993 as a means of promoting commercial tree growing, addressing land degradation, improving watershed protection and fostering employment in the wet tropics of northern Australia. This program was a major component of the Commonwealth Government's compensation package following the decision to stop logging in the tropical rainforests of north Queensland. The program underwent several changes of emphasis until 2000 when it ceased. Other reforestation programs operating in the region over this time included the Wet Tropics Tree Planting Scheme, the Queensland DPI Joint Venture scheme and several other smaller schemes. These have helped establish some 3,200 ha of plantation on privately owned land in northern Queensland. Other reforestation schemes have operated in southern Queensland and northern New South Wales. Collectively these have probably created around 6,800 ha of new plantation. Most of these are dominated by rainforest species and most planted sites contain a mixture of species rather than the traditional single species monoculture. This chapter describes the development of these various planting schemes and reviews the consequences they have had.

Introduction

Farm forestry, or the growing or management of trees on farms, has for some time been seen as an environmentally and socially responsible approach to forestry that can achieve a wide range of grower, regional and community-wide benefits whilst contributing to land rehabilitation, integrated catchment management and sustainable industry development. The Community Rainforest Reforestation Program (CRRP) was one of the first major investments in farm forestry in tropical Australia. The CRRP has generated a wealth of experience in small-scale tropical plantation development, regional development and integration of multiple land management objectives. This experience should provide a valuable basis for the future development of farm forestry and timber plantings in the tropics and subtropics of Australia.

The National Forest Policy Statement released in 1992 (Commonwealth of Australia 1992) set broad goals to cover all aspects of forest management in Australia. These goals included conservation, wood production, water supply and catchment management, tourism, employment and public awareness through the sustainable management of native forests and plantations. Under this policy, the Wood and Paper Industry Strategy (Commonwealth of Australia 1995) was released identifying the potential of farm forestry to contribute to the development of a sustainably managed timber resource and regional development. This resulted in the establishment of an $18 million fund to support the development of farm forestry programs across Australia.

The Commonwealth commenced the Farm Forestry Program in 1993 (Donaldson pers. comm.) with the aim of promoting commercial tree growing and management on cleared agricultural land across

Australia (AFFA 2003). The focus of the Farm Forestry Program was largely based on eucalypt and pine plantings in temperate zones of southern and eastern Australia but the CRRP benefited from the policy environment of the 1990s which lent support to its development and eventual funding.

The potential for growing “specialty” timbers in tropical and subtropical areas such as north Queensland, south east Queensland and northern New South Wales (NSW) was identified in the early 1990s (e.g., Shea 1992). Wet tropical and subtropical environments with greater than 1,000 mm rainfall, occur in three relatively narrow coastal strips along Australia’s east coast: north Queensland’s wet tropics, central Queensland in particular the Mackay region, and the large area from southern Queensland to around Port Macquarie in NSW. All of these areas had significant timber industries based on harvesting of natural stands of tropical and subtropical species. The rainforests of these areas also share a suite of highly prized species that have demonstrated commercial application including red cedar (*Toona ciliata*), silky oaks (*Grevillea robusta* in the south and *Cardwellia sublimis* in the north), maples (*Flindersia* spp.), hoop pine (*Araucaria cunninghamii*) and kauri pine (*Agathis robusta*).

In early trials conducted by the Forestry Department in north and south east Queensland, hoop pine outperformed a number of other native tropical rainforest species in terms of overall growth rates, timber yield and ease of management (Gould pers. comm.). As a result of these early trials, efforts to grow and develop silvicultural systems for other tropical species have been relatively limited. The primary focus of government and industry has been to maximise wood production; and hoop pine together with plantations of the fast-growing exotic species *Pinus elliottii* and *Pinus caribaea*, seemed to fulfil this objective on the sites that were available for reforestation.

An overview of recent trends in rainforest reforestation in north eastern Australia

The overall area planted with predominantly rainforest species (not including plantings with exotic pine or eucalypts) across north eastern Australia amounts to around 50,000 ha (see Table 1). This estate is scattered in small pockets across a large area and is dominated by state government owned (public) hoop pine plantations (87%) with the remainder including a wide variety of species and planting designs that cover both trees for productive uses and for purely environmental outcomes. Our experience growing tropical tree species in Australia is still relatively limited.

In more recent times, trials to establish plantations based on rainforest species planted in monocultures, mixtures and for both production and other purposes have been undertaken in both Queensland and New South Wales through research organisations, government-supported farm forestry programs and through the interest and passion of individual landholders. In total these plantings on private land amount to less than 15% of the area planted to hoop pine by state forestry organisations (Table 1).

In the wet tropics of north Queensland, little over 3,000 ha of tropical tree plantings have been established through programs including the CRRP (1780 ha), the Wet Tropics Tree Planting Scheme (around 850 ha), the state-funded DPI Joint Venture Scheme (160 ha), Treecare (area not quantified but probably < 100 ha) and through groups such as Trees for the Evelyn and Atherton Tablelands (TREAT) and local Landcare activities (400 plus ha). Species performing successfully in this region are presented in Bristow *et al*. (Chapter 6). The experiences from the CRRP are described in more detail later in this chapter.

Farm forestry in the Ingham district (southern coastal wet tropics) began slowly but was soon embraced by the farming community. The CRRP was the first major farm forestry initiative in the area and most plantings were designed to provide multiple outcomes rather than timber production alone. Farmers were able to address a range of land degradation issues, riparian habitat restoration and the utilisation of land unsuitable for cultivation and conventional crops because of topography, stoniness or poor drainage (Collins pers. comm).

In central Queensland there have been a number of farm forestry plantings in the last 20 years, mainly in the Mackay Whitsunday region (>1,000mm/annum rainfall). Other areas of plantation activity are the Rockhampton / Gladstone coastal region, and the inland areas of the Dawson Valley (near Theodore, see Chapter 1 -Figure 1) and Nebo Broadsound shires (southwest of Mackay) which are mostly lower rainfall <1,000mm/annum rainfall, and considered 'dry' tropics plantings.

The Mackay-Whitsundays plantings have been in association with state/commonwealth government sponsored programs (including the CRRP). Most plantations are within the wetter coastal strip. The main species planted in this area are mixed rainforest (CRRP making the largest contribution), eucalypt monocultures (*E. pellita*, *E. grandis*, *E. resinifera*, *E. cloeziana*, *C. citriodora*), *Pinus caribaea* and hoop pine (total 420 ha) (Allen, pers. comm.).

The farm forestry plantings in the Rockhampton / Gladstone coastal region have mainly been established in the last 10-15 years. Again these plantings have mainly been associated with government sponsored programs. In this region the area of plantings are unquantified (Allen pers comm.). 'Dry' tropics plantings in the Dawson Valley and Nebo Broadsound inland areas of central Queensland consist mainly of taxa trials and demonstrations testing a mix of eucalypts, acacias, casuarinas, rainforest and exotic cabinet timbers; the total trial area is less than 50 ha (Allen pers. comm.).

Farm forestry in southeast Queensland has shown an upward trend in the past 12-15 years with many landholders showing an interest in the establishment of commercial rainforest/cabinet timber plantations. Most plantations are small compared to commercial plantations and range from 1-5 ha in area. Most have been established on basalt or alluvial creek flats protected from frosts with a minimum rainfall of at least 1,600 mm per year. Some government and non-government programs have assisted planting and availability of planting stock (Lott *et al*. Chapter 3).

Successful species in southeast Queensland include blackwood (*Acacia melanoxylon*), black bean (*Castanospermum australe*), red bean (*Dysoxylum muelleri*), silver quandong (*Elaeocarpus grandis*), Queensland maple (*Flindersia brayleyana*), silver ash (*F. schottiana*), silky oak (*Grevillea robusta*), white beech (*Gmelina leichardtii*) and white cedar (*Melia adezarach*). There is a growing interest in the establishment of silver quandong as a monoculture plantation species because of it fast growth and early realisation of timber values. Early milling of thinnings at age six and eight years shows the species has the potential to be harvested from plantations at age 18-20 years (see Glencross and Nichols Chapter 7).

The situation in north eastern NSW is similar to that of southeast Queensland (refer Lott *et al*. Chapter 3). Sites are predominantly focused on the better basalt soils and in areas with higher rainfall. By far the most popular choice of species for small-scale farm forestry is native rainforest cabinet timber species. Early monitoring and data analysis have revealed promising growth and form for a number of species. The more successful species are silver quandong, Queensland maple, southern silky oak and silver ash (Novak pers. comm.). Glencross and Nichols (Chapter 7) give further detail on trials in northern NSW. The high level of private grower interest has been reflected by the activities of the Subtropical Farm Forestry Association, which was formed by growers some ten years ago and now has over 600 members (Novak pers. comm.).

Table 1 Tropical and subtropical "rainforest" plantings in north eastern Australia.

Region	Area and Type of Plantation Estate
Wet tropics (north Queensland) – rainforest and mixed hardwood plantings	**3,100 – 3,200 ha** mainly mixes of eucalypts, maples, hoop pine and other rainforest species such as silver quandong (sources: Skelton and Sexton unpublished; NQAA and CRRP annual reports) Approximately 1,850 ha are forestry plantings, with 1,250 ha environmental rehabilitation or revegetation plantings.
Mackay /Central Queensland region – rainforest and mixed hardwood plantings	Not quantified, probably around **500 ha** (source: Rohan Allen pers.comm)
South-east Queensland – rainforest and mixed hardwood plantings	**400 ha** (source: Sewell pers.comm) Including 264 ha cabinetwood plantings.
Northern NSW – rainforest and mixed hardwood plantings	**2,700 ha** (source: Novak pers. comm) Approximately 50% of this is commercial plantings. 1,800 ha confirmed by surveys in 1996 with up to a further 900 ha planted since this time – mostly mixed rainforest species with some wet sclerophyll inclusions (source: Novak pers. comm)
TOTAL OF PRIVATE ESTATE	**6,800 ha** Approximately 4,100 ha of this was established in forestry-style plantations, the remainder is revegetation plantings
Queensland State government owned hoop pine estate	**44,800 ha** 800 ha of hoop pine on Atherton Tablelands, 5,000 ha in other areas of north and central Qld and 39,000 ha of hoop pine in SEQ (DPIF Pocket Facts 2003)
TOTAL ESTATE	***Approximately 52,000 ha of some 50 main species***

By far the most coordinated and well-funded program was the Community Rainforest Reforestation Program (CRRP) which operated in north Queensland from 1992 to 2000, and also in central Queensland from 1996. The following case study of CRRP outlines its history, achievements and lessons learned, and has implications for future farm forestry programs.

The Community Rainforest Reforestation Program – A case study of farm forestry in the tropics

Background

North Queensland is the home of Australia's only significant area of tropical forests. The wet tropics, a region along the Queensland coast between Townsville and Cooktown (latitude 15-19° south and longitude 145-146° 30' east), has around 600,000 ha (Forwood Panel 2 1974) of tropical forests and until the 1990s, had a significant timber industry based on tropical species including Queensland maple, black bean and red cedar.

Most of the region consists of a narrow coastal plain flanked by foothills and mountains up to 1,600 m (Tracey 1982). The distinctive features of the region can be attributed to the high rainfall and terrain diversity (Werren, 1992). Average rainfall for the region is generally in the range 1,000 – 5,000 mm per annum, although extremes of over 10,000 mm per annum can occur in some of the higher mountain regions, with rainfall predominantly falling in the summer from December to March (Tracey 1982).

Coupled with the rainfall variability, the geological parent materials (from five major rock types and the soils derived from them), play a significant role in the distribution of vegetation complexes forming a very diverse array of rainforest, sclerophyll and wetland mosaics across the region. Tracey (1982) identified some 23 major vegetation communities in the humid tropics, of which 13 are considered as “rainforest” systems. There is exceptional diversity within these vegetation systems with over 3,400 vascular flora, 90 mammals, 360 birds, and a rich array of reptiles, frogs and invertebrates (Werren 1992).

In addition to its natural values, the climate and soils have also been valuable for human settlement and the establishment of rural industries including dairy, beef, sugar cane and horticulture, particularly tropical fruits. Tourism, small business development, bananas, beef cattle, and value-added agricultural systems are increasingly driving economic development whilst low-value commodities such as sugar cane, dairy and tobacco are all experiencing declines (McDonald and Weston 2003). The region supports a population of 244,786 (Australian Bureau of Statistics 2001).

The Hawke Federal Labor Government was elected in 1983 and came into power on a strong environmental platform led by the commitment to “Save the Franklin” River. At around this time, several reports indicated that the tropical forests of north Queensland were being logged at an unsustainable rate. Due to the outstanding biological and cultural values, and evolutionary significance of the tropical forests, the World Heritage Commission inscribed the Wet Tropics of Queensland World Heritage Area (WTQWHA) as a property on the World Heritage List in 1988. The new WTQWHA encompassed the majority of the publicly owned forested land in the coastal ranges from Townsville to Cooktown and included the bulk of the productive forests on which the local timber industry was based. The World Heritage listing was initiated by the Commonwealth Government and generated significant hostility from local communities in north Queensland, particularly those around Atherton and Ravenshoe where the timber industry was a major economic activity.

In recognition of the impacts of the change to many north Queensland timber businesses and the subsequent impacts on regional towns and communities dependent on these businesses, the commonwealth government announced a $73 million Structural Adjustment Program to provide transitionary assistance in employment and business development. This program included $37 million of compensation that was paid directly to regional sawmillers and councils affected by the listing.

The CRRP was a major component of the Commonwealth Government’s response to community reaction against the listing of the World Heritage Area and calls for compensation to businesses and communities affected by the loss of the timber industry. The original proposal was strongly influenced by the work of Cassells (1993) who proposed new forms of forestry that encompassed environmental and social outcomes as well as the traditional economic ones. This coincided with a significant body of international work resulting from the failure of large-scale forestry enterprises to deliver economic benefits in development projects. Westoby (1987) mapped the change in philosophical approach to forest management in his *Purpose of Forests*. He summarised the new direction for forestry as “making trees serve people” (Westoby 1987 p. 257). This was an intrinsic component of the CRRP at its inception, but also a source of many of the tensions which would later plague the scheme as trade-offs between production and other objectives could not be agreed between the groups responsible for management of the program.

The proposal for a "new timber industry based on the growing of cabinetwoods and hardwoods" (Shea 1992) was submitted to the Commonwealth Government in 1991 by eleven far north Queensland local government councils to secure funding to support the region through the changes that would result from removing the greater part of the public forests in the region from production.

In their submission, the councils drew heavily on Shea's (1992) case that an opportunity existed for the region to establish a "new industry" to supply much of the world's high quality timbers. This argument was based on the increasing demand for logs imported by developed countries from the tropical countries, coupled with the level of deforestation and consequent supply implications in the supplier countries. This new industry would rely on the development of timber plantations using traditional monoculture forestry species such as hoop pine and kauri pine, native eucalypt hardwoods, as well as both native and exotic rainforest cabinet species, which would be intensively managed for high quality timber production. The initial phase of the scheme was envisaged as the planting of about 30,000 hectares over 40 years, employing around 100 people by year ten.

The roles of Councillor Mike Berwick, Mayor of Douglas Shire, and the Right Honourable Ed Casey, Queensland Minister for Primary Industries at the time, were critical in negotiating and collaborating with Mr Simon Crean, Federal Minister for Primary Industries, to provide the cooperation and support required to make the concept of a tropical farm forestry program a reality.

The councils appointed Queensland Forest Service of the Department of Primary Industries (DPI) as the agency to manage the new timber industry scheme and the Commonwealth appointed Dr Joe Baker to chair a CRRP Management Committee (CRRPMC) with representatives from the Commonwealth, DPI and from local governments through the Northern Queensland Afforestation Program Joint Board (NQ Joint Board), a regional local government formed to manage the employment and training component of the program.

The CRRPMC developed a vision for "healthy vegetated catchments, maximising wood production, environmental protection and employment". It also agreed on four specific goals for the CRRP.

Goal 1: Develop a Private Timber Plantation Resource Base for a Sustainable Timber Industry in the North, with a major emphasis on Native Rainforest Species

One of the actions under this goal was to facilitate the transfer of designated responsibilities from the CRRP to the grower cooperatives. It was envisaged that government, through the CRRP, would develop joint ventures with the private sector in this region, and also formulate a timber prospectus (DNR 1996). Native rainforest species had been identified by Shea (1992) as having significant economic potential, and the region was well placed to take advantage of this, as it was the only significant wet tropical area in Australia and had some existing infrastructure developed for the utilisation of timber from the region's natural forests.

Goal 2: Address the problems of land degradation in the wet tropics

Land clearing, fragmentation of native vegetation and inappropriate land use leading to erosion, weed infestations and sedimentation of streams were identified as issues in the wet tropics. In particular, the rate of land clearing during the late 1980s and early 1990s was particularly high (Goosem 2002) and some 68% of wet tropics ecosystems are currently listed as threatened or of concern (Weston and Goosem 2004). The CRRP committed to only establishing plantations in areas previously cleared and aimed to significantly contribute to land rehabilitation through reforestation and creating a mosaic of treed vegetation across the landscape.

Goal 3: Provide for improved water quality by establishing vegetation buffers along rivers and streams

A key rehabilitation issue identified for the wet tropics region was the extent of clearing, fragmentation and degradation of riparian vegetation systems with consequent impacts on biodiversity conservation, water quality and the health of the Great Barrier Reef Lagoon (Vize 1996). Targeting river and stream buffers as replanting zones was considered the highest priority rehabilitation activity in the region.

Goal 4: Train a workforce to support the long-term practice of rainforest plantation establishment.

Retraining and employment of displaced timber workers and rural long term unemployed was a central component of the CRRP proposal. It was recognised that ex-timber workers would have skills relevant to a new forest plantation industry. The Labor Government had introduced new labour market programs as part of its policy platform on unemployment and negotiated these as part of the CRRP. Development of growers' technical and business skills became the central component of the extension programs associated with the CRRP.

Why Tropical Farm Forestry?

The key factors supporting the establishment of a farm forestry program in north Queensland were:

- land availability;
- warm, sunny climate with high rainfall – expected fast growth rates;
- range of timber species including – but not restricted to – high value tropical cabinet timbers;
- protection of ecological values of the region (particularly reef and rainforest) through land stabilisation, revegetation and protection of waterways;
- sustainable land-based enterprises were seen as more appropriate for areas bordering world heritage or with significant ecological values;
- rural unemployment, including displaced timber workers; and the
- development of small- to medium-sized businesses to assist depressed regional economies.

Keenan and Annandale (1999) identified 134,500 ha of privately owned, cleared land suitable for timber plantations. Annandale *et al.* (2003) refined this work to exclude high value agricultural land, identifying some 86,000 ha of climatically and operational suitable land within 200 km of Cairns.

These factors were used in the early design of the CRRP program, which targeted degraded farm land within a 200 km radius of Cairns, particularly on riverbanks. Social and economic considerations were incorporated into the program through employment programs, training, and support programs investigating marketing, timber utilisations and product investigation. One of the unique features of CRRP, compared to other farm forestry programs in Australia, is that it included a range of native and exotic tropical timbers. Table 2 lists the top ten species planted from a total pool of some 175 species used over the life of the program.

Table 2 Top ten species planted by the CRRP. (Source: CRRP database)

Species	No. sites planted	No. seedlings planted
Eucalyptus pellita	310	134,499
Araucaria cunninghamii	208	105,195
Eucalyptus cloeziana	225	98,775
Flindersia brayleyana	453	90,665
Agathis robusta	317	62,866
Elaeocarpus grandis	390	60,379
Eucalyptus grandis	132	52,962
Eucalyptus tereticornis	177	38,178
Eucalyptus microcorys	98	27,791
Corymbia citriodora	125	27,233

Employment and Regional Development

As unemployment in Queensland was high in the early 1990s, key thoughts behind the development of the CRRP included the need to provide regional employment opportunities and build a skills base for the new farm forest industry. Many businesses had been directly impacted by the listing of the WTQWHA with resultant impacts on small townships such as Ravenshoe and Tarzali, and the regional economy in general. Of around 20 timber mills in the region dependent on native forests only three mills exist today and two of these are likely to close by 2010.

Though not part of the original farm forestry concept, the inclusion of a labour market program was essential to securing government funding. This was because it was a way to achieve some of the social outcomes targeted by the CRRP. It linked directly with the Commonwealth’s Landcare and Environment Action Program (LEAP) (and in the Mackay area also through Regional Environment Employment Projects (REEP)). Across the life of the CRRP, approximately 880 people were employed through these programs. These involved six months employment and vocational training in Certificate I in Rural Skills (for forestry and agriculture workers).

Although there was strong support for skill building and developing a workforce for the region from the CRRPMC, the imperative to employ large numbers of unemployed people, on what was effectively a short term rotation, drove many of the operational arrangements that were set up for the management of the CRRP. The programs were relatively inflexible and could not be adapted to the needs of a farm forestry program. The CRRP therefore was required to adapt itself to incorporating these programs.

The CRRP strategy conceived the idea of developing the skills of the labour market participants and supporting the establishment of small contracting businesses to undertake plantations operations. As the size of the resource increased it was expected that these businesses would become financially viable and that a transfer of the operations to the private sector would occur. It was hoped that the CRRP would create a skilled labour pool that these contracting businesses could draw upon.

In tandem with the development of the contracting businesses, CRRP conceived an active role for landholders in forest management through the development of grower groups and a regional timber cooperative. This was seen as an essential component due to the small size of many of the holdings. A cooperative could provide assistance to growers, particularly during the harvesting and marketing phases.

The North Queensland Timber Cooperative was formed in 1997 and currently has 25 active members. The Cooperative now focuses on value-adders and processors rather than growers, in an attempt to create a service business that is more market and product-development oriented.

A significant contribution of the CRRP was its focus on "community." This started through seeking community input into program design through public meetings sponsored by the CRRP Management Committee. When the program entered its second phase, this evolved into a focus on landholder education and participation in farm forestry. Herbohn *et al.* (Chapter 14) and Harrison *et al.* (Chapter 15) give a summary of the social and economic research conducted during the CRRP.

Institutional and management structures

Although the CRRP was established as a long term program with four clear objectives it was dogged by constant changes in direction, predominantly caused by change in funding commitments and management direction from the Queensland Government. Four clear phases in the progress of the CRRP can be identified – the first three occurred under the management of the Queensland Department of Primary Industries/Natural Resources and the fourth occurred when the CRRP was managed directly by local government and community groups.

Phase 1 – The 'New Forestry': 1992-1994

- Directed by CRRP Management Committee made up by representatives from Commonwealth, state and local government.
- Four clear objectives identified with a major focus on tropical species; the focus was to get trees planted and to respond to community concerns.
- Plantation operations were managed by DPI.
- Labour market programs were managed by NQ Joint Board.
- The key species groups used were eucalypts, native softwoods and Queensland maple and silver quandong (*Eucalyptus pellita*, *Eucalyptus cloeziana, Araucaria cunninghamii, Agathis robusta, Flindersia brayleyana* and *Elaeocarpus grandis*).
- Most plantings were very small in area (less than 2 ha); attention was focussed on creek banks and degraded farmland.
- Extension activities were limited to promoting the CRRP to enlist landholder participation.
- Only limited research was supported (e.g. fertiliser and herbicide trials, marketing studies).

DPI managed the operational side of the CRRP (and the National Farm Forestry Program funding) and the NQ Joint Board undertook to run the labour market program, the organisation of vehicles and the training of participants in the program. A management committee was established to oversee the program and report directly to State and Commonwealth Ministers. The committee was made up of a Chair (Dr Joe Baker), three heads of local government, state representatives (DPI) and commonwealth representatives. The four goals of the program were formulated and adopted by the Ministers as the overarching general objectives.

Planting programs began in 1992/93 and initially focused on small sized plantings with an emphasis on creek plantings and the rehabilitation of degraded farmland. This continued into the next year as the majority of landholders entering the program did so for land rehabilitation and aesthetic purposes (CRRP survey; Paroz and Sexton 1999). At any given time around 100 trainees from the LEAP and REEP were employed for a six month period.

Seven species, listed above, made up around 65% of the seedlings planted in the first planting season. The speed at which the CRRP commenced meant that only a restricted range of species was available in sufficient numbers for planting in the first few years. Seedlings were procured through a tender process, with the majority sourced from DPI's two regional forest nurseries (Walkamin and Ingham), and additional plants from Yuruga Native Plant Nursery and a small school nursery near Cape Tribulation. All seed came from natural forests since there were no genetically improved seed available although some eucalypt provenance trials began during this period. Landholders carried out site preparation prior to planting and for the first few years the CRRP provided seedlings, planting and some site maintenance for free (Table 3). As the program progressed it was recognised that landholders needed to take more ownership of their plantations and levies were charged (Table 3).

Table 3 Landholder levy for plantings over the life of CRRP (Wilson pers. comm.).

Year of the CRRP	Landholder levy for conventional plantation	Landholder levy for agroforestry planting
1992/93	$0/ha	$0/ha
1993/94	$0/ha	$0/ha
1994/95	$150/ha	$75/ha
1995/96	$150/ha	$75/ha
1996/97	$150/ha	$75/ha
1997/98	$600/ha	$300/ha
1998/99	$1200/ha	$1200/ha

Phase 2 – Increasing Emphasis on 'Production' Forestry: 1995 – 1997

- Directed by CRRP Management Committee made up of Commonwealth, State, Local Government and community representatives.
- Overall objectives remained the same but the program modified to reflect the new focus on planting designs, species diversity, mixed species plantings and landholder participation.
- Introduced preferred planting size of 5 ha with minimum planting size of 2 ha.
- Operations managed by CRRP Management Unit set up within QDPI-Resource Management Group (later QDNR).
- Labour market and NQ Joint Board components phased out with wind up of the LEAP Program in 1996.
- Extension services and support for landholders given greater emphasis, including the establishment of a growers' cooperative and growers' groups; the North Queensland Timber Cooperative established in 1997.
- Modest support for research including the establishment of 75 mensurational plots in newly established plantings between Cooktown and Ingham.

During Phase 2, the CRRP was transferred, with DPI Forestry's resource management arm, over to the new Queensland Department of Natural Resources (DNR). DNR took over full responsibility for the State's contribution to CRRP. A specific CRRP Management Unit was set up and had responsibility for planning, seedling procurement and the development of landholder support services.

Extension services, with a mandate to empower landholders to actively take up farm forestry activities and training, were given greater emphasis. Field days, workshops and field inspections to properties provided landholders with information and advice on all aspects of tropical silviculture (pruning, thinning, etc.) and timber production (sawmilling, storing, etc.).

The CRRP released its Strategic Plan in 1996 (DNR 1996). The strategy focused on the transfer of responsibility for farm forestry from government to the private sector by the year 2000 (which did not eventuate). It proposed the following:

- increased attention to farm forestry extension services and the development of growers' groups across the region;
- the formation of a timber marketing cooperative and the transfer of CRRP extension staff to support cooperative members and grower groups;

- the development of private nurseries for the provision of good quality seedlings (at market price) for timber production;
- that nurseries act as farm forestry information centres;
- the continued phasing in of planting levies towards full recovery of plantation establishment costs from land owners by 1998/99;
- increased support for research and development; and
- the development of tropical agroforestry programs in universities.

By 1995, CRRP was planting more mixed eucalypt and acacia plantations. This style of planting was supported by trials carried out in Hawaii (Debell *et al.* 1985). Other designs were developed to replicate the dominance of the cabinet timber species in the rainforests and the need to reduce branching and weed growth on these tropical sites. Studies conducted by the Rainforest Cooperative Research Centre (CRC) and DPI's Queensland Forestry Research Institute (QFRI) (Keenan *et al.* 1999) on plantation grown rainforest species in north Queensland also became invaluable in the design and silvicultural management of CRRP plantings. A high priority was placed on promoting timely thinning and pruning activities.

As the labour market programs drew to an end the CRRP's operational staff undertook the planting and maintenance of further plantings. DPI staff were utilised for field operations due to the lack of skilled contractors in the region. The last year of CRRP planting was 1997/98.

Phase 3 – Natural Heritage Trust: 1998-2000

- The CRRP Management Committee was replaced by the Tropical Queensland Vegetation Management Advisory Committee.
- The original CRRP objectives were maintained until 1999 when objective 1 was modified to omit "with a major emphasis on Native Rainforest Species".
- Field operations were limited to demonstration sites managed by QDPI-Forestry.
- The range of species used was changed to focus on more commercially productive outcomes.
- Extension services focussed on demonstration plantings and passing on operational skills to landholders.
- Continued support was provided to growers' groups and to the North Queensland Timber Cooperative.
- A Tropical Agroforestry course was initiated at James Cook University.
- Assisted with the ongoing measurement of CRRP mensurational plots although this research was now funded outside the CRRP.

The advent of the Natural Heritage Trust (NHT) required the CRRP to compete with other farm forestry programs for a limited amount of federal funds. At the same time, the Queensland Government began establishing a Regional Forest Agreement in south-east Queensland; this subsequently had considerable financial implications for the Queensland Government because it was unable to negotiate an agreed outcome with the Commonwealth Government. Combined, these factors led to a dramatic decrease in investment in farm forestry in north Queensland over this period.

The DPI co-funded CRRP, along with DNR and AFFA through the NHT's Farm Forestry Program in 1998. The DPI managed nursery operations and planting crews, and contributed directly to QFRI research projects. Program staff remained as managers of the plantings and continued to liaise with landholders. Extension services increased involvement with landholders, including advising and demonstrating pruning and thinning techniques.

The program established a tropical agroforestry bursary for post-graduate students studying in north Queensland. Further funds were provided to James Cook University to establish a tropical agroforestry course.

The CRRP developed a number of demonstration sites across the region with the assistance of a number of high-profile landholders. Brochures were compiled describing the purpose of the planting from the landholder's perspective, species used in the plantings as well as information on planting designs, methods of managing the developing stands and some of the lessons learnt.

These sites were signposted "farm forestry" and have provided an example of farm forestry successes in this region to ministers, overseas government tour groups (especially from Asia), university study groups, researchers, conference tours, farmers and other government agencies and private forestry organisations interested in promoting timber production in this region.

Phase 4 – Beyond the CRRP: after 2000

- No further CRRP funds for field operations.
- Tropical Queensland Vegetation Management Advisory Committee (until 2002).
- Final stages of CRRP managed by NQ Afforestation Association with support from Local Government Councils.
- Regional Plantation Committee established (Private Forestry North Queensland).
- Extension includes stronger links with formal training courses.
- Research programs continue to use the CRRP trial plots.
- James Cook University Tropical Agroforestry course established on an ongoing basis.

From 1998, the CRRP was funded through the NHT Farm Forestry Program, and the scope of the program was significantly cut back. As the Queensland Government gradually withdrew support, the program ceased operation in late 2000, and the scope of the extension activities was narrowed substantially to production of a regular newsletter, website and the collation of data to finalise annual reports.

By 2000, the Queensland Government decided that its core business was to focus on vegetation management and not farm forestry. DPI's Joint Venture program had not been further funded and DNR closed down its Treecare group. The North Queensland Afforestation Association Inc. (NQAA, formerly NQ Joint Board), which still managed the Wet Tropics Tree Planting Scheme and a number of labour market and training programs, accepted responsibility for the remaining NHT funds, staff and incomplete activities from the end of 2000 to late 2002 when the Program was finally wound up.

The focus at this time continued to be on extension and the NQAA was able to build stronger relationships with vocational training for grower groups and continue support to the core group of very keen landholders, including the members of the North Queensland Timber Cooperative, now a registered and operational cooperative. The NQAA continues to run a forestry training program through its training arm, FNQ Training.

At the same time, a Federal government initiative established a Regional Plantation Committee (now a Private Forestry Development Committee) in north Queensland known as Private Forestry North Queensland (PFNQ), with additional support from the State government. An extension of NHT funding to continue the employment of community-based coordinators resulted in the transfer of the remaining farm forestry extension function to PFNQ where it is being integrated with programs exploring market potential and providing information to assist potential growers.

Summary of outcomes of the CRRP

Some of the key achievements of the CRRP from 1993-2000 are summarised in Table 3.

In the short period that it functioned the program made significant progress in all four of its objectives. It began the process of creating a privately owned plantation timber resource based largely on native species from the region. It also began to address the problems of land degradation in the region and reforested significant areas of riverine landscape.

Finally, it helped provide work for a large number of people and provided training in reforestation.

There is still significant interest in farm forestry – in its myriad of forms – across the region and a number of the original CRRP landholder participants are still pursuing tree growing for pleasure and profit. Forest managers and researchers continue to collate and analyse the data generated by the CRRP plantings. The tropical timber estate established through the CRRP has also been invaluable for increasing our understanding of tropical silviculture and identifying opportunities for commercial plantation estates now generating significant private investment interest in both north and central Queensland.

Table 3 Summary of outcomes from the CRRP in north Queensland over 1993-2000.

Planting of 1,782 ha took place on 658 blocks over 5-6 years, with the largest planted area on the Atherton Tablelands (Skelton and Sexton, unpublished data), as well as smaller areas of plantings on the wet tropical coastal plain around Cairns to Innisfail and around Mackay.
The plantings fostered landscape complexity and helped restored some plant biodiversity to many areas of the landscape. In the Atherton Tableland, for example, plantings included 1,179,657 seedlings of some 175 species of native and exotic trees in mixtures containing up to 31 species in a single planting blocks (Skelton and Sexton, unpublished data).
Productivity was restored to some degraded lands. For example, plantings of around 320 ha (20% by area planted in the wet tropical areas) carried out on degraded and unproductive land (Harrison 2001).
Riverine and creek bank plantings were carried out on over 150 ha or 12% by area planted in the wet tropical areas (Harrison, 2001). Although no direct measures were made to assess subsequent improvements to water quality, anecdotal evidence suggests improvements have occurred (Herbohn *et al.* 2000).
The program involved over 600 landholders (1992 – 1997 from CRRP Annual Report 1996-97). Many of these landholders were introduced to basic skills in plantation establishment and management via extension and training programs.
A North Queensland Timber Cooperative was established to provide information on growing forests to members and collective marketing of the timber produced.
Employment was provided for 880 people through the Landcare and Environmental Action Program (LEAP), of which over 60% subsequently found employment or were able to undertake further training directly after taking part in the program (CRRPMC 2000);
Assisted the establishment of the James Cook University Tropical Agroforestry Course and a bursary program for five recipients.
Establishment of a schools program to introduce tropical farm forestry to children in primary and secondary schools in the region.
Produced a range of publications for extension purposes including species notes for tropical timber species
Assisted in research and development activities in seedling production, nursery practices, silviculture of tropical species, etc.

Acknowledgements

The authors would like to thank the following for their contributions to the CRRP and to informing this chapter: Dr Joe Baker Chair (CRRP Management Committee (1992-1997), Chair Tropical Queensland Vegetation Management Advisory Committee (1998-2002)); Cr Mike Berwick (Mayor Douglas Shire Council, Chairman NQ Joint Board/NQAA and member of the CRRP Management Committee (1992-1997)); Colin Creighton (Regional Manager (Natural Resources) DPI North Queensland (1994-1997) and member CRRP Management Committee (1994-1997)); Jim Donaldson (DPIE representative on the CRRP Management Committee (1992-1997)); and Keith Gould (District Forester DPI Atherton (1992-1993) and CRRP Management Committee member).

Rod Collins (CRRP Officer Ingham (1995-2001)), Rohan Allen (DPI Senior Project Officer Mackay), Ashley Sewell (DPI/DNR Farm Forestry Extension Officer (1992-1998)) and Martin Novak (Subtropical Farm Forestry Association), provided contributions on Ingham/dry tropics, Mackay/central Queensland, south-east Queensland and northern NSW included in the introduction. We thank Sandra Wilson at the EPA in Atherton for locating information on landholder levies from old CRRP documents.

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II

Propagation and Establishment of Rainforest Timber Trees

3. Seed and seedling supply for farm forestry projects in the tropics and subtropics of eastern Australia

Rosemary Lott, Gary Sexton, and Martin Novak

Abstract

At least 6000 hectares of farm forestry plantings have been established within the tropical and subtropical regions of eastern Australia over the past ten years. These plantings comprise over 170 species (mainly native rainforest species) and most were undertaken by government-funded programs and groups such as the Community Rainforest Reforestation Program (CRRP) in north Queensland, the Treecare scheme and Landcare in southeast Queensland , and the Subtropical Farm Forestry Association in northern New South Wales. Documentation of the species propagated and the nursery management issues involved in supplying these programs was limited.

We surveyed nurseries and seed collectors to determine the problems encountered in the planning, ordering and supply of planting stock of tropical and subtropical timber species for these community farm forestry projects. Particular problems, especially initially, were reliable supplies of good quality seed, short seed storage life, pests and diseases including fungal pathogens, and the need for improved pots and potting mix for ease of planting and good survival in the field. To address these problems, the nursery and farm forest program managers had to acquire local experience in seed collection, germination and nursery silviculture and planning to meet planting schedules. This chapter reviews some of the problems encountered, and concludes with some recommendations for managing the supply of good quality planting stock for future farm forestry in the tropics and subtropics.

Introduction

By the year 2000, approximately 4,000 ha of hardwood and mixed plantations of rainforest species plantations and farm forestry had been established in Queensland, and 2700 ha of mixed plantations of rainforest species in New South Wales (see Vize *et al.* Chapter 2, Wood *et al.* 2001). A significant proportion of this was established by small-growers, and on private land (Wood *et al.* 2001). Most plantings were undertaken by government-funded groups such as the Community Rainforest Reforestation Program (CRRP) in north Queensland, the Treecare scheme and Landcare in southeast Queensland, and the Subtropical Farm Forestry Association in northern New South Wales. Many of the rainforest species planted were comparatively new to forestry practice and there was little knowledge of their silvicultural requirements or of how to raise seedlings of these species in nurseries.

We surveyed managers from twelve plant nurseries and several professional seed collectors within the tropics and subtropics of eastern Australia, who were involved in supplying these community tree planting schemes during the 1990s. The survey obtained information on the range of species recommended for and used in each region, as well as the methods of seed procurement, labelling and recording of seed batches, seed storage and germination used by these nurseries. The survey also sought information about nursery propagation mixes used, fertilizer regimes, pests and diseases in the nursery and key problematic species. Nurseries were also asked to comment on the level of advice that they gave to growers.

Using the results, this chapter identifies the problems that affected seedling supplies to farm forestry plantings, the quality of planting stock, and planning issues with regard to improving supply. The role of nurseries in future programs is considered.

Our survey concentrated on the experiences of nurseries in supplying the tree planting schemes during the 1990s. However we have also noted current practices when mentioned by the nurseries and these are included in the Results section, written in the present tense. Our survey excluded the larger scale industrial plantations established by government agencies and investment companies. Nor did it investigate nursery supply to the Joint Venture schemes which commenced in Queensland and New South Wales in the late 1990s.

Tree planting schemes

North Queensland

This region had two large tree planting programs: the Community Rainforest Reforestation Program (CRRP), funded by the National Farm Forestry Program (see Vize *et al.* chapter 2, this volume), and the Wet Tropics Tree Planting Scheme (WTTPS). Both programs operated over most of the 1990's. The objectives of the CRRP included creating a timber resource as well generating some conservation and watershed protection benefits. The WTTPS focused on rainforest revegetation of degraded sites within the Wet Tropics for largely conservation reasons. Other tree planting programs also existed, such as TREAT (Trees for the Evelyn and Atherton Tablelands), Treecare and Landcare. Estimates of the areas planted are given in Vize *et al.* (Chapter 2).

Southeast Queensland

Several tree planting schemes also took place in southeast Queensland. In 1989 the Queensland government launched the "Caring for our Countryside' policy, with support from the Commonwealth Government (Agtrans Research 2004). This program had three components: (a) the Tree Assistance Scheme (TAS) that provided free and concessionally priced trees to landholders, (b) Treecare research and (c) the Treecare extension services that funded twelve extension officers across the state (Agtrans Research 2004). In southeast Queensland the scheme applied in the Caloundra, Caboolture, Kilcoy, Maroochydore, Brisbane and inland Burnett regions, and 148,000 tree seedlings were distributed to 485 landholders over the period the scheme operated; 32% of applications from landholders were for plantings of commercial intent – but see further below. The scheme was initially managed by the Queensland Forestry Service (later to become the Department of Primary Industries - Forestry) and then, in 1996, by the Department of Natural Resources. The program ceased in 2000 and state government forestry extension has now virtually ceased (Agtrans Research 2004). Some additional state, commonwealth and local government funding was received by southeast Queensland Landcare groups during the 1990's (e.g. see Noosa Landcare 1997). Noosa Landcare has used some NHT funds to establish permanent measurement plots in selected mixed species plantations and to store tree performance data in a database. Other tree growth measurements in southeast Queensland plantings have been made by Ashley Sewell (DNR), by QFRI (e.g. Dickinson *et al*. In press) and by Glencross and Nichols (RIRDC project SCU-7A).

In 1996 Queensland commenced a Joint Venture scheme which offered equity and shared harvest rights between participating landholders and DPI Forestry in hardwood plantations established on the landholders' private land. The four species planted in southeast Queensland were *Araucaria cunninghamii* (hoop pine), *Eucalyptus cloeziana* (Gympie messmate), *E. pilularis* (blackbutt) and *Corymbia citriodora* subsp. *variegata* (spotted gum). These Joint Ventures contributed to the farm forestry area and community awareness of farm forestry, but did not plant rainforest species (apart from *A. cunninghamii*) and had a primarily production focus.

There has been no regional level inventory (or centralised record as in CRRP) of farm forestry planting in southeast Queensland. The TAS nursery distribution records were rarely collated so we do not know whether all seedling orders were collected, or planted (K. Brady, DNR 1999 pers. comm.).

Some TAS applicants said the seedlings were for commercial purposes (see Lott 2001) but most sites had little maintenance or were planted for aesthetic reasons (M. Baxter pers. comm.) and are unlikely ever to be harvested. However some TAS and subsequent eucalypt and rainforest plantings are well maintained, and will provide timber in the future, e.g. via the Mary Valley Farm Forestry Cooperative, and Noosa Landcare.

The National Farm Forest Inventory estimated that 892 ha of hardwoods and mixed species and 97 ha of softwood (predominantly *Araucaria cunninghamii*) were established in farm forestry plantings in southeast Queensland, but consider this may be a substantial underestimate (Wood *et al.* 2001).

Northern New South Wales

The Subtropical Farm Forestry Association (SFFA) was established in 1993 as a result of a conference held in the region (Novak and Bracker 1994). The conference attracted over 200 participants. Most of these were growers interested in native trees for timber, environmental and aesthetic reasons. The interest of growers in the region is reflected in an average annual SFFA membership of 150 involving over 600 individual members. It is estimated that SFFA members have planted approximately 2.5 million trees on some 2700 hectares since the Association was formed mostly, as environmental and woodlot plantings (Novak pers. obs.).

Surveys of SFFA members by the Association (SFFA Newsletter 1995, 2000) revealed that a majority of members (61%) have an interest in Landcare and environmental plantings; 48% were interested in rainforest cabinet timber plantings and for 41% the main interest was in commercial plantings. That is, landholders were interested in farm forestry for a variety of reasons and not just production forestry. It is interesting that a similar range of motivations existed with the TAS applicants in the Gympie region of Queensland (Lott 2001), landholders in the Obi Obi catchment in southeast Queensland, landholders in the Richmond River catchment in northern NSW and landholders in CRRP shires in north Queensland (Emtage et al. 2001; Emtage and Specht 1996, 1998; Harrison et al. 1996).

The SFFA initially received funding through the Commonwealth government (DPIE) Farm Forestry Program, and later through the Natural Heritage Trust (NHT). Funding allowed payment of an extension officer, and enabled approximately 40 landholders to plant demonstration plantings. Fourteen of these demonstration plantings are still being measured for long term growth data. This data is stored in a database together with other growth measurements made originally by Southern Cross University staff and students (Specht and Digby 1995). The SFFA also runs field days and, until 2002, farm forestry introductory courses.

The SFFA has worked closely with many of the local nurseries. It has encouraged high standards and professionalism with regard to propagation and seed collection. These nurseries have been encouraged to utilise local provenance material where possible to promote regional genetic integrity and to use seed collected to standard recognised rules for ensuring adequate genetic diversity (see Seed Procurement section, this chapter). The SFFA has produced a manual for growers on establishing trees (Subtropical Farm Forestry Association 2001). Other active tree-planting groups in northern New South Wales included Richmond Landcare and Greening Australia.

Nurseries supplying these schemes: Then and now

Both government and private nurseries supplied the tree planting schemes, as well as seedlings for sale to the general public.

North Queensland

Approximately six nurseries produced seedlings for the various schemes in North Queensland. Over the course of the 1990's these nurseries supplied well over two million rainforest and eucalypt seedlings. In the case of CRRP, seedling orders were as high as 400,000 seedlings per year and around 1.5 million seedlings were produced between 1992 and 1997. DPI-Forestry's nursery at Walkamin grew a wide range of species, including rainforest hardwood and softwood species, which were generally available for purchase by the tree planting groups or members of the public. It also supplied the State government farm forestry program, Treecare. The largest private nursery (Yuruga) specialised in a wide range of native forest species for the general public, but also began developing clonal seedlings for private forestry companies.

Following the withdrawal of government support for these programs, nurseries have experienced a decline in the demand for cabinet timber seedlings. Today, the DPI nursery only grows rainforest hardwood and eucalypt seedlings on a contract basis. Currently, its main activity is to propagate clonal material and seed for its pine plantation estates. Yuruga nursery continues to provide clonal timber trees for large private forestry companies outside the north Queensland region but it also specialises in a wide range of native forest species for the general public. Most of the smaller nurseries that, in the past, produced tens of thousands of seedlings for these programs have closed (Beitzel pers. comm.).

Southeast Queensland

In southeast Queensland, the main nurseries which supplied Treecare, the Tree Assistance Scheme (TAS), and early Landcare and local landholder plantings, were the DPI Forestry nurseries at Bunya, Beerburrum and Toolara. The nursery at Bunya was also, until closing in June 2004, a major supplier of rainforest species and eucalypts to the general public in the southeast Queensland and to adjoining regions e.g. northern New South Wales. In later years smaller private businesses and Landcare nurseries were established to supply seedlings on a project basis or to grow seedlings specifically for local planting and sale. Some of these smaller nurseries rely solely on rainforest species for business while others, particularly several of the larger ones, also produce eucalypts and acacias as part of their main production. Barung and Noosa Landcare nurseries both produce rainforest, eucalypt and acacia seedlings, as well as some understorey species.

Large numbers of seedlings were produced. The DPI Forestry nursery at Bunya provided seedlings for the TAS and Treecare scheme from the Scheme's inception. It also provided seedlings to the Beerburrum nursery for distribution. In 1996/97, Bunya nursery's total plant sales were 70,000 Vic pots (e.g. rainforest species) and just under 60,000 net pots (primarily eucalypts). Recent sales in 2002/2003 were similar with nearly 77,000 Vic pots and 82,200 net pots (McLeod pers. comm.). These figures include general sales to the public. The DPI Forestry nursery at Toolara grew mainly eucalypts, *Melaleuca* and *Callistemon*, with rainforest species probably comprising less than 10-20,000 per year (M. Baxter pers. comm.) Of these, several thousand *Elaeocarpus* were grown, and a few growers obtained lots of 400-500. Most seedlings were sold in smaller lots, or mixed species lots of 50-100 seedlings.

The number of seedlings grown by the private and Landcare nurseries was initially small but increased over time. From small beginnings with volunteer labour in 1989, Barung Landcare has grown – it produced an estimated 10,000 seedlings ten years ago, and expects to produce about 165,000 plants in 2004 (Willis pers. comm.).

Noosa Landcare estimated that its nursery produced 28,000-32,000 tree and understorey seedlings when it commenced in 2000, and expects to produce approximately 100,000 plants in 2004 (Clarke pers. comm.). Now that government funding is reduced, both Landcare nurseries are producing a much larger proportion of seedlings for contract plantings, although sales to smaller private landholders are still important. Plantings by absentee landholders (e.g. doctors, lawyers, out-of-state landholders) are an important component of their sales. As well as managing the nurseries, the Landcare staff organise and hold local farm forestry field days, plant demonstration sites, monitor tree growth, and provide public education and local advice to landholders. These activities then provide feedback and support to the nursery.

Northern New South Wales

There are approximately 20 nurseries in northern NSW that now grow rainforest species whereas there were only six or seven existing ten years ago. Most are small nurseries which produce less than 10,000 seedlings per year, although a few produce up to 60,000 seedlings per year. Some nurseries rely solely on rainforest species for business while others, particularly several of the larger ones, also produce eucalypts and acacias. Seedlings have also been brought into the region from external nurseries in southeast Queensland and mid-north coast NSW but most of the seedlings used in the region have come from local nurseries.

About 50% of the nurseries operate as mixed businesses which produce seedlings as well as provide farm forestry consultancy services and some contract planting. Over the last two to three years the demand for rainforest timber species has fallen significantly while the demand for rainforest species for rehabilitation has increased. This is probably a result of a shift in local government priorities (e.g. catchment management councils) towards conservation plantings in this region.

Factors influencing landholders' choice of species

Several factors have influenced the species landholders have chosen to use in farm forestry plantings across the regions.

From the beginning a key influence was the advice received from farm forestry extension officers employed by government and other tree planting organisations (e.g. Greening Australia). These extension staff contributed greatly to landholder awareness of timber species, silvicultural management, timber production and potential markets. This information was passed on via field days, education programs and personal contact. The knowledge held by extension workers originated from experience in the local forest or timber industry or from government forestry staff. This was later supplemented by their own personal experiences in the field as well as from reports and research findings.

Advice was often sought as to the natural distributions of species and the results of research trials that provided information on growth rates (see Lott 2001). Another issue was the timber properties of particular species. Initially, a wide range of timber species was recommended based primarily on milling properties and former market prices for trees cut from natural forests. However there was scant information on the timber properties of plantation-grown timbers or of future market prices in the post natural forest logging era.

Some recent estimates of demand for cabinet timber species have been compiled by Harrison and Herbohn (1996), Herbohn *et al.* (1996) and Herbohn *et al.* (1997) but the issues of timber properties and market prices for plantation-grown timbers are still being researched.

Conservation values, aesthetics and the desire for shelterbelts and land rehabilitation were another set of factors influencing species choice. For land rehabilitation and conservation plantings, locally endemic species were preferred. Many landholders also chose to use mixed species plantings, which were also promoted by CRRP and advocates such as Kooyman (1996) and Mitchell (1996).

Irrespective of whether trees were being planted for commercial or conservation reasons it soon became clear that some species were very sensitive to site conditions. Some of the high value rainforest timbers could be widely planted (e.g. *Elaeocarpus grandis* (silver quandong), *Flindersia* spp.) while others such as *Cardwellia sublimis* (northern silky oak) and *Castanospermum australe* (black bean) proved difficult to establish and could only be planted on a very narrow range of sites.

In north Queensland, demonstration sites were established by CRRP, in conjunction with landholders, to allow for the transfer of this information. These initial farm forestry plantings were eventually to be the key indicator of species suitability in the various sites across the regions.

Seed availability and ease of propagation also influenced which species were supplied by nurseries to farm forestry. Nurseries initially selected species for propagation based on recommendations through word-of-mouth, field observation, and scattered information from various other sources. Over time their own experience influenced recommendations.

Over time tree-growers' own experience of species performance in field plantings supplemented the above information. Today the situation is less experimental – most nursery clients have received advice from a professional farm forestry officer or have found information on the internet relating to the species they are interested in planting.

Choices were based largely on biological constraints on what could be planted, but were also influenced by suggestions by various agencies regarding species that should not be planted. For example, some shire councils have actively opposed the planting of non-indigenous and non-endemic species, and requested that the seedlings planted for farm forestry be grown from seed obtained from the local area.

Exotic species in general are frowned upon by some landholders and members of the public. For example, conservationists have voiced concern over the potential spread of the exotic *Pinus* species from plantations into surrounding native vegetation in both southeast and northeast Queensland. An exotic timber species *Chukrasia tabularis* has been found regenerating beneath mature *A. cunninghamii* plantations and within regrowth forests in north Queensland's plantation estate (Ward *et al.* 2001). As a consequence, this species was removed from the CRRP species list and thereafter not recommended for planting on sites in close proximity to World Heritage listed rainforest. In southeast Queensland, some Landcare groups are now wary of planting *Flindersia brayleyana* (Queensland maple) adjacent to riparian areas, because of its prolific seed production and ease of germination, from which seedlings could potentially invade remnant vegetation.

Species choices have been tightly constrained in the Joint Venture programs managed by Queensland and New South Wales. The Joint Venture schemes have employed professional foresters who have been required to recommend a small number of pre-determined commercial species. Unfortunately, some of the initial plantings have nearly failed due to species being planted outside of their suitable environment range with consequent pest and disease attacks. Later Joint Venture plantings have used stricter criteria in selection of sites that were more suited to the particular species' requirements. However, landholders have not always understood the importance of appropriate site-species matching.

Table 1 Species planted in largest numbers by farm forestry projects in the tropics and subtropics of Australia in the last ten years.

North Queensland[1,2]	Central Qld[3]	Southeast Qld[2]	Northern NSW
Eucalyptus pellita	*Elaeocarpus grandis*	*Flindersia brayleyana*	*Araucaria cunninghamii*
Araucaria cunninghamii	*Nauclea orientalis*	*Flindersia australis*	*Flindersia brayleyana*
Eucalyptus cloeziana	*Melia azedarach*	*Flindersia schottiana*	*Elaeocarpus grandis*
Flindersia brayleyana	*Trema orientalis*	*Flindersia xanthoxyla*	*Agathis robusta*
Agathis robusta	*Flindersia brayleyana*	*Elaeocarpus grandis*	*Castanospermum australe*
Elaeocarpus grandis	*Flindersia schottiana*	*Grevillea robusta*	*Grevillea robusta*
Eucalyptus grandis	*Eucalyptus pellita*	*Gmelina leichhardtii*	*Flindersia schottiana*
E. tereticornis	*Eucalyptus cloeziana*	*Rhodosphaera rhodanthema*	*Flindersia australis*
E. microcorys	*Eucalyptus grandis*	*Melia azedarach*	*Dysoxylum muelleri*
Corymbia citriodora	*Acacia mangium*	*Toona ciliata*	*Flindersia bennettiana*
Castanospermum australe	*A. melanoxylon*	*Castanospermum australe*	*Flindersia xanthoxyla*
E. resinifera		*Araucaria cunninghamii*	*Gmelina leichhardtii*
Blepharocarya involucrigera		*Agathis robusta*	*Melia azedarach*
Cedrela odorata		*Cedrela odorata*	*Rhodosphaera rhodanthema*
E. camaldulensis		*Argyrodendron trifoliolatum*	*Toona ciliata*
Acacia mangium		*Argyrodendron actinophyllum*	
Paraserianthes toona		*Dysoxylum mollissimum*	
F. schottiana		*D. fraserianum*	
		Eucalyptus cloeziana	

1. *CRRP data*
2. *Species are listed in order of preference for north and southeast Queensland.*
3. *Rohan Allen pers. comm. (DPI Forestry). Other species widely planted in central Queensland have been* Agathis robusta, Araucaria cunninghamii, Blephocarya involucrigera, Castanospermum australe, Eucalyptus acmenoides, E. citriodora, E. drepanophylla, E, grandis, E. resinifera, E. tereticornis, F. australis, Grevillea robusta, Paraserianthes toona, Terminalia sericocarpa *and* Toona ciliata.

The main species supplied by nurseries

A large number of rainforest tree species have been used in various reforestation plantings. The CRRP planted over one hundred and seventy species across a wide range of tropical environments (Skelton unpublished data). One hundred and sixty five of these were from rainforests.

Similarly, in central and southern Queensland and in northern New South Wales, a wide range of rainforest species was planted as well as key eucalypt species (e.g. Glencross and Nichols Chapter 7, Lloyd 1998, R. Allen pers. comm.).

The species supplied in the largest numbers by the nurseries interviewed are shown in Table 1. All of these species produce high quality timber though not all have rapid growth in plantations, and some species were not endemic to the area in which they were eventually planted. A wide range of less well-known and slower growing species were also planted in each of the regions, but in smaller numbers. For example, of the 156,000 seedlings planted in the CRRP program's first year (1993), 90% were represented by 17 species, while the remaining 10% was made up of 60 species. Similar percentages were common in later years.

Fast-growing *Flindersia* species (mainly *F. brayleyana*) and *Elaeocarpus grandis* were commonly planted in all regions. In North Queensland, wet sclerophyll forest eucalypts and native pine species (*Araucaria* and *Agathis*) used in the government plantation estate were also preferred by the CRRP and nursery clients and planted in large numbers (Table 1).

In CRRP plantings, *Eucalyptus pellita* (red mahogany) or *Elaeocarpus grandis* were often planted as alternate rows among mixed rainforest species plantations in the wetter sites. Species such as *Eucalyptus tereticornis* and *Corymbia citriodora,* were planted on the lower rainfall sites (eg. near Mareeba) and colder sites (eg. Ravenshoe).

In addition to the material for the CRRP, some of the north Queensland nurseries interviewed also provided seedlings for conservation plantings for WTMA and Greening Australia. For these, the nurseries grew the rainforest species in Table 1, as well as large numbers of *Flindersia* spp., *Grevillea robusta*, *Melia azedarach* and other species.

With the exception of *A. cunninghamii*, all of the species planted in all the regions came from undomesticated planting stock, including the eucalypts. Improved seed of *E. pellita* commenced use in the later DPI Joint Venture plantings of the late 1990s-early 2000 in north Queensland (Nikles pers. comm.).

Seed procurement

Constraints

Seed of subtropical and tropical rainforest species becomes available at different times of the year. Although there is published information on general fruiting times for many species (e.g Boland *et al.* 1992; Floyd 1989) it requires repeated local observation to detect annual and local variation in flowering habits of particular species and to select trees with good form and reliable fruit production. According to the nurseries and seed collectors surveyed, planning is needed well in advance to ensure that the seed of the desired species and provenance is available. Growers must also be made aware of any potential delay in supply.

One of the main problems with collecting seed from rainforest species is that the size of seed crops can vary greatly between years, making it difficult for nurseries to plan the numbers of seedlings that might be produced. Some species are known to be sporadic reproducers, and may only fruit abundantly every 7-10 years. For example, *Flindersia schottiana* was recognised as one of the main cabinet timber species in all the major farm forestry programs in the wet tropics and subtropics. However, the seeding phenology of this species is extremely variable and it very rarely produces a heavy crop. On one occasion, CRRP sourced *F. schottiana* from a nursery in northern NSW to compensate for a lack of supply in north Queensland.

The timing of seed maturity varies within a species' population and even within a single tree. As a result, the maturity of seed collected at any particular time can vary considerably. While this seed may germinate readily if sown fresh, this is not always the case after the seed is stored for any length of time or after freezing.

There are recommended standards for seed collection to give good quality seed from a known provenance (locality). Seed should be collected from at least ten large adult trees (with good form and growth) which are at least 100m apart, to minimise the extent of common descent.

Approximately equal amounts of seed should be obtained from each tree, if they are to be bulked as a provenance seedlot (Williams and Matheson, 1994).

The principles behind seed collecting can be obtained from the DPI Forestry Tree Seed Centre's website (www.forests.qld.gov.au/forind/forestry/seedcent.htm). Advice on seed collection and storage is also given by Greening Australia, and in texts such as Langkamp (1987).

Where possible, DPI Forestry collected seed using the recommended standards. The SFFA encourages its seed collectors to collect from at least 10 different parent trees of good form and growth, and to use local provenance where possible. However, due to resource constraints and the desire to supply the popular species each year, some smaller nurseries in southeast Queensland and northern New South Wales have sometimes collected and sown seed from a single, heavy-fruiting tree.

Although their accessibility is tempting, it is not advisable to collect seed from isolated trees in paddocks which are distant from large patches of forest. There is some scientific evidence that plants in small remnants may contain a higher percentage of inbred or self-fertilised seeds, and such seed may not be as vigorous as that from undisturbed forest (e.g. Young *et al.* 1996, Buza *et al.* 2000). Yuruga nursery suspects that *Flindersia brayleyana* seed obtained from individual trees that are isolated from the main body of rainforest, produces a larger proportion of deformed and runty seedlings than seed collected from trees growing in the main rainforest. Also, the percentage of good healthy seedlings from seed collected from trees in small forest remnants seems to have dropped off considerably compared with past decades (Radke pers. comm.).

Seed sources used by nurseries

It was a CRRP requirement that its supplying nurseries obtained the seed for their seedlings from the DPI Forestry Tree Seed Centre. An exception to this was where plantings were in environmentally sensitive areas (World Heritage Areas such as the Daintree). Here, CRRP required that seed was sourced locally (Beitzel pers. comm.) to ensure protection of World Heritage values.

For rainforest species which were not routinely available, the DPI Forestry seed collectors generally undertook collections for CRRP use. CRRP staff also sourced some seed and provided it to the nurseries. For example, good collections of *Toona ciliata*, *Acacia* sp. and *Eucalyptus* sp. seed were obtained from the Dorrigo farm forestry group (Greening Australia) and *Acacia* seed was sourced from Tasmania and Victoria.

DPI nurseries in southeast Queensland used the DPI Forestry Tree Seed Centre for all seed. Most of the other surveyed nurseries in south east Queensland and northern New South Wales purchased seed of key timber species (e.g. *A. cunninghamii, E. pellita, E. cloeziana*) from the DPI Forestry Tree Seed Centre. However they generally used locally-collected seed, often collected by the nurseries or friends of these nurseries. In south east Queensland, Landcare budget constraints meant that very little seed could be purchased from local seed collectors. In northern New South Wales, nurseries initially collected their own seed or purchased it from local seed collectors. However as some became busier, they bought seed from the DPI Forestry Tree Seed Centre. Community environmental concern about the use of non-local provenance has now resulted in some these nurseries reverting to locally collected seed.

Seed batch details

Genetic variability within a population can be pronounced. Often, the wider the distribution of a species the more variability there is within its genetic pool (Evans 1982). Seedlings from some localities or provenances have better field survival in certain sites, or can produce taller, faster-growing trees. Hence, when growing a species for commercial objectives it is desirable to obtain the best genetic material available from a reputable seed supplier. Seed obtained from major seed centres is supplied with batch number, provenance details and sometimes, germination rates or percentage viable seed.

Initially, the CRRP did not specify provenance for its seed supply. But in later years, as experience was gained, the provenance of eucalypt and acacia seed was stipulated in nursery contracts. Based on recent experience of eucalypt performance, Noosa Landcare now requests known provenances for some eucalypt species. In contrast, because of its requirement for local provenance for all species, Barung Landcare specifies that purchased seed should come from the nearest possible locality in south east Queensland.

All of the nurseries interviewed routinely recorded seed batch number (or collection location) and the seed collection date, for both purchased and self-collected seed. However, nurseries differed as to whether seed batch details were retained through to seedling sale and field planting. For smaller nurseries, the records appeared to be used more for planning where to obtain next year's seed, than for determining seedlot performance in field plantings.

Seed handling and storage

The large variability in seed crop size between years, means that it may be desirable to store seed between sowing seasons. Inappropriate storage of seed can result in fungal attack, a rapid loss of seed viability, and increased mutation in seedlings.

However, species differ in their ability to survive seed storage. There are two basic types of seed – orthodox and recalcitrant. Orthodox seeds can be dried to a low moisture content (gentle drying to 5-10%) and then stored for at least several months before germination (Roberts 1973). Typically, these seeds are small or thin, sometimes winged and often wind-dispersed, e.g. *Flindersia* spp., *Agathis robusta*, *Eucalyptus* spp. If suitably dried, most orthodox species can be stored at four degrees Celsius.

Species with recalcitrant seed initiate germination soon after seeds are shed and have poor storage longevity (Farrant *et al.* 1988). Most fleshy-fruited and many other rainforest species are recalcitrant. The longevity of these species varies from a few days to months and, because of their high moisture content, they are prone to fungal attack (Harrington 1972; Chin and Roberts 1980, Nicholson and Nicholson 2000). Nurseries that collect and sow rainforest species make sure all flesh is removed from seeds before storage, or sowing, to minimise disease and predation (Floyd 1989; Robertson pers. comm.).

Recalcitrant seeds do not tolerate drying below approximately 30% moisture content and therefore cannot be frozen without cell damage (Roberts 1973). Most are sensitive to chilling injury at lower temperatures (King and Roberts 1979). If storage is required, seed requirements must be determined on an individual species basis (e.g. see Farrant *et al.* 1988; Bonny 1987; Lott 1986), but there has been almost no research on Australian rainforest species. Seed centers only supply fleshy-fruited species such as lilly-pilly on a pre-order basis, as shelf life is limited. Such seed is supplied from current crops where available and is not kept in storage (Borg pers. comm.).

Rather than storing seed most nurseries commonly sow the softer or fleshy species directly into seed trays, and hold the seedlings in a shade house with minimum nutrients and low light until they are required for potting. This low-light, low-nutrient environment mimics the rainforest understorey where small seedlings may survive for many years waiting for a chance to grow into forest trees.

Freezing seed

The seed of some orthodox species can be stored frozen, providing the seed is fresh and suitably dry when frozen (Table 2). *Cardwellia sublimis* seed is suitable for freezing, with very little loss of viability over the three years tested (Borg pers. comm.). At room temperature *Paraserianthes toona* (Mackay cedar) seed has a very short viability (up to 6-8 weeks; Goschnick pers. comm.), however seed can be frozen (if very fresh) and has been known to germinate within the day of being defrosted and sown (Radke pers. comm.).

Frozen seed is easier to handle if frozen in smaller packaged amounts. Frozen seed cannot be defrosted and restored for a later time. In the past, it has been observed that the germination of frozen seed has been erratic, even across single seed trays. The cause is believed to be premature defrosting and refreezing of seed through inadequate temperature regulation in standard refrigerators. Yuruga nursery has since concluded that the use of standard refrigeration is inadequate for the safe freezing of seed (Radke pers. comm.). Most nurseries find freezer storage is unnecessary.

Table 2 Tropical species which can be stored frozen* (below -15 degrees C) (Source: Borg, DPI Forestry Tree Seed Centre).

Species
Agathis robusta
Araucaria cunninghamii
Blepharocarya involucrigera
Cardwellia sublimis
Eucalyptus coolabah
Flindersia brayleyana
Toona ciliata

**Seed must by very fresh and dried to a suitable moisture content.*

Seed germination and seedling growth

Germination method

There has been little formal research on germination of Australian rainforest species and most nurseries have learnt by trial-and-error. Table 3 outlines some general germination methods recommended for a range of rainforest seed types.

Many rainforest species will germinate using standard methods. Germination mixes (substrates) are usually finer than those used in potting mixes in order to retain more moisture for the hydration of dormant seed. Seed is placed on top of the mix and lightly covered either with more of the mix, coarse sand or vermiculite. Trays are placed in a shade house and kept moist by spraying with water four to five times a day. Germination trays should be monitored on a daily basis to ensure disease and pests are kept under control. If fungal or any other disease is suspected it is best to remove trays to a holding area and immediately treat all stock with an appropriate biocide. Good nursery hygiene should minimise fungal and insect pest attack, and is especially important in tropical situations.

Table 3 Rainforest seeds and their propagation (Source: Nicholson and Nicholson 2000).

Type of seed	Example	Notes
Species with fleshy fruits with hard stones	*Schizomeria ovata**, many Elaeocarpaceae spp., *Elaeodendron* spp., *Halfordia* spp.	The (fruit) flesh usually irrelevant –the stone needs to be breached by filing, chipping, cracking or accelerated composting. Seed germinates only when the stone breaks down, which may be 2-10 years. However innate seed maturation times may mean that the seed dies if the stone is opened too early. Can sow seed densely and wait. Can oversow successive year's crops into the same tray. Old fruits are often worth collecting as the seed is likely to be still viable.
Capsuled fruits with arils and firm seeds	*Sloanea* spp., *Dysoxylum* spp., *Aglaia* spp., most Sapindaceae	Rapid germination; viability is usually very short. Fruit best collected from the tree before insect infestations develop, though seeds spat out by birds or flying-foxes are useful as pre-cleaned and usually free of insects. Since the arils develop after the seed, fruit can sometimes be collected when still slightly immature. The capsules and arils should be removed and the seed planted within a day or two for best results. Drying and/or prising to open the capsules is sometimes necessary. However, direct hot sunlight may harden the capsules making them difficult to open and may also overheat any black seeds that are exposed.
Soft, fleshy fruits with several to many small seeds	*Solanum* spp., *Tasmannia* spp., *Ficus* spp., many *Rubiaceae* spp., *Rubus* spp., some Myrtaceae spp.	Viability times, and hence seed storage times, vary greatly. If the viability time is not known, early processing and sowing is advisable. The flesh should be separated from the seed if possible as it can inhibit germination or reduce even distribution of seed in the tray. Larger seeds can be squashed out of the fruit by hand but the finer ones need to be sieved. If the seeds are too tiny to sieve the whole fruits can be mixed with fine sand to a crumbly texture before sowing.
Firm fleshy fruits with one to a few large seeds	most Lauraceae, many *Syzygium* spp., many Sapotaceae spp.	These seeds should be peeled immediately after collection, soaked to drown insect larvae, and sown as soon as possible. Even larvae-free seed may have short viability. If peeling is difficult it is usually not necessary, as in *Acmena* and *Waterhousia* spp. Germination is generally rapid but some harder seeds may delay for many months.
Very large seeds	*Castanospermum australe*, some laurels, some Myrtaceae spp., *Idiospermum australiense*	Little treatment is required but fairly prompt sowing and space to accommodate vigorous early root systems is important. Growth often slows suddenly when the cotyledons are exhausted.
Winged seeds	*Flindersia* spp. *Heritiera* spp., *Ceratopetalum* spp., *Backhousia* spp., some Proteaceae, many Monimiaceae spp.	These can be difficult to collect as sudden release often occurs in a high wind. Seed should be collected just as the first capsules open. Long-lived and generally storable if kept dry (except for *Heritiera* spp.) these seeds need little or no treatment. They should be covered only lightly by the germination medium.
Very small seeds, usually in dry capsules	e.g. *Quintinia* spp., *Caldcluvia* spp. *Geissois* spp., *Lophostemon confertus*, orchids	These seeds have long viability until they are wet. They need a fibrous, airy but moisture-holding germination medium and should be sprinkled sparsely on top. They have no spare energy to push through any covering or to recover from drying out, and the delicate seedlings are very susceptible to slug attack.
Hard-coated seeds	e.g. *Alphitonia* spp. *Cassia* spp., *Commersonia* spp., and some *Acacia* spp.	Some hard-coated seeds can be nicked to allow water penetration through the seed-coat and others, such as *Commersonia* spp. and *Alphitonia* spp, can be boiled briefly and soaked. Others are more intractable and respond only sporadically to various assaults. Burying and resurrecting into warm, light conditions can achieve remarkable results, as can a simple stirring of the growing medium.
The rest	There is a wide diversity of other fruits and seeds.	Refer to Nicholson and Nicholson for details of a few example species.#

 # None of these are species commonly grown in rainforest regeneration plantings or plantations in Queensland or northern NSW.
**Schizomeria ovata strikes well from cuttings. See: www.brisrain.webcentral.com.au/database/Schizo_ovata.htm*

Some species require special treatment to promote germination. For example the seed of hard-coated species such as *Acacia melanoxylon* is either scarified or soaked in hot or cold water to break dormancy. Other species such as *Acacia* spp., *Elaeocarpus grandis*, *Schizomeria ovata* can be slow and erratic, germinating over many months (Willis pers. comm.; Table 3). The percentage of usable seed or vigorous seedlings can also be quite low for some species (e.g. *F. brayleyana*). Despite germination rates being provided by seed centres, nurseries found considerable variations in actual germination rates in particular seedlots (Tunley pers. comm.). For these reasons, most rainforest species are sown directly into germination trays and the resulting seedlings dibbled (plucked) out into individual containers once they have reached a stage where they have developed their first true leaves.

Most nurseries sow deep-rooted species (such as many of the *Eucalyptus* genus and some of the Meliaceae including *Khaya senegalensis*), and large-seeded rainforest species (e.g. *Castanospermum australe*, black bean, and *Araucaria bidwillii*, Bunya pine) directly into individual containers in order to avoid J-roots (where roots become twisted upwards during re-potting then must twist downwards to grow). Nurseries often sow three to four eucalypt seeds directly into each tube, to ensure adequate germination and to allow some early selection for vigour. Once the seeds have germinated only the most vigorous individual is retained. In recent years, some eucalypt species from good provenances have shown good viability and seed can be sown as one seed per tube (Clarke pers. comm).

Further general information on propagation of Australian natives can be found in Doran (1986) and Langkamp (1987). Some species-specific germination methods are given in Doran (1986), Floyd (1989), Bonny (1987), and Nicholson and Nicholson (2000).

Recording and maintaining batch numbers

There can be marked differences in growth among provenances at a given site, and their relative performance may change between sites (Eldridge *et al.* 1993). By recording seed batch numbers at nursery production and through to field planting, valuable information may be obtained on the performance of seeds from different provenances for a range of sites.

Without appropriate protocols, seed batch information can be easily lost between nursery stages: when seeds are being sown, when pots or tubes are replaced in planting trays, when successful seedlings are dibbled or sorted according to height, when trays or pots are shifted around the nursery, or as nursery customers choose and move seedlings. Although generally labelled at sowing, nurseries and field managers varied as to whether the integrity of seed batch details was maintained into the field. Generally, seed batch was not recorded for field plantings hence much of the past ten years of farm tree planting gives no provenance information.

Within the DPI Forestry nurseries and in the larger private nurseries seed batches were recorded at the nursery level and then passed onto planting crews for recording on the CRRP database. However, field position of different provenances within a planting was only recorded for research trials. For the routine plantings, the CRRP team recorded the species planted at each site, not the provenance or location of each species *within* each planting site. If there were two provenances provided for a species planting then there is no record of where each batch of seedlings was planted, or whether they were mixed.

A common source of confusion in retaining provenance details occurs during replanting. For the CRRP, replanting occurred where survival rates at three months post-planting fell below 80%. Seedling losses were catered for in the initial seedling order. However, it was the practice not to plant the same species at sites where survival rates were low due to diseases or pests. Details of replant species and provenances were often not recorded in field notes or on databases. Neither were details of replants recorded in New South Wales (SFFA), nor southeast Queensland plantings.

Types of planting pots used in nurseries

The five main types of pots or containers used to grow farm forestry species in Queensland and New South Wales were Vic pots, native tubes, net pots, Hiko cells and bags. The pots differ in size and handling properties and in appropriateness to species and climate (Table 4). Note that Vic pots and native tubes are essentially the same. Smaller containers have reduced handling and transport costs, while larger containers with their greater soil volume give added safety to plants in difficult conditions (Doran 1986).

Table 4 Pot types used in nurseries (adapted from SFFA 2001).

Type	Description	Dimension
Hiko	hard plastic trays with moulded cells	Small 40 mm x 87 mm (with insert) Large 50 mm x 100 mm
Native plant tube	square hard plastic pot	50 mm x 50 mm x 125 mm deep
Supa Grow Tube	round hard plastic pot	75 mm dia x 125 mm deep
Space saver	round hard plastic pot	100 mm dia x 150 mm deep
Litre bag	round soft plastic bag	75 mm dia x 200 mm deep
Vic pot	square hard plastic pot	45 mm x 45mm x 125 mm deep
Net pot	round hard plastic pot	40 mm dia x 64 mm deep

The use of tubes in the production of seedlings was based on price and success in the field. Vic pots (12.5cm high by 4.5 cm square) were found to be very effective in producing good healthy seedlings for most species planted by the CRRP as well as in nurseries in southeast Queensland and northern New South Wales. DPI Forestry nurseries have recently changed to these pots for *A. cunninghamii* seedlings because of problems with the roots coiling at the base point of the traditionally-used round (5cm) tubular pots (Heilbronn pers. comm.). The DPI Forestry Bunya nursery used Net pots for eucalypts and Vic pots for rainforest species.

Hiko pots were also used to produce *Eucalyptus pilularis* and *Flindersia schottiana* seedlings for the CRRP in a New South Wales nursery. In one planting of *E. pilularis*, seedlings from the two pot types (Hiko and Vic) were planted in spare blocks beside one another. Observations were that the field survival rate of the seedlings grown in Hiko pots was around half that of those grown in Vic pots. Although not a formal experiment, it was noted that many of the Hiko seedlings developed poor root systems and fell over at an early age (Carroll pers. comm.). The cost per plant grown in the Hiko was 35c, compared with 55c-$1.32 per seedling grown in Vic pots. The greater volume of the Vic pot seedlings can therefore be worthwhile in terms of field survival and growth, despite the higher seedling cost. Similarly, some northern New South Wales nurseries use bags or larger pots, because field performance is better especially for more difficult sites.

J-rooting was identified early in the CRRP program as a serious nursery problem. At the time, the seed of most species was germinated in seed trays and then dibbled into tubes. The result was that if the tap root bent upwards at the re-potting stage, the root system would develop an upward then a downward root system (J-root). Once planted, the young tree is susceptible to being blown over by strong winds.

The problem mainly occurred in those species that developed deep rooting systems (e.g. eucalypts and mahoganies) and J-rooting was overcome through the development of pots (e.g. Vic pots) which trained young roots to grow down the pot wall rather than in a spiral fashion (see Dunn *et al.* 1997).

Potting mixes

A good potting mix will support the development of healthy vigorous seedlings that can be taken out of the pot easily and successfully grown in the field. In practice, a variety of mixes have been used. Not all of these have been suitable. For example, sometimes the mix could fall away from roots when plants were removed from pots prior to planting, leaving roots bare. This problem could occur when the potting mix had too much coarse material. After these problems arose, potting mixes used in north Queensland nurseries had to be approved by CRRP management, with the condition that the nursery supplied healthy seedling stock in a potting mix that did not fall away from the seedling's root system at planting.

Potting mixes varied between the regions and from one nursery to the next. Over time, the nurseries experimented with the mixes they used. Table 5 gives three mixes used in north Queensland.

Table 5 Composition of potting mixes used in three nurseries in north Queensland.

Nursery	Mix	Ratio
Daintree	Peat, sand and peanut shell with slow release fertiliser	Unknown
Yuruga	Pine bark peat and sand	90:10
DPI Forestry	Pine bark peat, coarse perlite and vermiculite	33: 40: 27

Generally a base substrate of pine bark or peat is bought from an accredited supplier, and then mixed with coarse gravel or sand, and/ or perlite or vermiculite for porosity, then supplemented with slow release fertilisers and sometimes trace elements. DPI Forestry Bunya used a different mix for eucalypts and rainforest species due to the length of time the seedlings require in the pot. The turn-around for eucalypts from seed to seedling is about 6–12 weeks, whereas a rainforest species may spend months in the nursery. Some rainforest species, such as *A. cunninghamii*, have an extended nursery phase of about 18 months, and are grown in a porous potting mix that will not get waterlogged but will sustain the seedlings through the full 18 months. DPI Forestry's *A. cunninghamii* mix consists of 50% peat, with 25% pine bark, and 25% coarse river sand (K. Robson pers.comm.).

In 1995 DPI Forestry nurseries started dipping pots in a solution of copper oxychloride to prevent seedling roots coiling within the pots (see Huth *et al.* 1996, Dunn *et al.* 1997). This process was carried out extensively on eucalypt seedlings produced for CRRP and is now used in *A. cunninghamii* seedling production. Caution should be exercised when using this treatment as there are some species that may be adversely affected. For example, Heilbronn (pers. comm.) found that lemon scented gum (*Corymbia citriodora* subsp. *citriodora*) was the most sensitive, resulting in burnt leaves. After initial losses, copper oxychloride is no longer used on rainforest species.

Time from germination to planting

The length of time a seedling spends in a nursery contributes significantly to the cost of the plant. Seedlings of eucalypt species are cheaper than those of rainforest tree species, because of rapid seed germination and seedling growth.

Pot size is also a constraint on nursery seedling size and duration in the nursery. In general, eucalypt seedlings grown in tubes cannot be held over in the nursery for any length of time due to the inability to limit growth while in a container: by the third month seedlings have outgrown tube resources, the roots have compacted and the stem length has grown beyond the roots' ability to sustain vegetative growth. If planted, there is a good chance that the seedlings will not perform well because of poor condition and root crowding.

In contrast to eucalypts, seedlings of some rainforest species can be held over from one year until the next. For example, species of *Flindersia* and the Meliaceae family can be carried over from one season to the next without any noticeable effect on early field performance.

When seedlings are being carried over it is important to limit fertiliser applications and maintain lower levels of light in order to reduce growth. Fertiliser should be applied when the nursery wants to re-start plant growth. When removing such plants from containers, attention to root development is necessary to ensure they have not become root-bound during the carry-over period. Seedlings left too long in the container suffer root balling and circling which are characteristics that reduce plant survival and growth (Doran 1986).

Before seedlings leave the nursery they must be “hardened” so that they are less prone to heat and water stress when transplanted to the field. This usually takes the form of reduced watering and increased sun, but nurseries differ in the regimes applied.

Problematic species

Over the course of the reforestation programs it became clear that certain species were difficult to grow in nurseries. The following species can be difficult to propagate but remained popular for planting:

***Elaeocarpus grandis* (silver quandong)**

Germination of the seed of this species is often difficult due to the stony endocarp (stone or shell). Many nurseries bulk-sow seed into large seedbeds and dibble out seedlings as they germinate. This has often led to a lack of uniformity in seedling maturity and uncertainty in delivery times. As a result of this species’ germination pattern, it was selected for vegetative propagation trials (Nikles and Robson Chapter 4). The results were favourable and the practice of growing *E. grandis* from cuttings was adopted quickly by the CRRP program, which was struggling at the time to fulfil its requirements. Some nurseries have also tried cracking the shell of this species and have had very good germination results. Bulk sowing of fresh seed is still current practice in southeast Queensland.

***Flindersia schottiana* (silver ash)**

This species would have been planted on more sites and in larger numbers during CRRP’s operational phase if more seed had been available. Unfortunately, this species does not set fruit every year and when it does, seed set is often very modest. The seed of this species can be effectively stored frozen (Yuruga nursery pers. comm.). Vegetative propagation trials were carried out on five *Flindersia* but all showed poor rootability and low numbers of roots per cutting; *F. schottiana* was best at 14% rootability (Nikles and Robson Chapter 4**).**

***Gmelina* species (white beech)**

The fruit of these species are often full of insect larvae and the seed is prone to drying out as it ages. This renders most of the seed unviable and useless for commercial sowing. In vegetative propagation trials, *Gmelina fasciculiflora* showed some promise (Nikles and Robson Chapter 4). If superior trees were selected for use as seed trees, it might be worth fumigating the fruit in order to produce viable seed for the nursery industry.

***Toona ciliata* (red cedar)**

Even under nursery conditions, *Toona ciliata* can be attacked by the tip moth borer *Hypsipyla robusta*, especially when seedlings are grown without shade.

Toona ciliata propagates readily from cuttings and Yuruga nursery is currently assessing clones for strike rate (rooting ability) and vigour (health and growth). If the strike rate is low, clones are removed from production despite superior growth and vigour, as they are five times more costly to produce than individual clones with a high strike rate.

The related Central American timber tree, *Cedrela odorata* (West Indian cedar), suffers less damage from this pest (Floyd and Hauxwell 2001). At one site in northern New South Wales, *C. fissilis* grafted onto *T. ciliata* rootstock have received less damage by tip moth than ungrafted *T. ciliata* (Bygrave and Bygrave 2005).

Plant management

Price of planting stock

CRRP ordered between 200,000 and 450,000 seedlings per year with considerable price variation between species. Rainforest timber species ranged from 75c to $1.32 (but the price of the more problematic species prices varied little between nurseries). The price of eucalypt seedlings varied greatly between nurseries ranging from 55c to $1.32 for the same quality seedling.

In southeast Queensland, seedlings in Vic pots are approximately $2.00-$2.70 (approximately $1.50 wholesale) and in Net pots, $1.50. In northern New South Wales, plant nurseries produce a wide range of species in various container sizes. Stock price has not changed much in the last ten years, apart from an increase in the price of Hiko pots. Currently, seedlings can be obtained in both 50ml and 80ml tubes for $1.30 and $2.50 respectively while in the ‘cheapest’ nursery, stock can be purchased at prices between 65c to $1.50 per seedling, depending on the species. Seedlings can also be purchased in bags and depending on the size, can range from $1 to $3 per seedling (Novak pers. obs.).

The main reason for the variation in price between eucalypt and rainforest species was the time taken to produce a healthy seedling ready for planting. *Araucaria cunninghamii* and *Agathis robusta* are in the nursery for close to 18 months before they are ready for planting. However, as they were species propagated for DPI Forestry use, they were made available to the CRRP program at the same cost as all other species ($1.32).

Pests and diseases

Pest and diseases of rainforest species are not well known (see King and Lawson Chapter 8). A good standard of nursery hygiene is essential in mitigating the risk of pest and disease. Nursery stock is prone to fungal attack especially when grown in areas of high humidity. In the hot humid tropics of northern Queensland fungal diseases can be especially problematic and fungicide or ventilation will not necessarily control the incidence of fungal attack on susceptible species such as *Eucalyptus cloeziana* and *Acacia melanoxylon*.

Some insect problems are most acute on particular species. For example, *Flindersia* species and *Tectona grandis* (teak) have suffered leaf mite attacks in several nurseries surveyed. The cost of biocides is a constraint for smaller nurseries and some consider the most cost effective way of reducing mite populations is through maintaining a clean and well-ventilated nursery.

As mentioned, Meliaceae species can be attacked by the tip moth borer in the nursery, especially once plants are placed in full sun to harden off. *Dysoxylum* species and *Toona ciliata* have been affected by this pest in the south. In the north, nurseries have attempted to alleviate this problem through spraying with various insecticides.

Rodents can cause a considerable damage to seedling production, especially where nurseries are situated in close proximity to rainforest. Rodents are a problem in north and southeast Queensland.

Plant transport

The transport of seedlings is an operation that requires considerable attention to detail and these costs can add 10% to the cost of a seedling. The transport method must ensure that seedlings arrive in a good condition for planting. Care must be taken to avoid excessive transpiration, mechanical damage from exposure to wind, or loss of soil from the roots (Doran 1986). A heavy watering is commonly carried out immediately prior to plants leaving the nursery, and there should be a minimum delay between delivery and planting of plants (Doran 1986). In some of the smaller nurseries in southeast Queensland, clients collect seedlings directly from the nursery so space to hold seedlings until collection can be a planning concern.

Time of delivery

When planning a farm forestry project, the planting time must be determined before a schedule of operations can be formulated. Scheduling must take into account the sourcing of seed, the time taken to grow seedlings, site preparation, seedling delivery and planting arrangements (labour and machinery). Once arrangements have been finalised, the time of seedling delivery becomes critical. If the nursery fails to produce the seedlings at the agreed time, a planting may not go ahead or a planting may fail due to adverse weather conditions. It is therefore important to maintain contact with the nursery to ensure seedlings will be delivered on schedule.

The time of planting is often determined by seasonal conditions, especially in the tropics and subtropics. Therefore it is critical that seedling production be scheduled for delivery at the appropriate period of the year. In north Queensland this period can vary anywhere from the beginning to the end of the wet season (January-April) depending on the location of a planting (Atherton Tablelands, the semi-dry tropics or in the high rainfall areas of the wet tropics). In some areas within this region, the wet season can be short and intense, while the dry season can be extensive, with the occasional severe frost.

In southeast Queensland and north eastern New South Wales, the planting season ranges from early spring to May, depending on the volume of planting work to be completed, the onset of summer rains, and the need to avoid periods of extreme heat and high evaporation which would stress young plants. In cooler, wetter areas such as Maleny in southeast Queensland, less-hardy species are planted in spring to ensure a full season’s growth on frost-susceptible sites (Wilson pers. comm.). More drought susceptible species (rainforest species) are planted in late summer to mid autumn (mainly March-May), after sufficient rain has fallen and temperatures have moderated.

Eucalypts are mainly planted in early spring to early summer, to ensure a full season’s growth, particularly in frost-prone or ‘hard’ sites. Some contract-planting businesses now water-in their seedlings, and plant from spring onwards.

Risk management

Risk management is both a matter for nursery staff, and for any farm forestry program relying on the nurseries. Risk management in the production of seedlings was the key to a successful planting season – good plant hygiene and management practices are central to the supply of vigorous and healthy seedlings.

When arranging seedling contracts the CRRP management considered not only price but also the possibility a nursery might fail to supply a key species. In an attempt to manage this risk the CRRP tendered out the majority of its seedling requirements to four main nurseries. Production of seedling numbers for key species was therefore spread across several nurseries.

The CRRP contracts stipulated:

- nursery accreditation;
- prompt communications concerning nursery problems;
- species and seedling numbers;
- seed sources or seed provenance details;
- pot size;
- potting mix (including fertiliser);
- height of seedling on delivery (2:1 ratio between seedling height and depth of pot);
- access to nursery by CRRP staff to inspect seedling development;
- seedlings free of root defects such as J-rooting and root girdling;
- pest and disease-free planting stock; and
- time of delivery.

Rather than objecting to the cost of accreditation, some nurseries viewed it as an indication of their professionalism and a factor that potential customers should consider as part of their risk management strategy (Yuruga pers. comm.).

The CRRP seedling orders included a 10% surplus to cater for the uncertainties associated with weather and the general survival of seedlings in nurseries and in the field. Any excess seedlings at the end of the planting season were given way (or sold cheaply) to other projects in the region.

A problem in north Queensland, southeast Queensland and New South Wales was that initially, most nurseries were new or expanding businesses and staff were not experienced in large-scale propagation of cabinet species. The CRRP managers found that in most instances, the quality of rainforest seedlings produced improved over time, as nursery staff became more experienced with growing these species. Exceptions to this could be related to nursery staff turnover and loss of experience and procedures. For example, one of the DPI- Forestry nurseries went through managerial changes on a yearly basis. Most new managers had a limited background in nursery production of rainforest species and were unfamiliar with the endemic pests and diseases.

In northern New South Wales and southeast Queensland, farm forestry programs utilise rainforest species mostly at a smaller scale. Nevertheless, in the early years of Landcare and Joint Venture plantings, similar problems were experienced in the supply of seedlings of even quality, good standard, and delivered on time in order to respond to sometimes unpredictable rain events. Some prior contracts for seedlings now give nurseries more certainty for operations.

Role of plant nurseries in farm forestry

Traditionally, nurseries provide information and advice on the plants they supply to customers. However with such a range of species and sites, and the infancy of Australian subtropical and tropical farm forestry, most nurseries were cautious about the type of advice they gave. The nurseries interviewed stated they gave advice on growth performance and the management of various species, but often avoided recommending which species to plant. Choice of species for specific sites was seen to be the responsibility of the landholder and the extension staff advising them. However, most nurseries attempted to keep up to date with extension advice and feedback from clients on species performance. This, no doubt, influenced their nursery practices and the types of species propagated.

Conclusions

At the time reforestation with rainforest species began there was only limited knowledge about the propagation requirements of most species being planted. Most of the nursery techniques and management experience gained over subsequent years has been accumulated through a process of trial and error. This also led to some changes in the species being propagated as the reliability of seed supplies improved and germination and field performance became better known.

One of the key problems in using rainforest species is the sporadic and variable seed production by rainforest trees, and the difficulty in storing seed of many species. This affects seed quantities available for sowing by nurseries, and the species available for planting in any one year. A common belief that any seed can be obtained at any time of the year is not true (Kitchener pers. comm.) and can lead to disappointment on the part of the growers and lack of farm forestry coordination within the region.

Government-funded farm forestry programs fostered the growth of nurseries and employment of nursery and extension staff. When these projects ceased, nurseries experienced a decline in demand for seedling stock. Nurseries either had to close, downsize, or convert to multiple-objective businesses, which combined nursery, contract-planting and consultancy. These operations reduce the time available for field days and providing information to the public. With the cessation of government-funded farm forestry extension, knowledge and experience of the propagation phase of farm forestry has become less accessible to growers. Nurseries feel that this has also affected public interest in farm forestry.

Several factors relating to plant nurseries have been identified as critical to the success of any future farm forestry program. They include the need for:

- experienced or professionally qualified nursery staff;
- continuity of staff and in particular, the nursery managers;
- accessibility to a reliable supply of good quality, viable seed, from local seed sources when required;
- tree improvement for rainforest timber species selected for use in the humid tropics and subtropics;
- comprehensive nursery records and labelling of provenances to field planting stage;
- good nursery management including hygiene to minimise pests and diseases in the hot humid conditions experienced;
- production of healthy good quality seedlings, supplied on time for planting schedules; and
- feedback and information flow between research, extension and nursery staff on propagation techniques and species performance in the field, for purposes ranging from land rehabilitation to timber production.

Nurseries have improved the knowledge of propagation of Australian rainforest species, and can play an important role in providing tree-growing advice to growers. Further nursery-phase research would enable them to undertake this task more efficiently. Better coordination of reforestation and farm forestry at the regional level (for natural resource management and timber marketing purposes) would provide a more predictable demand for planting stock, with potential flow-on effects for the stability of nursery enterprises.

Acknowledgements

We would like to thank the nursery managers and seed collectors who responded to our survey and provided information on their nursery operations. Murray Keys and Mila Bristow are gratefully acknowledged for comments on an earlier version of this manuscript.

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Appendix 1: Nurseries and seed collectors interviewed

Nurseries

- DPI Forestry Bunya nursery – main propagation nursery and supplier for the Tree Assistance Scheme administered by DPI Forestry and later by the Department of Natural Resources. (Note that in the 1990's the DPI Forestry nurseries at Toolara and Beerburrum also did some propagation, but in later years, they supplied stock produced from Bunya.) (interviewees: Ted and Robyn Macleod)
- DPI Forestry Toolara nursery (interviewee: Malcolm Baxter)
- Barung Landcare – started as a nursery in the early 1990's in Maleny. Initiated using some government funding. Now self-funding nursery - Two paid staff plus volunteers. Some project-based funding, e.g. NHT revegetation projects, where the nursery supplies the stock. Approx 75% of the customers are now private customers. (interviewee: Nick Willis)
- Noosa Landcare - Nursery started in 2002. Initiated using some government funding and volunteer labour. Nursery is still not self-sustaining, but is recovering some costs. Starting to sell to the public, and some to Mary River Catchment Coordinating Committee. (interviewees: Gary Clarke and Damien Morley)
- DPI Forestry Walkamin nursery - main producer of seedlings and cutting-grown plants for the Community Rainforest Reforestation Program (CRRP). In the first few years of CRRP this nursery coordinated all the growing and delivery of seedlings from the DPI-Forestry Ingham nursery and the private nurseries (interviewee: Jill Heilbronn).
- Yuruga Nursery - a private nursery situated on the Atherton Tableland at Walkamin. It was the main private nursery to supply CRRP with seedlings. The nursery now produces cutting-grown eucalypt hybrids for the 'bluegum' industry and several high value cabinet timber species such as teak and African mahogany. It specialises in growing a wide range of native rainforest species (interviewees: Ann and Peter Radke).
- Daintree River Nursery – a private nursery situated in the tropical lowlands north of Cairns. This nursery has produced seedlings for the CRRP and also for the Wet Tropics Tree Planting Scheme (interviewees: Eddie and James Beitzel).
- Nunyara Nursery – was a private nursery situated in Mackay. It produced seedlings for CRRP and now for the farm forestry group in the district. They are trialing several exotic species as well as native rainforest and hardwood species.
- Tunley Nursery – a small private nursery situated near Malanda on the Atherton Tableland. It provided a wide range of farm forestry timber species to the CRRP (Interviewee: Alan and Bev Tunely)
- Five NSW nurseries were interviewed but all wish to remain anonymous.

Seed Collection

- Steve Kitchener, previously DPI Forestry seed collector, Atherton.
- Tony Borg, previously Queensland Tree Seed Centre, Beerwah.
- Darryl Goschnick, Queensland Tree Seed Center, Beerwah. Email: Tree.Seed@dpi.qld.gov.au;

4. Vegetative propagation and preliminary field performance of sixteen rainforest tree species in north Queensland

D. Garth Nikles and Ken J. Robson

Abstract

This study assessed sixteen rainforest tree species, from nine taxonomic families, for amenability to vegetative propagation (VP) via rooted cuttings, as a possible means for overcoming constraints on seedling deployment of these species that were considered to have potential for plantings of various kinds. Elaeocarpus grandis *and* Cedrela odorata *(the latter being the only exotic species included) were found to be highly amenable to VP. Several other species (*Acacia aulacocarpa, Agathis robusta, Alloxylon flammeum, Araucaria cunninghamii *and* Gmelina fasciculiflora*) exhibited sufficient potential such that, if improvement in key propagation traits could be achieved in the future, then VP may become a viable deployment strategy for these species as well. In contrast,* Blephocarya involucrigea, Cardwellia sublimus, Castanospermum australe, *five* Flindersia *species and* Musgravea heterophylla *were much less promising for VP under the conditions employed.*

For a subset of three species, highly significant differences among clone means were demonstrated for two key VP traits (rootability and number of roots per rooted cutting). Differences were also observed in other species and in the propensity of hedged seedlings of all sixteen species to produce coppice shoots.

Rooted cuttings of seven species were included in one or two field trials for preliminary assessment of the potential of these species for deployment as clones. The more promising species for growth as rooted cuttings on at least one site were E. grandis *(outstanding),* C. odorata, A. cunninghamii *and* A. robusta*. Rooted cuttings of* A. aulacocarpa *grew moderately well, but apparently less well than seedlings at both sites. Those of* A. flammeum *and* G. fasciculiflora *were not promising for growth at either site, nor for survival at one site. Differences between clones in survival and growth were observed in some species.*

Based on the results of this preliminary study and other work, prospects for VP, clone selection and deployment as individual clones or clone mixtures using rooted cuttings, seem good for a few of the species. Further work would be required to achieve realisation of the potential of the promising species.

Introduction

A report was prepared in 1994 by the then Queensland Forestry Research Institute (QFRI) identifying tree domestication needs for the main species being planted under the Community Rainforest Reforestation Program (CRRP). It also defined the appropriate tree domestication strategies for these species (Nikles *et al.* 1994). It was recognised that some of the species of interest were characterised by constraints on regular production of large numbers of seedlings due to one or more of the following features: produce viable seed infrequently; have fruits, cones or seeds severely attacked by pests; have fleshy-fruited or other types of seed that do not store well; and/or have seeds that are difficult or slow to germinate.

Producing planting stock vegetatively (as rooted cuttings from limited seedling supplies) may avoid these problems and potentially allow more rapid genetic development of some species through deployment of superior families or clones (Evans and Turnbull 2004). Consequently, research on the amenability of such species to vegetative propagation (VP) was identified as worthy of attention within the program.

QFRI had been developing methodology for the VP of coniferous species for several years (Walker *et al.* 1996a). It was intended to apply this methodology, with modifications, to the propagation of several rainforest hardwood species. Evans and Turnbull (2004) reviewed the history of development and the present status of clonal plantations of forest trees and showed that many species are being deployed as rooted cuttings, including several rainforest species. In Vietnam, selected clones of the interspecific hybrid between the rainforest *Acacia* species *A. mangium* and *A. auriculiformis* are planted operationally (Kha 2001). It was reported by Arnold *et al.* (1998) that *A. aulacocarpa* was being considered for large scale deployment as rooted cuttings in the Philippines.

Table 1 details the fifteen native and one introduced species (*Cedrela odorata*), across a range of nine taxonomic families, that had been recommended by experienced foresters in the area as candidates for domestication and use in the CRRP. Information on these (and other species) covering natural distribution and conservation status, wood quality, biology, genetic variation and breeding activities with them is given by Nikles *et al.* (1994). These species were chosen for an exploratory study of their amenability to VP and potential for deployment to plantings in the form of rooted cuttings as mixed, identified clones.

Table 1 List of the 16 rainforest tree species tested [14 hardwoods and two conifers (c)] – all native except *Cedrela odorata*. [1]

Species' scientific name	Species' common name	Family
Acacia aulacocarpa Cunn. Ex Benth.	brown salwood	Mimosaceae
Agathis robusta C. Moore es F. Muell (c)	kauri pine	Araucariaceae
Alloxylon flammeum (W. Hill & F. Muell.) P. Weston & Crisp	satin silky oak	Proteaceae
Araucaria cunninghamii Aiton ex D. Don (c)	hoop pine	Araucariaceae
Blepharocarya involucrigera F. Muell.	rose butternut	Anacardiaceae
Cardwellia sublimis F. Muell.	northern silky oak	Proteaceae
Castanospernum australe A. Cunn.& A. Fraser ex Hook	black bean	Fabaceae
Cedrela odorata L.	West Indian cedar	Meliaceae
Elaeocarpus grandis F. Muell.	silver quandong	Elaeocarpaceae
Flindersia bourjotiana F. Muell.	Queensland silver ash	Rutaceae
Flindersia brayleyana F. Muell.	Queensland maple	Rutaceae
Flindersia iffliana F. Muell.	hickory ash	Rutaceae
Flindersia pimentaliana F. Muell.	maple silkwood	Rutaceae
Flindersia schottiana F. Muell.	northern silver ash	Rutaceae
Gmelina fasciculiflora Benth.	white beech	Verbenaceae
Musgravea heterophylla L. S. Sm.	briar silky oak	Proteaceae

[1] *Available records of seed origins are given in Appendix 1.*

Toona ciliata M. Roemer (red cedar) (Meliaceae), an Australian "icon" among rainforest timbers, was not included in the study because of its well-known, extreme susceptibility to the shoot borer (*Hypsipyla robusta* Moore). Furthermore, the species was known already to be highly amenable to propagation by rooted cuttings from seedlings (Haley 1957; Collins and Walker 1998).

This chapter gives an overview of the establishment and initial management of seedling hedges planted in 1993 and 1994. It describes shoot production following first hedging, the rootability of cuttings from the shoots and the numbers of roots produced per rooted cutting. For a subset of species, the early field performance of rooted cuttings clones and seedlings in trials undertaken in north Queensland in the 1990s is outlined. The potential of the species for further planting in north Queensland is examined briefly in the light of results of this and other work. Also, recommendations are made on the support required to derive definitive conclusions from work of the kind that was undertaken in this preliminary study.

Materials and methods

Hedge establishment and management

The botanical and common names and the taxonomic families of the species chosen for the study are detailed in Table 1. Seedlings for the study were procured from stock at the Department of Primary Industries - Forestry's plant nursery at Walkamin near Atherton. Available information on seed sources is given in Appendix 1. An area within the nursery boundary was prepared with planting lines ripped and mounded at two-meter intervals. In October 1993, seedlings of eleven hardwood species (Table 2) were planted at intervals of one meter in the prepared rows along with weed matting (Figure 1), These seedlings were then managed as hedges to produce cuttings for use in screening trials of rootability and related aspects of VP.

Table 2 Rootability (percentage of cuttings set that rooted), average number of roots per rooted cutting and the average number of shoots produced per hedge plant in a three-month period for each of 11 rain forest hardwood tree species. Numbers of cuttings set per species ranged from 35-386, reflecting the prolificacy of coppicing.

Species' scientific name	Species' common name	Mean rootability (%)	Mean no. roots per rooted cutting	Mean no. shoots per hedge plant over a 3-mth period
Acacia aulacocarpa	brown salwood	59.0	13.8	4.5
Alloxylon flammeum	satin silky oak	71.8	6.2	6.6
Blepharocarya involucrigera	rose butternut	0.6	3.0	7.3
Castanospernum australe	black bean	26.8	2.0	4.6
Cedrela odorata	West Indian cedar	86.7	17.2	4.6
Elaeocarpus grandis	silver quandong	73.2	8.7	17.1
Flindersia bourjotiana	Queensland silver ash	8.8	3.2	2.4
Flindersia brayleyana	Queensland maple	5.7	1.0	2.0
Flindersia iffliana	hickory ash	3.0	1.0	2.0
Flindersia schottiana	northern silver ash	14.3	2.2	3.3
Gmelina fasciculiflora	white beech	52.3	4.0	13.7
	Overall mean	**36.6**	**5.7**	**6.2**

Figure 1 A section of a hedgerow showing the weed matting and plants of *Gmelina fasciculiflora* some three months after topping in January, 1994.

In March 1994, similar rows were established for the other five species – two conifers, *Agathis robusta* (kauri pine) and *Araucaria cunninghamii* (hoop pine), and three hardwood species *Cardwellia sublimus* (northern silky oak), *Flindersia pimentaliana* (maple silkwood) and *Musgravea heterophylla* (briar silky oak).

For each of the 16 species there were three replications of rows containing 22 plants of each species for propagation studies, and one 22-plant row for observations (results not reported here) on the coppicing ability of each species.

Hedge seedlings planted in October 1993 were topped at a height of 30 cm in January 1994, to stimulate production of coppice shoots (see Figure 1). The numbers of shoots produced in the following three months were counted in April 1994. Hedges planted a year later were similarly topped and observed for shoot production in 1995.

The data collected on shoot production of the hedges of the 11 species planted in 1993 are reported as species' means in Table 2.

Nursery trials of rootability

Following topping of the hedges in January 1994, juvenile coppice shoots were collected in April 1994 from a range of recorded positions and ages of each hedge for each of the 11 species. These were both single and multi-noded and in 5 cm and 10 cm sections. These were prepared by reducing the leaf area on the shoots to about half (Figures 2, 3).

Replicated trials were established to investigate the effects on propagation traits of:
- shoot length and position in hedge plant;
- cutting length, diameter and segment order (from apex to base);
- rooting medium (various mixtures of sterile peat, vermiculite and perlite);
- concentration of Indole 3 Butyric Acid (IBA); and
- clonal identity.

Figure 2 A rooted cutting of *Gmelina fasciculiflora* showing the reduced leaf area, extensive callus and root system developed nine weeks after setting and placement under mist.

Figure 3 A multi-node cutting of *Alloxylon flammeum*, now rooted, showing the reduced leaf area of the original cutting, and an extensive root system developed by 16 weeks after setting and placement under a misting system.

Detailed results of all these studies are yet to be published. However the following provides an overview of: rootability (number of the cuttings with roots as a proportion of the number of cuttings set expressed as a percentage), the average number of roots per rooted cutting, and the effects of some cuttings treatments applied to three of the species.

For the comparison of species for rootability and roots formed per rooted cutting, shoots from 11 species (Table 2) were cut into 5 and 10 cm sections (these are referred to subsequently as cuttings). The base of each cutting was then dipped in a commercial rooting hormone containing 0.8% I.B.A prior to setting in 100 cm^3 tubes (Vic forestry tubes) containing, as rooting medium, a 3:2 mixture of vermiculite and sterile peat or perlite. The numbers of cuttings set per species varied greatly (35 to 386), reflecting the relative prolificacy of shoot production following topping of hedge plants.

The cuttings were placed in a shadehouse (60% shade) with frequent mist irrigation supplied via foggers (controlled by a balance arm and mercury switch misting unit). This maintained a thin film of water on the leaves at all times, reduced temperatures and minimised water loss from the cuttings.

Further experimental settings of cuttings were carried out in October and December 1994. Additional species tested in these settings included the five species named above that were established in hedge rows in March 1994. These settings included 315 cuttings of *A. cunninghamii* with varying numbers of cuttings of apical (132) and progressively more basal segments (Walker *et al.* 1996b). In all cases, rootability and roots per cutting with roots were assessed by counts made 16 weeks after setting.

For *C. odorata*, *G. fasciculiflora* and *E. grandis*, studies were also made of the effects of shoot length, segment order, cutting length and diameter and clone identity on rootability and number of roots per rooted cutting. Data were analysed as a 3 x 5 factorial for each trait.

Field trials of seedlings and rooted cuttings

The rooted cuttings produced by the five hardwood species that gave rootabilities greater than 50% (Table 2) were planted as identified clones into two field trials to compare their growth and tree quality with that of seedlings. Two trials, one on the north Queensland coastal lowlands (“Coast trial”) and the other on the Atherton Tableland (“Tableland trial”), were established early in 1995. A third trial using coniferous species was established on the Atherton Tableland in 1996 to observe the performance of rooted cuttings clones of *A. robusta* (kauri pine) and *A. cunninghamii* (hoop pine). In view of the preliminary nature of all the field trials, and resources available, the data obtained were not analysed statistically.

Plantings of hardwoods (1995)

Coast trial

This trial was planted in March 1995 at Utchee Creek near Innisfail on land owned by a participant in the CRRP. The site was almost flat at approximately 50 m above sea level (asl) with mean annual rainfall (MAR) of approximately 3000 mm. The soil was a red earth derived from metamorphosed parent material. The site had been used previously for sugar cane cropping. Site preparation included ripping of planting lines to 30 cm depth at 5 m intervals. Prior to planting, the lines were treated with knockdown and pre-emergent herbicides to kill grasses and other weeds. Planting was at 3 m spacings along the ripped lines.

The experimental design was randomised complete block (RCB) with three replications of the nine treatments (seedlings and rooted cuttings of four species, and rooted cuttings only of the fifth species, *Alloxylon flammeum*) (Table 3). Plots, each of a single species as either rooted cuttings or seedlings, comprised five rows of four trees.

During the first four years, weed control with herbicidal sprays was applied as required to ensure weed competition, especially from grasses, was minimised. After 1999 the maintenance of the trial was left in the hands of the landowner. The growth rate and health of the trees deteriorated after the fourth year due to highly competitive tropical grasses invading the trial.

The diameter at breast height over bark (DBHOB) and tree height were measured (where possible) in May 1998 when the trials were 3.5 years old. Notes were made in June 2003 on the relative performances of the species.

Table 3 Summary of 3.5 year survival and height, and of later observations on seedlings and clones of five hardwood species established in Coast and Tableland (T'land) field trials in 1995.

Species, type of planting stock and (no.) of rooted cuttings in Coast & T'land trials	Survival (%) [1]		Height (m)		8-yr DBHOB (cm)		Observations made in June, 2003
	Coast	T'land	Coast	T'land	Coast	T'land	
Acacia aulacocarpa							Growth good on both sites; but form very poor
Seedlings	100	43	5.66	6.05			
Clones	97	22	4.78	3.83			
Alloxylon flammeum							Growth poor on both sites
Seedlings			No seedlings				
Clones	74	13	2.83	1.88			
Cedrela odorata							Growth much better on T'land site – cf *Gmelina*
Seedlings	93	100	3.65	6.89			
Clones	89	100	2.96	7.93			
Elaeocarpus grandis							Best-/equal-best-growth species on both sites
Seedlings	100	85	5.87	5.61	7.48	9.61	
Clones	95	86	6.42	7.89	7.58	9.87	
Gmelina fasciculiflora							Growth very poor on T'land site – cf *Cedrela*
Seedlings	100	80	3.83	0.91			
Clones	97	51	3.12	1.15			

[1] *Survival calculated on basis of number of plants planted per plant type per species, ie. 60 and 40 in Coast and T'land trials respectively.*

Tableland trial

This was planted in 1995 at Yungaburra, on the land of a participant in the CRRP. The site had a slight slope to the south east at approximately 800 m a.s.l with MAR of approximately 1200 mm. The soil was a red kraznozem derived from basalt. The site had been fallow for several years and occasionally carried some grazing cattle. Site preparation involved forming rows of small mounds at 5 m intervals with a double pass plough. Prior to planting, the lines were treated with knockdown and pre-emergent herbicides to kill grasses and weeds. Planting was at 3 m spacings along the lines.

The experimental design was as the same as that of the Coast trial, ie. a RCB, but with two replications. There were rooted cuttings of each of five species and seedlings of all species except *Alloxylon flammeum* (Table 4). Plots contained four rows of five trees.

During the first four years, weed control was carried out by the application of herbicidal sprays to ensure weed competition was minimised. After 1999 the maintenance of the trial was left in the hands of the landowner. The Tableland site was grazed (cattle) from 1999. Less competition from grasses than in the coastal site led to better continued growth and survival.

Diameter breast high over bark (DBHOB) and tree height were measured (where possible) in May 1998 when the trial was 3.5 years old. Subsequently, the trial was observed at various times including in June 2003 when notes were made on the appearance of each species.

Planting of conifers (1996)

This trial was planted in Compartment 202 Dreghorn, State Forest 310, Gadgarra on the Atherton Tableland in January 1996. The site is located on a 10-15% slope at 650 m a.s.l. with a MAR of approximately 2000 mm. The soil was a red krasnozem derived from basalt. Originally, the site carried upland rainforest that was cleared in June 1939 and planted with hoop pine in December 1939. This crop was harvested between 1992 and 1995. Site preparation for the 1996 trial comprised contour strip ploughing at 5 m row spacing (two passes with plough). A second rotation *A. cunninghamii* plantation was established in February 1995 on the area, except for a section that was left vacant for the clonal trial.

The planting stock for the trial was rooted cuttings of clones of *A. robusta* (six clones) and *A. cunninghamii* (Papua New Guinea provenance, ten clones). No seedling controls were available for planting. The different age, provenance and management of the adjacent *A. cunninghamii* plantation precluded its use for the establishment of sample plots with which to compare the clones.

The planting comprised species-separate, unreplicated plots of six rows by 18 trees (108 plants) of each species at 5m x 2.5m spacing. On average, there were 18 and 10 rooted cuttings per clone for the *A. robusta* and *A. cunninghamii* respectively, but numbers per individual clone varied considerably. Weed control was the same as that applied in the adjacent commercial plantation, i.e. occasional herbicide sprays.

DBHOB was measured in May 2003 when each tree was also scored (1 to 4 scale) for stem breakage point (% of total height), lean (degrees of displacement from vertical), axis persistence (proportion of total height from ground to first fork) and stem straightness (combination of the number and severity of bends). For ‘breakage’ and ‘lean’, high scores indicated good trees; the reverse was the case for ‘axis persistence’ and ‘straightness’.

Results

Hedge development and rootability of cuttings

The data collected on shoot production in this part of the work are reported (for the hedges planted in 1993) as species’ means in Table 2.

In the hedges, it was observed that some species grew very slowly, and some did not respond to hedging with prolific shoot production. For example, *C. sublimis* and *M. heterophylla* plants grew very slowly and neither species produced sufficient quantities of shoots, cuttings nor rooted cuttings for adequate field testing.

The latter comment applied to several other species, most notably the *Flindersia* species, *B. involucrigera* and *C. australe*. In contrast, *E. grandis* and *G. fasciculiflora* responded to hedging with prolific shoot production such that averages of 17.1 and 13.7 shoots per hedge were produced in a three month period respectively (Table 2).

The rootability (percentage), mean number of roots per cutting and the average number of shoots collected per hedge plant over a three month period from April through to July of 1994 for the 11 hardwood species are presented in Table 2. The average of all species for the three propagation parameters were 36.6%, 5.7 roots and 6.2 shoots, but the ranges among species varied greatly – from 0.6 to 86.7%, 1.0 to 17.2 roots and 2.0 to 17.1 shoots (Table 2).

The greatest overall success was with *E. grandis* which exhibited high rootability (73%), above average number of roots per cutting (8.7) and the highest shoot production in a three month period (17.1 shoots per hedge). No other species ranked as well for all three propagation parameters, though

Cedrela odorata came close, being first for rootability (86.7%) and roots per cutting (17.2), but equal 5th for mean number of shoots per hedge (4.6).

Other species with prospects for amenability to VP, based here on arbitrary criteria of rootabilities greater than 50% and a ranking of fifth or better among the 11 species for at least one of the other two propagation traits, were *Alloxylon flammeum, A. aulacocarpa* and *Gmelina fasciculiflora.*

Unfortunately, *B. involucrigera* and all four of the *Flindersia* species had relatively very low rootabilities (0.6% and 3.0% - 14.3% respectively) and below average numbers of roots per cutting; and the *Flindersia* species had low shoot production (all less than 3.3 shoots per hedge in a three month period). However, *B. involucrigera* was relatively prolific in shoot production (average of 7.3), ranking third. Although *C. australe* averaged 26.8% rootability (rank 6), the number of roots per cutting and number of shoots per hedge plant were low (2.0 and 4.6 respectively).

Rootability of the conifer *A. cunninghamii* was high at 89.4% for apical cuttings (Table 4) and is reported more fully below. With this species (and the other conifer, *A. robusta*), the shoot multiplication rate from each hedge was low due to the strong dominance of the tallest orthotrophic shoot in each hedged plant, a characteristic of *A. cunninghamii* described elsewhere (Nikles *et al.*, 2004 a).

Table 4 Means for rootability of *Araucaria cunninghamii* cuttings taken as apical and progressively more basal segments of shoots from seedling hedges (from Walker *et al.* 1996b).

Segment	No. cuttings set	Rootability (%)
1 (apical)	132	89.4
2	91	67.0
3	61	55.7
4	26	30.8
5 (basal)	5	20.0

It was observed that, of the propagation media and rooting chemicals tested, the best appeared to be a mixture 3:2 of sterile peat and perlite, with 0.8% IBA; and most species produced roots from both single and multi-nodal cuttings.

Effect of propagation treatment

Results of analyses of the effects of five cuttings treatments on the VP traits rootability and total numbers of roots per rooted cutting of *C. odorata, E. grandis* and *G. fasciculiflora* are given in Table 5. There was a very strong statistical significance of differences for clonal identity (ie. between clone means) for all three species for both traits. The other, four treatments had variable and generally inconsistent effects with respect to propagation traits and species. For example, these four treatments had significant effects on roots per cutting of one species (*C. odorata*), but only cutting length affected rootability in this species. In contrast, only one treatment (shoot length) significantly affected roots per cutting of *G. fasciculiflora,* while only one treatment (cutting diameter) did not significantly affect its rootability. Cutting diameter was not significant for rootability of any of the three species nor, for *G. fasciculiflora,* with respect to number of roots; however, it played a relatively minor role in affecting numbers of roots in the other two species (Table 5). Perhaps these barely discernible patterns are to be expected in the case of species from three very different taxonomic families.

Table 5 Results of an analysis of variance (showing F values) of the effects on rooting parameters of four cutting treatments assessed on three species - *Cedrela odorata, Elaeocarpus grandis* and *Gmelina fasciculiflora.*

Parameter	Rootability			Number of roots per rooted cutting		
Treatment	*C. odorata*	*E. grandis*	*G. fasciculiflora*	*C. odorata*	*E grandis*	*G. fasciculiflora*
Shoot length	ns	ns	2.3***	2.1*	ns	5.3***
Segment order	ns	1.1*	1.5**	1.8*	ns	ns
Cutting length	3.6**	ns	1.5**	2.3***	ns	ns
Cutting diameter	ns	ns	ns	3.7**	2.6*	ns
Clonal identity	37.1***	21.9***	34.0***	32.8***	34.2***	64.6***

Asterisks indicate levels of statistical significance: * *(0.05),* ** *(0.01)* *** *(0.001).*

The data for each of the same three hardwood species were tested for differences in rootability dependent on which segment a cutting represented along a coppice shoot (from apically to basally). Results suggested *G. fasciculiflora* was the only species in which there was a clear trend of increasing rootability and of numbers of roots produced per rooted cutting as cuttings were taken more basally, ie. fourth-segment cuttings rooted better (69.7%) than apical cuttings (43.3%), and had more roots (averages of 4.8 and 3.1 respectively).

The overall rootability of the 315 *A. cunninghamii* (conifer) cuttings set from five different segments representing apical and progressively more basal portions of shoots was 70.5%. Numbers of cuttings per segment and corresponding rootability means are given in Table 4. Although not analysed statistically, the results suggested a trend of decreasing rootability as cuttings were sourced from segment progressively more distant from the apex, a trend opposite to that of the hardwood *G. fasciculiflora*, as mentioned above.

Field trials of seedlings verses rooted cuttings

Planting of hardwoods (1995)

The results of this analysis is presented in Table 3, should be interpreted cautiously because rooted cuttings of only five hardwood species (one without accompanying seedling controls) could be planted, in one year only (1995), and the maintenance these trials was sub-optimal after 1999.

Coast trial

Survival 3.5 years after planting was high to very high (more than 89%) for both seedlings and rooted cuttings of all species except *A. flammeum* (the rooted cuttings-only sample for this species showed 74% survival). It is evident from the means given in Table 3 that there were no large differences in survival of seedlings versus rooted cuttings for any of the four species that could be compared.

The best species - plant type combination for height at 3.5 years was the *E. grandis* rooted cuttings (6.42 m); least tall were the *A. flammeum* clones (2.83 m). The *E. grandis* rooted cuttings were more than half a meter taller, on average, than seedlings of that species (5.87 m) giving nearly a 10% superiority. Results were opposite for the other three species in which rooted cuttings were only from 84% to 81% of the height of seedlings. The *A. aulacocarpa* rooted cuttings at 4.78 m were the next tallest after *E. grandis*, but it was observed that their form was very poor since all trees were multi-stemmed. *C. odorata* and *G. fasciculiflora* trees grew at similar rates (averages close to 3 m), with seedlings performing moderately better that the rooted cuttings for both species.

Tableland trial

Survival rates were high for rooted cuttings and seedlings of *C. odorata* (both 100%) and *E. grandis* (86%, 85%). However, for the other two species where the plant types could be compared (*A. aulacocarpa* and *G. fasciculiflora*), survival of rooted cuttings (at 22% and 51% respectively) was only 51% and 64% of the survival rates of seedlings. *A. flammeum* rooted cuttings showed extremely low survival (13%).

The best species - plant type combination for height on this site were the *C. odorata* and *E. grandis* rooted cuttings (7.93 m and 7.89 m respectively). The rooted cuttings of *C. odorata* averaged one meter taller than the seedlings (6.89 m), while the *E. grandis* rooted cuttings averaged more than two meters taller than the seedlings (5.61 m). The *G. fasciculiflora* seedlings and rooted cuttings and *A. flammeum* clones grew poorly averaging 0.91 m, 1.15 m and 1.88 m respectively. The rooted cuttings of *A. aulacocarpa* (averaging 3.83 m) grew much more poorly than seedlings (6.05 m).

Sites combined

Survival

In the 1995 trials, survival on the Coast site was high for all species and for both seedlings and rooted cuttings. However, on the Tableland site, both plant types of *A. aulacocarpa* and the rooted cuttings of *A. flammeum* survived very poorly (Table 3). Since *A. aulacocarpa* cuttings especially had a large average number of roots (Table 2), this result is surprising. It may have been due to unrepresentative damage by cattle and/or weeds.

Growth performance of rooted cuttings vs seedling

Comparisons were possible for four species and for height only. In general, the height differences were neither large nor consistent – except that the *E. grandis* rooted cuttings were taller than seedlings of this species at both sites. At the Coast, the rooted cuttings of *E. grandis* only were taller (6.42 m) than seedlings (5.87 m). On the Tableland, the rooted cuttings of *E. grandis* and *C. odorata* (equally tall on average – 7.9 m) were clearly superior to seedlings, while the reverse was the case for *A. aulacocarpa.*

Whereas the rooted cuttings of *E. grandis* surpassed the seedlings in height at age 3.5 years at the Coast and Tableland sites by 9.4% and 41% respectively, the respective differences in DBHOB at eight years of age were only 1.3% and 2.7%.

Clone effect

For all species, it was observed that individual clones of rooted cuttings substantially out-grew the seedlings, and there were large differences between clones within species. For example, the mean height of the *G. fasciculiflora* seedlings at the Coast site (3.8m) was higher than that of the rooted cuttings (3.1 m); however, the mean height of individual clones ranged from 1.3 m for clone 19 to 4.45 m for clone 9. Clonal variation of lower magnitude was also observed in *C. odorata* and *E. grandis*. This opens up possibilities, if confirmed, for rapid improvement of growth through testing and selecting clones in some species.

Species-by-site

With one exception, all species in the 1995 plantings had good early survival on both sites, the poor result shown for *A. aulacocarpa* on the Tableland site (Table 3) being due, most likely, to cattle damage. The *C. odorata* seedlings grew twice as well on the Tableland site, with the clones almost three times taller. On the other hand the *G. fasciculiflora* grew better on the Coast site. The *A. aulacocarpa* grew well on both sites; however, stem form was poor (on both sites) with each tree multi-stemmed. The *A. flammeum* performed better on the coastal site, where it was more than one meter taller than the Tableland cohorts. *E. grandis* out-grew all other species on both sites. These inconsistencies suggest taxa by site interaction could be strong for species, such as *C. odorata*, perhaps need careful matching with location. Alternatively, *E. grandis* gave indications of broad adaptability.

Observations made in both plantings in June 2003

A visual assessment of both 1995 sites in June 2003 indicated that inadequate management of weeds in the Coast trial, and of grazing in the Tableland trial, had compromised these trials. Both seedlings and clones of *E. grandis* on both sites and of *C. odorata* on the Tableland site, still showed promise under the conditions that prevailed.

Planting of conifers (1996)

The results at seven years of age, presented in Table 6, need to be interpreted cautiously, because the planting did not include seedlings, was unreplicated and was established at a single site.

Table 6 Performance at seven years of age of clones from rooted cuttings of *A. cunninghamii* and *A. robusta* planted in the Gadgarra State Forest, Atherton Tableland.

Species	No. of clones	No. of trees	Survival (%)	DBHOB (cm) Spp mean (=*a*)	Best clone (=*b*)	Percent increase (*b*-*a*)
A. cunninghamii	10	87	80.6	15.35	16.78	9
A. robusta	6	88	82.4	9.26	11.09	20

Note: DBHOB – diameter breast high over bark.

Both species gave high average field survival (80.6% and 82.4% respectively). The numbers of trees surviving per clone (not shown) ranged from 7 to 13 for *A. cunninghamii* (an average of 10 had been planted per clone), except for one clone of which only three were planted; and 11 to 15 for *A. robusta* (an average of 10 had been planted per clone), except for one clone which had 22 surviving from 26 planted. There were considerable differences in clone means for DBHOB as indicated by the means of best clones versus species means expressed as a percentage (9% and 20% for *A. cunninghamii* and *A. robusta* respectively). However, since the planting was unreplicated, these observations must be interpreted cautiously.

The trees had been scored in May 2003 for straightness, stem breakage, lean and axis persistence. However, the results (not tabulated) showed only very small differences between species and between clones within species. In general, the *A. cunninghamii* clones were impressive in growth and straightness; the latter observation was not expected on the basis of past experience with some unimproved Papua New Guinea hoop pine seedling stock (Nikles and Robson 2004).

Discussion

There appear to be large differences among the 11 hardwood species in terms of their responses to the various treatments. However, only one species 'stood out' as highly satisfactory on all evaluation criteria and that was *E. grandis*.

The finding of high VP potential for *E. grandis*, a native rainforest species with seed very slow to germinate (Nikles *et al.* 1994) suggest rooted cuttings could substitute for seedlings in many future plantings of this species. Moreover, *E. grandis* showed highly significant variation of rootability and roots per cutting between clones, and clonal differences in survival and growth were also observed in the field trials. These preliminary findings indicate it could be a good candidate for family and clonal forestry, if commercial planting were contemplated in suitable areas. Furthermore, its superior performance in other, widespread CRRP plantings (of seedlings) across a range of soils and rainfalls as well (Bristow *et al.* Chapter 6) indicates it is a species that could be planted with considerable confidence where a rainforest species with high survival, rapid growth and the particular wood properties of *E. grandis* (Bootle 1995) are prime requirements.

The responses and prospects of the other species are now discussed, first the hardwoods and then the conifers. In both cases this discussion is in the approximate order of their apparent amenability to VP.

The introduced species, *C. odorata*, also showed high amenability to VP (especially if shoot production in hedges could be enhanced) and, potentially, to clonal selection. However, with this species it appears very desirable to allocate it to locations and/or sites rather carefully since its growth in the field was very much better at the Tableland than the Coast site in the present study (the latter site had edaphic constraints). The species registered 'moderate' growth rates in each of the three soil type-rainfall regimes in which it was tested under the CRRP, but numbers of trees measured per site were small (Bristow *et al.* Chapter 6).

Keenan *et al.* (1998) reported 9.5 year performance of several *C. odorata* provenances grown as seedlings as part of a species trial on a Coast site near Innisfail, north Queensland on a much better soil ('red, weakly laterised kraznozem derived from basalt') than that of the Coast site. Survival at this site was high. The mean height of the best two, well-replicated, *C.odorata* provenances (17.1 m) was similar to that of the better teak (*Tectona grandis*) (16.9 m), but the basal area per ha of the former was 40% higher. All *C. odorata* provenances (except one from Colombia, which also had the best height growth, bole length and form) were attacked by the shoot borer *Hypsipyla robusta*; however, resistance to and recovery from attack appeared to vary among provenances and was greater than that of *Toona ciliata* (in a separate, mixed planting with *C. odorata*) and *Swietenia macrophylla*, the latter species (though surviving well) still exhibiting almost 100% multi-stemmed trees in 2004 as a result of early attack (Nikles pers. obs.). At 17.5 years of age, the *C. odorata* in this species trial still exhibited good growth and survival, though apparently less than that of *Pinus caribaea* var. *hondurensis* Barr. and Golf and *A. robusta*, and much poorer stem form than these two species. Thus *C. odorata* appears to have potential for commercial planting in north Queensland, but work on wood quality evaluation, assembly of germplasm (especially from the promising Colombian provenance), breeding, clone testing and site matching would be required before *C. odorata* cuttings could be recommended confidently for establishment in commercial plantings in the region.

In studies near Sydney of *A. flammeum* reported by Donovan *et al.* (1999), semi-hardwood cuttings from four year old, potted seedlings subjected to two humidity regimes and two bottom heat treatments, the best result (presented as 'mean root class' based on scores from 1 to 6), was a mean root class of 3.42. (We presume this was equivalent to approximately 57% rootability). *A. flammeum* was more amenable to VP in the present study (71.8% rootability). However, survival of its rooted cuttings at the Coast site was rather lower (at 74%) than commonly desired, and extremely poor at the Tableland site (13%). Its growth was among the poorest of the five species at both sites. Although this species is widely propagated vegetatively and planted as an ornamental, its in-stand growth rate was not evaluated in CRRP plantings reviewed by Bristow *et al.* Chapter 6), and no other information is available. More work on growth and adaptability in mixed or pure-stand deployment would be required with this species to determine its utility for plantings other than ornamental.

Two other hardwood species (*A. aulacocarpa* and *G. fasciculiflora*) could be considered potentially amenable to VP if a customisation technique resulted in sufficient improvement in one or two of the propagation traits (rootability, roots per plant and shoots per hedge per time). *A. aulacocarpa* appeared somewhat deficient in shoot production, but the latter might be enhanced by improved hedging technique. Growth of *A. aulacocarpa* rooted cuttings was moderate on both field sites; however, survival and stem form were very poor on the Tableland site, possibly due to cattle damage.

Nikles *et al.* (1998) reported on a collaborative genetic improvement and conservation program of the then QFRI and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) that involved, among other things, clone tests of *A. aulacocarpa* established in north Queensland using rooted cuttings from hedges developed from cuttings taken from shoots produced on 80, three year old trees selected for superior growth and straightness in a large base population of seedling seed orchards (SSOs) that were pollarded at about 1 m above ground. In all, the SSOs comprised 304 open-pollinated families of several Papua New Guinea provenances. All selections gave some rooted cuttings, but only about one half of the clones had a rootability in excess of 50%. Three clone tests of varying numbers of clones plus comparable seedlings, and a clonal seed orchard (CSO) of 63 clones, but no seedling controls, were established with rooted cuttings in the field. Analyses of the results of measures of height, diameter and stem straightness score undertaken at 22 or 26 months at two sites showed: a) slight superiority of clones to seedlings for height, but the reverse for diameter; b) significant superiority of clones over seedlings for stem straightness; c) significant differences between clones for all three traits at both sites; and d) significant, positive genetic correlations of clone means between sites.

These results for height growth of seedlings versus rooted cuttings at one site (coastal) did not conform to the indications from the trials reported in Table 3 (seedlings taller than rooted cuttings at both Coast and Tableland sites, both plant populations derived from unimproved source material). However, this would be expected because of the intense, phenotypic selection applied in the choice of trees included in the clone tests reported in Nikles *et al.* (1998). The strong differences between clones in growth and stem form support results with many other species (Sedgley and Griffin, 1989). The stability of clone performance across divergent sites found by Nikles *et al.* (1998), if confirmed, would augur well for simplified breeding of *A. aulacocarpa* (without regionalisation). The collaborative program progressed to the planting of a small, second-stage base population in 1997. Unfortunately, however, this resource was lost a few years later; and it proved impractical to maintain the 63-clone CSO. (Thirty clones remain at the coastal-site test which could function as a CSO if managed adequately). Thus, prospects for utilising this species, known to be slower growing than three other tropical acacias and the *A. mangium* x *A. auriculiformis* hybrid (Kha 2001), in north Queensland seem limited.

G. fasciculiflora had a moderate rootability of 52.3%, ranked second among 11 hardwood species for rate of shoot production, but gave below average roots per cutting. Improvement of rootability and roots per cutting would be desirable. This might be achieved technologically and certainly via clone selection, since strong clonal differences in these propagation parameters were demonstrated (Table 3). However, the growth of rooted cuttings was disappointing, especially at the Tableland site where prospects for utilising this species seem limited. It is worth noting that the hedges of this species retained at the Walkamin nursery provided the only source material for supplying the small demand for planting stock for a period due to the unavailability of seedling stock. Seed production and seed viability is often low while storage is problematic and germination is very protracted (Nikles *et al.* 1994).

All four of the *Flindersia* species and some other species of reforestation interest, including *B. involucrigera* and *C. australe,* are not likely to be suitable candidates for VP because of their low to very low rootability and very low rankings for one or both of the other propagation traits. In CRRP plantings, *C. australe* grew moderately well on soils from basalt (highly fertile), but slowly elsewhere (Bristow *et al.* Chapter 6). Though both these species would seem, therefore, to have limited prospects for industrial plantings in north Queensland, *C. australe* has potential for rehabilitation and mixed-species plantings as constraints on availability of regular supplies of nursery stock from seed (storage life approximately three months –D. Goschnick pers. comm.) or rooted cuttings might be alleviated by the collection and use of small, wildling plants that are often abundant in natural forest.

The non-amenability of the *Flindersia* species to VP is particularly unfortunate in the case of *F. brayleyana*. It is an acclaimed cabinet wood species that has been planted in small amounts over many years (Anon. 1983; Keenan, 1998), and grew moderately well to fast over a wide range of conditions in CRRP plantings (Bristow *et al.* Chapter 6). However, Anon. 1983 found that both enrichment planting (or underplantings in natural forest) and open planting of *F. brayleyana* were unsatisfactory in trials in north Queensland. In contrast, plantings of the species in south Queensland in mixture with *A. cunninghamii* in the Mary Valley, and as underplants in young *Pinus* plantations in the Beerburrum area, have given impressive results; in the latter case *F. brayleyana* was the most productive of six rainforest species tested all of which had high survival and small, merchantable logs at 38 years of age (JA Simpson pers. comm.). Moreover, there was some evidence that the total production of the pine – maple mixture was greater than that of pure pine. Thus there could be an ongoing call for limited amounts of planting stock of *F. brayleyana*. Satisfaction of the demand would appear to be feasible only via seed collections from the wild, or via seed orchards although none have been established yet.

However, seed production is sporadic (extremely little seed has been produced in a clone bank of grafts planted in the Kuranda State Forest in the 1950s – authors' observations), and pod collections from spaced, in-forest trees [as opposed to isolated, more accessible ('paddock') or forest-edge trees which may sustain considerable inbreeding] are now expensive (S. Kitchener pers. comm.). It is encouraging to note that heavy crops of seeds occur in forest and remnant paddock trees in some years (A. Irvine and R. Lott pers. comm.) and that widely-spaced seedlings of some of the *Flindersia* species reported on here are capable of fruiting by 10 years of age (E. Wiles pers. comm.).

With regard to the two conifers, *Araucaria cuninghamii* is a species regularly planted commercially on the Atherton Tableland in north Queensland (Anon. 2002) using seed from clonal orchards of the breeding program in south Queensland (Nikles *et al.* 2004 b). A CSO of principally Papua New Guinea provenances established near Atherton in 1995 is producing significant crops of seed cones which, however, are expected to contain mostly infertile seeds due to the limited production of pollen to date (Nikles pers. obs 2004). Prospects for deploying south Queensland and Papua New Guinea *A. cunninghamii* hybrids in the future seem promising in view of their superiority at four years of age (Dieters *et al.* 2000), their excellence at almost nine years of age (G. Nikles pers. obs. 2004) and the high rootability of the species as reported in the present paper. The latter feature is conducive to propagation of superior hybrid families or clones.

Bristow *et al.* (Chapter 6) reporting around eight-year growth of CRRP plantings of this species in five soil type – rainfall regimes, found it produced 'moderate' growth across this wide range of conditions thus showing its versatility as a species for plantings. The high rootability of apical cuttings from seedlings in this study (89.4%) supported the good results reported for south Queensland provenance seedlings - averages of 82.3% and 75.3% across 15 and 12 families respectively (Walker *et al.* 1996b). Good, seven year survival and growth of the clones reported on here (Papua New Guinea provenance), and similar survival and growth of rooted cuttings and seedlings of south Queensland provenances in south Queensland trials planted in the early 1990s (M.J. Johnson pers. comm.), would encourage consideration of VP to maximise the use of scarce seed of outstanding families from the breeding program, especially if the low multiplication rate from hedges could be overcome (Nikles *et al.* 2004 a,b).

No record is now available of the rootability of the other conifer in the study, *A. robusta*. It is thought to have been similar to that of *A. cunnninghamii* since similar numbers of cuttings were likely to have been set, and the same number of rooted cuttings was available for field planting of each species (108 plants). Although the seven year diameter of the *A. robusta* was only 60% of that of the *A. cunninghamii* in the unreplicated planting of this study, growth of the former species in the CRRP plantings reviewed by Bristow *et al.* (Chapter 6) was rated in the same diameter-growth-rate class (moderate) as *A. cunninghamii* in the three, soil type – rainfall regimes where they could be compared. However, in longer-term comparisons in south Queensland, *A. robusta* is outgrown by *A. cunninghamii* (Nikles 2004). *Agathis robusta* has an unusual capacity to be propagated vegetatively via root shoots and rooted shoots are known to develop into impressive stands to at least 16 years of age in south Queensland (Nikles 2004). Following a series of early studies on the induction and management of root shoots from *A. robusta* seedlings in south Queensland, it was concluded that, by this means, “a planting program could be supported once plants (seedlings) are established in the nursery” (Haley 1957). In the species trial reported by Keenan *et al.* (1998), *A. robusta* now (at 17.5 years of age) appears second only to *P. caribaea* in survival and growth (Nikles pers. obs.). The excellent wood quality and exceptional natural pruning capacity of *A. robusta* (Nikles 2004) also are attractive features of this species that should be taken into account when considering species for planting in north Queensland. [The wisdom of planting *A. robusta* extensively in some areas in south Queensland is questionable due to the heavy losses of near-mature plantations in the Mary Valley in the 1960s caused, primarily, by attacks of the kauri coccid, though better site and provenance selection might make plantation establishment more successful in the future (Nikles 2004)].

The very strong effect of clone differences on both rootability and total number of roots per rooted cutting in the three hardwood species assessed directly (Table 5), and the observed effect on propagation and field performance on additional species included in this preliminary study, is in keeping with results from many other tree species (Sedgley and Griffin 1989).

There were no obvious differences in growth between cuttings and seedlings of most species. However, for each species there were individual clones that substantially out-grew the seedlings and their clonal cohorts. The ability of *C. odorata* and *E. grandis* to root well, develop many roots and produce shoots prolifically, survive and grow well opens up possibilities for rapid improvement of growth via clone testing, selection and deployment of superior clones.

Consideration of the history of the work overviewed here reveals a number of problems associated with research that is essentially long-term: adequacy and continuity of funding, staff continuity, changes in priorities of funding bodies and research providers, how to ensure security and good management of field trials that are often distant from the bases of research workers, and others.

In hindsight, it is evident that the research overviewed here, although revealing *E. grandis* as a species with much promise for VP and deployment as rooted cuttings clones, was inadequately funded in terms of amount and continuity. As a result, it was not possible to adequately study hedge management, to test customisation of propagation protocol, to establish and properly maintain good field tests with sufficient species for a long enough period to obtain clear leads, nor to follow-up on preliminary leads. This experience provides a clear lesson with regard to future work of this kind – it would need to be funded adequately for some 15 years, and have clear protocols for managing changes of staff and of research priorities, and field trials.

Conclusions

A small number of the species tested were amenable to vegetative propagation and deployment as rooted cuttings, so problems associated with the regular production of seedlings in sufficient numbers to meet demands need not be a constraint on their deployment to plantings. Where *Elaeocarpus* *grandis* planting stock is required in quantity on a regular basis, the use of rooted cuttings and, in the case of commercial deployment, clonal testing and deployment of superior clones, backed by conservation of diversity, should be considered – this is an approach demonstrated successfully elsewhere with a variety of species.

Further studies aimed at determining the specific requirements for improving amenability to propagation vegetatively should be considered for the following species: *Acacia aulacocarpa, Agathis robusta* and, especially, *Araucaria cunninghamii* , as well as other very desirable rainforest tree species of unknown amenability to vegetative propagation not included in the work described here.

For some other species among those tested, consideration of their particular constraints would be required if domestication and deployment by VP were contemplated. These include *Cedrela odorata* (assembly of appropriate germplasm, breeding, improvement of shoot production in hedges and careful site matching); *A. flammeum* (potential for and utility in plantings other than ornamental); and *Gmelina fasciculiflora* (potential for improvement of rootability and roots per cutting, and for considerably improved growth rate in plantings).

Future nursery and field trials of the kind described here should be integrated and only considered for implementation in cases where adequacy and continuity of funding support, including adequate arrangements for security and management of field trials, are likely to be assured for an appropriate period of the order of 15 years.

Acknowledgements

Dr Russell Haines (then at QFRI) conceived the project, negotiated its acceptance by the CRRP Committee and maintained interest in it, thus encouraging the participants. Project planning was undertaken by Steven Walker who also directed implementation. Nick Kelly and Grant White are thanked for dedicated technical assistance in this project. Internal reviewers Drs Susan House and Mark Hunt are thanked for useful editorial suggestions.

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Appendix 1

Seedlot number and provenance (where known) for species used in the study.

Species	Seedlot no.	Seed provenance
Acacia aulacocarpa	3330, 17873	Wimpim-Oriomo, W Province, PNG
Agathis robusta	3562	Wongabel State Forest, plantation
Araucaria cunninghamii (PNG)	0006	Danbulla State Forest, plantation
Alloxylon wickamii	X = not known	X = not known
Flindersia pimentaliana	4260	X
Musgravea heterophylla	X	Kuranda State Forest, natural stand

5. Nutritional limitations to the early growth of rainforest timber trees in north Queensland

Michael J. Webb, Mila Bristow, Paul Reddell and Nalish Sam

Abstract

Most of the soils in the humid tropics of north Queensland available for growing rainforest trees are low in available nutrients. The major nutritional deficiencies have been classified according to soil parent material in order to develop a deficiency 'risk' table. From glasshouse trials using soils from across the region, most macronutrients (nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and sulphur (S)), apart from magnesium (Mg), has been found to be deficient in at least one soil, and every soil studied was deficient in at least one nutrient. Rainforest tree species responded to nutritional deficiencies in different ways and there may be an unrecognised loss in growth potential. Tree growth can be depressed under limiting nutrient supply but remain undiagnosed, as visual deficiency symptoms may not develop. We present a number of techniques to manage nutrients in timely and cost effective ways. These include techniques to ensure a continuous supply of nutrients to the roots during transplanting, rapid tests for deficiencies of N and P, and recognition of visual diagnostic symptoms of deficiency.

Introduction

Many people presume that undisturbed rainforests occur on highly fertile soils with substantial biomass, and high in biodiversity. Rainforests are maintained by the rapid and efficient cycling of nutrients resulting in little loss from such systems. Somewhat unexpectedly, rainforest soils are quite fragile and rapidly degrade after clearing and thus are generally quite poor in an agricultural context; they are often highly weathered, have inherently low fertility and ability to retain nutrients especially if organic carbon (OC) levels decline. Many soils in the humid tropics of north Queensland have little (usually less than 5 $cmol^{+}/kg$) cation exchange capacity (CEC) (Webb *et al.* 1997). The little CEC that they do have is often dominated by exchange acidity or can be attributed to organic matter. That these soils are able to support luxuriant growth, such as a rainforest, is testament to the recycling and retention abilities of the biomass rather than the soil.

Thus, it should be no surprise that removal of a rainforest also removes a large proportion of nutrients. This can occur through immediate export in logs, subsequent losses through runoff or leaching as there is little vegetation remaining to capture nutrients, or as in the case of N and other volatile nutrients lost from logging residue, as well as from the surface soil and litter, in burning of rainforest residue after clearing (Vitousek and Sanford 1986). Further, it should then be no surprise that to re-establish trees in such landscapes will require an input of nutrients. How these nutrients are applied, and at what rates and times, will contribute to the success of tree, and stand, establishment and growth (Evans 1992).

Plantations established on degraded ex-agricultural land, whether of monocultures of pines for sawn timber or eucalypts for pulp and fibre, uses inputs of nutrients (as fertilisers) to achieve and maintain growth and productivity (Evans 1992). So while it is generally recognised that the nutrient requirements may not match the nutrient supply, nutrients will be required to re-establish trees.

In the Community Rainforest Reforestation Program (CRRP), for example, a prescriptive dose of fertiliser (eg diammonium phosphate; DAP) was often used irrespective of the soil type being planted, its history, or the species being planted because of its affordability, availability and ease of application. There was some direct and indirect evidence that the DAP stimulated a response, in some situations, but research has since shown not necessarily in every situation.

In designed trials, Webb et al (2000a) determined that such a practice could be inappropriate for *Castanospermum australe* (black bean) and *Flindersia brayleyana* (Queensland maple) grown on a soil derived from metamorphic parent material as there was no response to added phosphorus (P), but would be highly appropriate for *Cedrela odorata* (West Indian cedar) and *Agathis robusta* (kauri pine) at the same site. In another example, Reddell *et al.* (1999) have shown that a single field application of well-placed slow-release fertilisers can be hundreds-fold more efficient than field applied fertilisers for the establishment and early growth of *Gmelina arborea* (white beech).

These examples highlight the challenges faced by CRRP staff in the early 1990's, as they considered establishment nutrition; each situation was different. The ability of a particular site to supply required nutrients for tree growth is dependent on many variables. The extent of site degradation, time since clearing/burning of the original vegetation, site management history (agricultural/pastoral/ horticultural) including fertiliser history of the site as well as weed control in the establishment phase (up to two years) all have major impacts on fertiliser responses (Webb *et al.* 1997, Bristow *et al.* 2005).

In this paper we highlight the results of research in north Queensland which (a) demonstrates the need to consider appropriate nutrient management in order to achieve good establishment and early growth of planted trees, and (b) led to the development of tools which are currently available to aid in the nutrient management of trees to achieve good establishment and early growth. Where possible, most of the work referred to here has been carried out in north Queensland. In addition, results are presented from tree establishment research in the Solomon Islands, Niue, Fiji, and Samoa.

Nutritional issues in relation to establishment and early growth

Extent, type, and severity of nutrient deficiencies in the wet tropics of north Queensland

In the early 1990's easily accessible published studies describing nutrient relationships for Australian rainforest timber trees, or indeed for any tropical hardwood plantations were limited. Since 1990, the total plantation estate in Australia has increased by 500 000 ha, with much of this area in Australia and worldwide having been reforested with species primarily grown for short-rotation pulp markets (Sedjo 1999, Gerrand *et al.* 2003). During this ten year period it has become clear that there are major nutritional constraints to the growth of timber trees in the humid tropics (Webb *et al.* 1995) including north Queensland (see Table 1, Webb and Reddell 2000, Webb *et al.* 2000a and 2000b). However, it was not always clear from these trials which particular nutrients are limiting tree growth.

In order to characterise the nutrient status of different soils, glasshouse trials have been used as a rapid screening technique to identify 'potential' nutrient deficiencies, which can help with designing effective follow-on field trials. Glasshouse trials test the soils ability to supply sufficient amounts of each of the nutrients essential for plant growth. The level of growth depression compared to a well-fertilised control is an indication of the severity of the deficiency. An example of this methodology is described for *Toona ciliata* (red cedar) in Webb *et al.* (1997). For example, using glasshouse trials with *T. ciliata* grown on a basaltic soil from Malaan on the Atherton tablelands of north Queensland, it is clear that when no nutrients ("Nil") are added that there is poor growth compared to that when adequate quantities of nutrients (Complete) are added (Figure 1).

Table 1 Effect of high and low fertiliser application on the growth of *Eucalyptus pellita* (red mahogany), *E. cloeziana* (Gympie messmate), and *Flindersia brayleyana* (Queensland maple) grown on soil derived from different parent material. Data are the mean and standard error (se) of four replicates.

Species	Tree Age (mths)	Soil Parent Material	Low Fertilisation		High fertilisation	
			Volume (m^3/ha)	se	Volume (m^3/ha)	se
Flindersia brayleyana	17	basalt	0.084	0.018	0.570	0.017
Eucalyptus cloeziana	17	basalt	1.76	0.32	3.56	0.39
Eucalyptus pellita	35	metamorphic	4.4	3.1	39.7	8.8

For details of fertilisers, rates, techniques, etc. see Webb. and Reddell (2000).

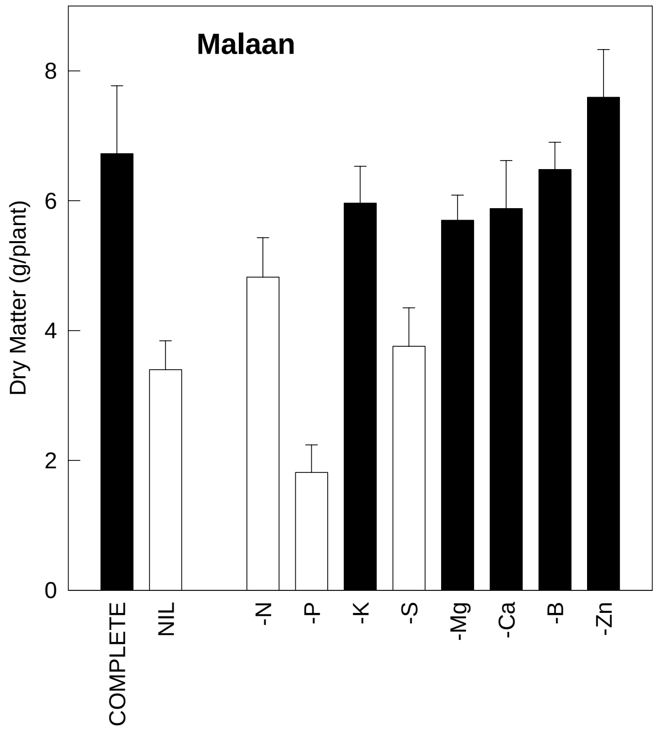

Figure 1 Growth of *Toona ciliata* (red cedar) after four months in an omission pot trial using basaltic soil from Malaan, north Queensland. The treatments applied were a complete nutrient addition as well as complete without: N (= -N); P (= -P); K (= -K); S (= -S); Mg (= -Mg); Ca (= -Ca); B (= -B); and Zn (= -Zn). This trial suggests this species suffers from a P deficiency when grown in this soil. Bars of the same colour are not significantly different when compared to the “Complete” or “Nil” treatments. Error bars represent the standard error of the mean.

Furthermore, these results clearly identify phosphorus (“-P”), as the most severely limiting nutrient in this soil as there is very little growth when P is omitted even when all other essential nutrients have been added. The next most limiting nutrient in this soil is sulphur (“-S”). Similarly, again using *T. ciliata*, another basaltic soil (Eubenangee series) from Innisfail the humid coastal lowlands of north Queensland soil was deficient in N, and to a lesser extent, P, K, and S; and another lowlands granitic soil from Feluga (Thorpe series) was found to be deficient in N and S (Webb *et al.* 1997).

Similar information has been collected using 35 soils from across the humid tropics of north Queensland in glasshouse omission trials. The results of these trials have been summarised by parent material, the severity of the nutrient deficiency, and the number times a particular deficiency was found (Table 2). This firstly shows that P is the most common severe deficiency; occurring in almost every soil tested except those formed on recent basalts. This P deficiency is shared by most tropical soils, especially plantation soils where additions of P and cations are generally required (Folster and Khanna, 1997). It is noteworthy that in soils other that those formed on recent basalts the two soils that did not show P deficiency had recently been in agricultural production with a history of phosphatic fertiliser use. Secondly, this data shows that the deficiencies and severities show some commonality within soils derived from the same parent material.

Table 2 Severity of nutrient deficiencies for tree growth at sites in north Queensland with particular soil types on the basis of parent material. This was determined through glasshouse omission trials *Agathis robusta*, *Castanospermum australe*, *Cedrela odorata*, *Eucalyptus grandis*, *Flindersia brayleyana*, *Gmelina arborea*, *Tectona grandis*, *Toona ciliata* and *Swietenia macrophylla*. NB. Soils derived from metamorphic rocks have been included as part of the metasediments.

Parent Material	**No. of Soils**	**Extent of growth reduction**	
		Severe (> 50%)	**Moderate (20 to 50%)**
		number of sites at which particular deficiency is present	
Basalt			
recent	2	nil	N-2
older	6	P-5, N-1	N-5, S-3, K-1
Metasediments	7	P-7, Ca-2	Ca-3, Zn-2, N-1, P-1, K-1, S-1
Granites	10	P-9, N-2, Ca-2, S-1, Cu-1	S-6, N-5, Ca-2, Mg-1, Zn-1, Cu-1, B-1
Mixed Alluvium			
well drained	2	P-2, K-1, N-1	K-1, Ca-1, S-1
poorly drained	2	P-2, S-1	N-2, K-1
Acid Volcanics	2	P-2	K-2, Cu-1
Beach Ridges	3	N-3, P-3, S-3, Zn-2, Mo-1	3xK, Zn-1, Mo-1

Key: "P-5" = 5 soils of this parent material were found deficient in phosphorus (P).

On the basis of these commonalities a 'risk assessment' table has been generated to further summarise and integrate the information into a form that could be used by land managers (Table 3). Once again it is quite clear that, independent of soil type, a P deficiency has a very high potential to severely reduce tree growth and that there is a high potential for N deficiency to limit growth in soils in the region.

While these results are not surprising, and add support to the CRRP practice of routinely applying a DAP as a prescriptive fertiliser (if we ignore species differences – see below), they also highlight the potential need to add other nutrients, especially Ca, K and S. These nutrients were rarely added in CRRP plantings unless DAP was not available and another source, or form, of phosphate was used. For example, single super phosphate will also supply calcium and sulphur, and triple super phosphate will also supply Ca.

Table 3 'Risk assessment' table to identify the nutrients that have the most potential to reduce production through insufficient supply. NB. Soils derived from metamorphic rocks have been included as part of the metasediments.

Parent Material		**Deficiency Index**	
	Very High	**High**	**Possibility**
Basalt			
recent	nil	N	
older	P	N, S	K
Metasediments	P	Ca	N, K, S, Zn
Granites	P	N, Ca, S	K, Cu, B, Mg
Mixed Alluvium			
well drained	P	N, K	Ca, S
poorly drained	P	S	N, K
Acid Volcanics	P	K	Cu
Beach Ridges	N, P, S	Zn, Mo, K	

What occurs under glasshouse conditions cannot be directly extrapolated to field situations. Ideally long-term results from field trials are needed and some measure of the overall economics of the situation considered. The CRRP was about reforestation of degraded lands and not necessarily about economic establishment of plantations (see Herbohn *et al.* Chapter 14). Indeed, for those landholders left to tend the young plantings, rapid promotion of growth during the establishment phase, which could lead to more rapid site capture, may be well worth the initial cost and effort.

The usefulness of glasshouse trials, and their limitations, has been confirmed in field trials in north Queensland and overseas, and the standard approach is described in Webb *et al.* (1997). For example, two species grown in a metamorphic soil showed a positive response to P fertiliser, as predicted, but another two did not (Webb *et al.* 2000a). Also, in the Solomon Islands, both *Gmelina arborea* (white teak) and *Tectona grandis* (teak) showed a positive response to P when grown in a soil derived from basalt but with a substantial difference in the magnitude of the response (Figure 2).

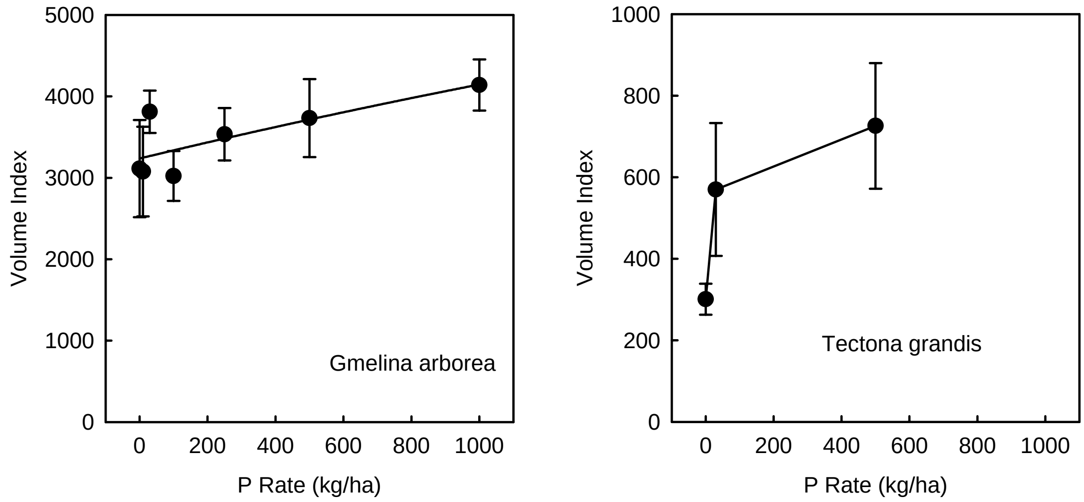

Figure 2 Growth response of *Gmelina arborea* and *Tectona grandis* to increasing phosphorus supply in a field trial on basaltic soil in Kolombangara, Solomon Is. Trees are 27 months old and have been supplied with sufficient amounts of all other essential nutrients. Error bars represent the standard error of the mean. This trial is an example of field testing of nutrient deficiencies first noted in preliminary glasshouse (nursery in this case) trials.

Thus, while glasshouse trials can be a useful indicator of potential nutrient deficiencies, such responses require field confirmation, especially if plantings are for economic gain.

In spite of this information on the severe nutritional limitations to tree growth under glasshouse and field conditions in soils of north Queensland commonly used for tree planting, and the information on which nutrients are most likely to be limiting in those soils, the concept of site specific fertilisation has rarely been adopted. Indeed, these same sentiments have been expressed in regard to the intensively managed tropical pine plantations in Queensland (Simpson 1998). Hopefully, site-specific nutrition research on tropical rainforest species will follow on from examples in other parts of the country with other timber species: viz, boron (B) on *Acacia melanoxylon* (Tasmania blackwood) (Fairweather and McNeil 1997); copper (Cu), zinc (Zn), P, N and other micronutients on *Araucaria cunninghamii* (hoop pine) (Richards 1967, Ryan 1982); manganese (Mn), and Zn (Cameron *et al.* 1986), micronutrients (Schonau and Herbert 1989, Cromer *et al.* 1993), and Cu and other micronutrients (Cromer 1996) on eucalypts.

Possible failure to recognise loss in growth potential

Whilst we have the ability to test soils both in glasshouse and field experiments for their ability to supply the necessary nutrients to support acceptable growth rates (Webb *et al.* 1995, Webb *et al.* 1997, Keenan *et al.* 1998, Webb and Reddell 2000, Webb *et al.* 2000a, 2000b) it is more common that small-scale tree growers will rely on observation and experience to determine if their trees are nutritionally healthy and therefore growing at an acceptable rate. Such observation may well be the basis for any decision to supply supplementary fertilisation.

In north Queensland, with so many species being grown and with trees from any one species potentially being obtained from quite genetically diverse stocks (see Lott *et al.* Chapter 3), it is difficult to establish an ‘acceptable’ or even ‘expected’ growth rate by which to judge the health of a stand. For example, the growth rate of young plantations of *Eucalyptus pellita* (red mahogany) in Australia and the South Pacific can range anywhere from 1 m/year to almost 5 m/year even though specific symptoms of ill-health may not have been apparent at the lower growth rates (Webb and Reddell 2000). Furthermore, this variation will continue as a result of genetic improvement and thus it is necessary to update acceptable growth rates. For example, for young plantation material Harwood *et al.* (1997) discuss a 10% increase in volume growth of second generation seed of selected provenances of *E. pellita*, and a 20-30% increase in volume growth over natural populations.

Thus, growers are usually dependent on their own previous experiences, or that of others, as to what constitutes a healthy stand. To a large extent, this is a judgement made on the physical appearance of the stand.

Unfortunately, reliance on simple appearance of a stand carries the possibility that the grower will fail to recognise a loss in growth potential. Whilst the use of visual symptoms of nutritional deficiencies can be a powerful tool in diagnosing and managing nutrient deficiencies in agricultural crops as well as trees (see Webb *et al.* 2001a), there are times when it may not adequately diagnose a reduction in growth rate as a result of a nutritional deficiency (Webb and Reddell 2000).

Nutritional deficiencies appear when the rate of growth exceeds the rate at which particular nutrients can be absorbed from the soil to support that growth. This results in tissues that have an inadequate supply of a particular nutrient to carry out the metabolic functions for which that nutrient is responsible. This is then manifested in a metabolic imbalance that results in the production of symptoms. A classic example is the yellowing of leaves in response to nitrogen deficiency because of a lack of protein for chlorophyll formation.

The production of symptoms is quite common when there is a gross imbalance of nutrients. However, we have found that when all nutrients are in balance, but are simply supplied at lower rates, growth rate may be reduced but no symptoms are apparent (Webb and Reddell 2000).

As an example, there is little evidence from their appearance, if assessed in isolation of the other treatments that the *Eucalyptus pellita* trees grown at lower nutrient supply (see Webb and Reddell 2000) are experiencing any nutritional stress. However, it is clear from comparison with trees grown at a higher nutrient supply (Webb and Reddell 2000) that they are not are not growing at their maximum potential. Furthermore, in spite of the large differences in growth rate, we were unable to detect any difference between these treatments through nutritional, biochemical, and physiological tests that should reflect differences in growth rate or levels of nutrition (Webb and Reddell 2000).

These results suggest that a vast number of trees may be growing at rates lower than their genetic potential and that this loss in production will not be realised.

Different species, different responses

For purposes of efficiency, we have used a single species, *Toona ciliata* (red cedar), to characterise the nutritional status of many of the soils reported above. However, it is quite clear from a number of experiments that different species may behave quite differently under the same edaphic and climatic conditions. Webb *et al.* (2000a) clearly showed that at the same site, *Cedrela odorata* (West Indian cedar) and *Agathis robusta* (kauri pine) responded to P fertilisers but *Castanospermum australe* (black bean) and *Flindersia brayleyana* (Queensland maple) did not.

At another site *A. robusta* showed little effect of fertiliser for at least two years yet *C. australe* responded immediately (Keenan *et al.* 1998). In the Solomon Islands, *Gmelina arborea* showed only a small response to added P fertiliser whereas added P more than doubled the volume of *Tectona grandis* (Figure 2).

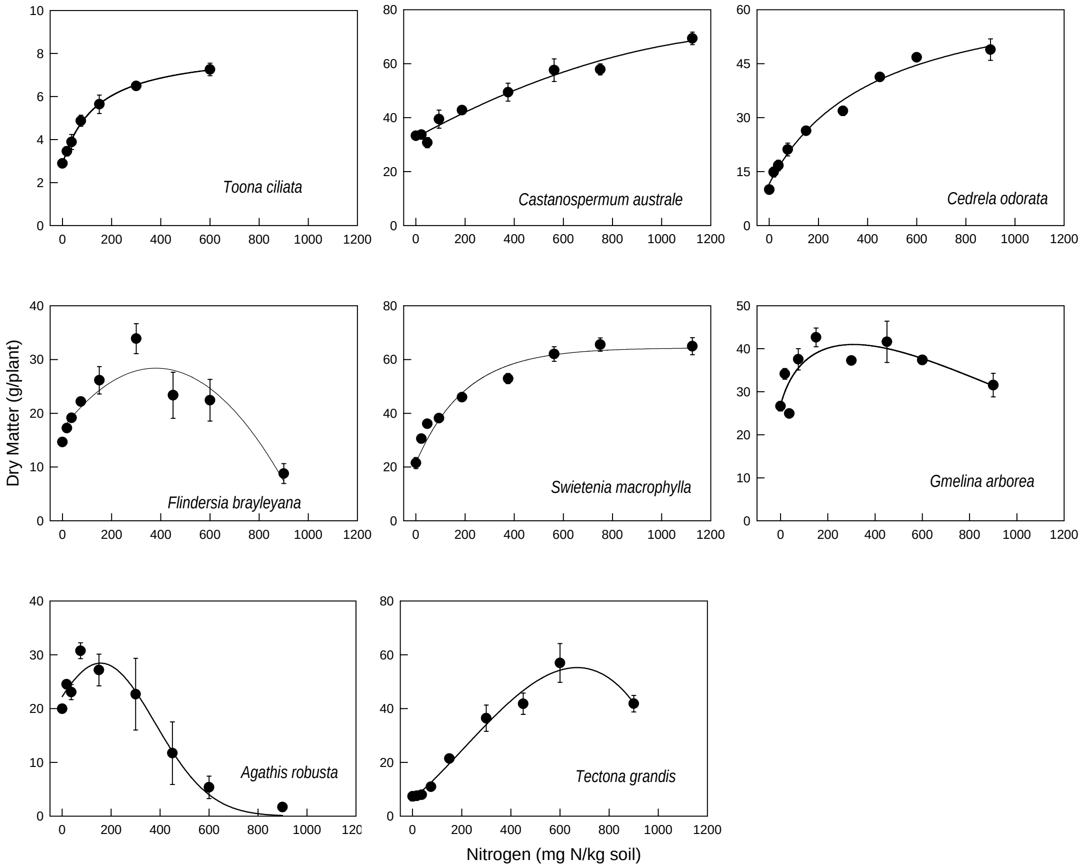

Figure 3 Dry matter response of rainforest timber species to nitrogen addition in a basaltic soil when grown under glasshouse conditions. Plants were harvested after growing for: 11 months, *Agathis robusta*; 12 months, *Castanospermum australe*, 13 months *Cedrela odorata*, 7 months, *Flindersia brayleyana*; 4 months, *Gmelina arborea*, 13 months, *Tectona grandis;* 7 months *Toona ciliata*; and 9 months *Swietenia macrophylla*.

Table 4 External requirements of N and P to achieve 90% of maximum growth*.

Species	N requirement (mg/kg)	P requirement (mg/kg)
Agathis robusta	45	32
Castanospermum australe	992	192
Cedrela odorata	741	56
Flindersia brayleyana	189	171
Gmelina arborea	187	222
Swietenia macrophylla	375	54
Tectona grandis	504	273
Toona ciliata	405	42

** N response was on a basaltic soil (PinGin series) from the Atherton Tablelands with a history of P fertilisation; P response was on a metamorphic soil (Galmara schist) from the humid coastal lowlands.*

The nutritional requirements for maximum growth also vary widely. In pot trials with a number of species, the pattern of response to N levels was markedly different among the different species grown (Figure 3).

This has resulted in 20-fold differences in external concentrations of N required for maximum growth (Table 4). Similar results have been found for P on the same species. However, the relative ranking for N differs from that for P (Table 4).

Visual symptoms of nutritional stress also vary widely among species. While some nutrient deficiencies result in visual symptoms that are common among many species (e.g. Fe deficiency) others are not as diagnostic. For example K and Mg deficiency symptoms are quite different in *F. brayleyana* but quite similar in *Gmelina arborea* (Figure 4). These results highlight the caution that is needed when extending the results for one species to another.

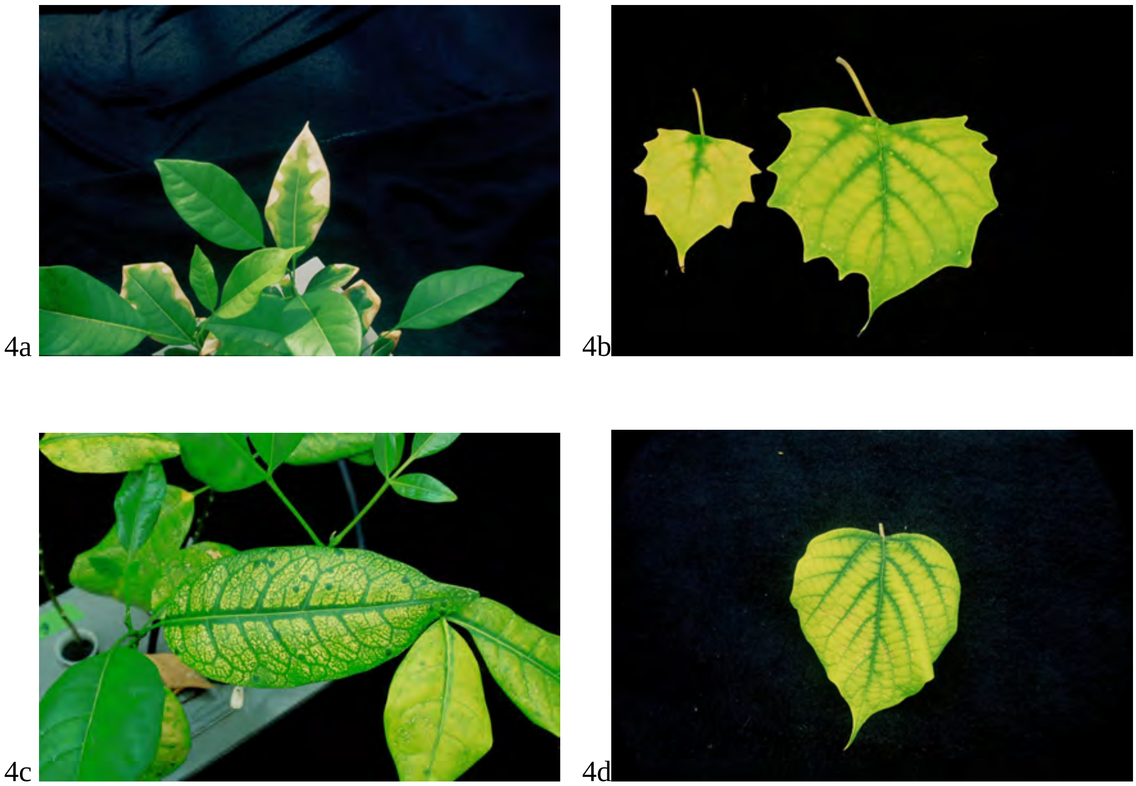

Figure 4 Potasssium (upper) and magnesium (lower) deficiency symptoms in *Flindersia brayleyana* (left, 4a & 4c) and *Gmelina arborea* (right, 4b and 4d).

Simple solutions using available technologies to improve establishment and early growth

The results presented above serve to highlight some of the issues faced by tree planters when considering a fertiliser strategy. While it is probably not practical to carry out experiments like those described above in order to determine the particular nutrient issues for a particular site and species being planted, these results and those presented below may aid in either avoiding nutrient deficiencies or managing those that are detected. For example, knowledge of soil parent material and site history may help in deciding what longer term nutritional issues will need to be addressed.

Slow release fertilisers

Although there are differences in the nutritional status of different sites, and differences between species in the way they respond to nutritional stress, there are some simple solutions that can improve establishment and early growth.

The first of these is to provide a continuous supply of nutrients to young plants especially during the transition from nursery to field. In many situations, planting material may be quite low in nutrients because of the length of time they are in the nursery or deliberate management decision used to 'harden up' the seedlings. Immediately after planting, roots need to develop to exploit the resources of the soil around them. Often the soils lack one or more nutrients, which may need to be supplied as fertilisers. These nutrients are usually applied to the surface or in a small slot for ease and efficiency of operation. In either case, these nutrients will have no effect until they come in contact with a root and are absorbed. This could take many weeks depending on many factors such as the growth rate of roots, the original location of the nutrient, the type of nutrient and form that is used, or rainfall to move the nutrient through the soil profile. This is likely to be when a young plant is most vulnerable to competition from other vegetation for resources. It is also a time that they have minimal resources with which to compete.

Universally in tropical forest plantations, establishment silvicultural recommendations for weed control are to maintain the tree rows free of weeds for the first couple of years, to remove competing vegetation allowing the trees to achieve rapid site capture. These recommendations extend for growing rainforest species (Subtropical Farm Forestry Association 2001, Bristow *et al.* 2005). With judicious weed control, careful individual tree application of fertilisers can be effective. Evidence for tropical eucalypts exists to suggest that this sort of technique is far less responsive when inadequate weed control is used (Keenan and Bristow 2001). The CRRP experience showed that these recommendations were not often followed; weed control was generally poor and thus competing grasses and weeds regularly received the fertilisers that were meant for the trees.

An alternative technique where nutrients can be packaged in pots in the nursery phase, then buried underground can be an efficient and effective way of delivering establishment nutrients to tree plantations. Studies have shown that by providing continuous access to nutrients through the planting phase, substantial improvements to early growth (to age two years) can be achieved (Woods *et al.* 1998, Reddell *et al.* 1999, Webb and Reddell 2000, Webb *et al.* 2000b). In general this has been done by providing a large amount of long-term slow release fertiliser in a medium that will facilitate the planting of the slow release fertiliser with the root ball and intact.

A good example of the use of this technique comes from work in the Solomon Islands with *Gmelina arborea* (Reddell *et al.* 1999). In brief, coir (composted and ground coconut husks) is mixed with both commercially available short-term (four to five month release time) and long-term (nine month release time) slow release fertilisers in reasonably large quantities (10- 20 g/L coir). The *G. arborea* cuttings used are usually only kept in the nursery for 6 weeks, after which they are transported to the field for planting. In this experiment, no field fertiliser was added to the trees. An important part of the planting process is to keep the root ball intact to minimise disturbance and maximise the retention of the slow release fertiliser around the roots. Although the fertiliser had no effect after six weeks in the nursery, there was an effect some six months later in the field (Figure 5). This effect was even more pronounced after 14 months (Reddell *et al.* 1999).

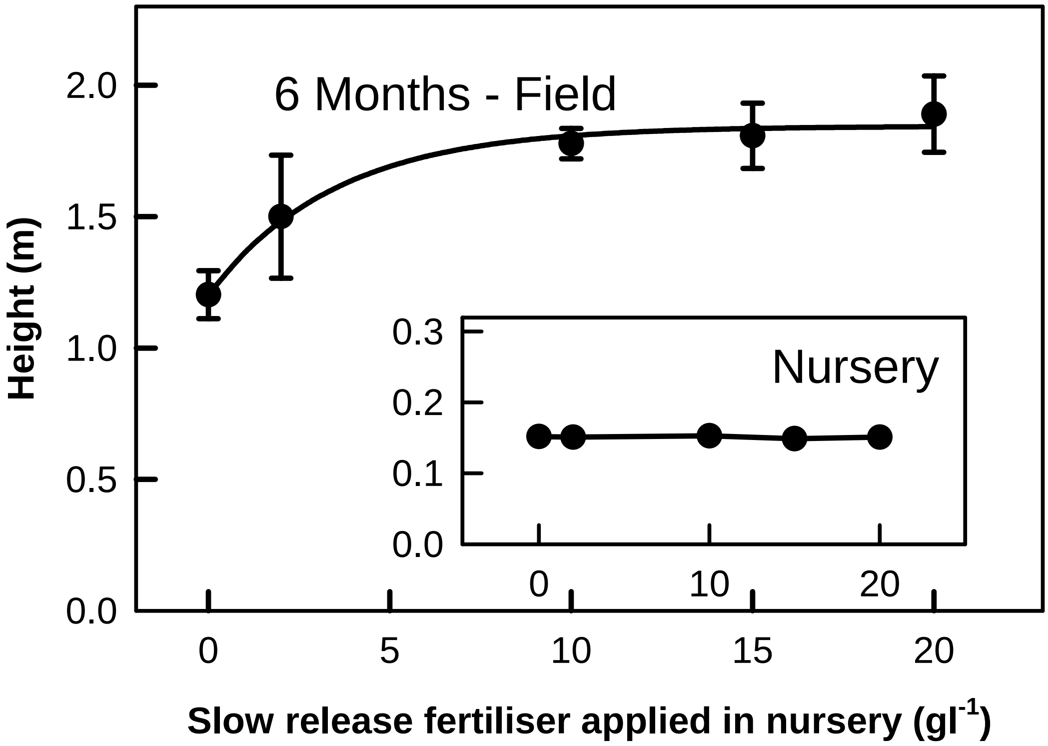

Figure 5 Effect of nursery-applied slow release fertiliser (details of fertiliser in Reddell and Webb 1999) on subsequent field growth of *Gmelina arborea*.

Although these rates of application are large by nursery media standards they are very small compared to routinely used rates of field applied fertiliser. For example, the amount of P added at the top rate in the nursery is some 300-fold less than that commonly added as field applied P. Because these soils in the Solomon Island have a high P-sorption capacity, these surface-applied P fertilisers are often ineffective. This approach has been so successful in the Solomon Islands that the plantation company no longer applies fertiliser post planting; instead they now control their fertiliser management in the nursery.

Similar trials in Australia have also shown considerable benefit of improving the availability of nutrients to tree roots during early growth. At a number of sites and on a range of soil types in north Queensland improving nursery and subsequent field nutrition has resulted in a doubling of height in six months (Webb and Reddell 2000) compared to the standard fertilisation practice. By 24 months the relative height differences had lessened but the stem volume of the well-fertilised tree was still more than double that of the tree fertilised using the standard practice.

Diagnosis by Symptoms

Sometimes growth rate may be depressed in young trees even though there are no symptoms of nutrient deficiency. This usually occurs when all nutrients are low in availability. However, when just one or two are out of balance we will often get visual symptoms, which, because of their particular feature, may be diagnostic of a particular nutrient deficiency. This information is captured in a book of descriptions and colour photographs depicting common nutrient deficiencies in young trees (Webb *et al.* 2001a). A second book is currently in production that will provide symptoms for *Castanospermum australe*, *Flindersia brayleyana* and *Agathis robusta*.

Although symptoms can be a useful technique for diagnosing nutritional problems, they should not be relied on as a sole management tool because by the time symptoms become visible it is often the case that stand or tree production has suffered. It is recommended remedial measures be applied in advance of visual symptoms appearing. Site and land use history, soil characteristics and nutrient deficiencies common to north Queensland soils presented as a 'risk assessment' in Table 3, may be a starting point.

Rapid Diagnostic Tests

In addition to traditional chemical analysis of nutrients to diagnose nutritional status of tropical timber trees (see Boardman *et al.* 1997), Webb *et al.* (2001b) have also developed rapid tests for determining N and P status using 'test strips'. These tests are rapid (a couple of minutes to complete) and while they may not provide the same degree of precision in determining the level of deficiency as tissue nutrient analysis, they have been used quite successfully in a "trouble shooting" sense to determine the nature of a problem and suggest a solution. For example, in the Solomon Islands, *Eucalyptus deglupta* (kamerere) seedlings in the nursery were quite chlorotic, suggesting nitrogen deficiency. However, when the sap was tested with a nitrate test strip it was clear that nitrogen deficiency was not the problem. Further investigation suggested iron deficiency as likely and a subsequent experiment with a foliar application of iron chelate confirmed this. Had traditional chemical nutrient analysis been undertaken, by the time the results would have been available the trees would have probably already left the nursery and been planted in a poor condition. Further, the cause of the condition (in this case, slow release fertiliser without added micronutrients) would not have been recognised and could have possibly re-occurred.

Conclusions

When developing a fertiliser strategy to achieve good establishment and early growth it is important to consider the:

- site and land use history, and soil characteristics;
- type of fertiliser, i.e. the nutrient needed;
- amount of fertiliser required;
- chemical form of that fertiliser (i.e. nutrient release rate);
- timing of application;
- site of application; and
- species being fertilised.

From a commercial point of view, it is also important to consider the cost/benefit of such a strategy, however it is important to consider more that just timber production as the benefit. That is, one should also consider the consequences of such a strategy in terms of its ability to reduce the costs of silvicultural activities. Trees with adequate nutrients grow better, capture the site more efficiently and shade out competing grasses and weeds. The ensuing increased tree growth, and consequent reduced weed control costs, can offset high fertilisation costs; which is part of good establishment silviculture.

Acknowledgements

We would like to thank Dr John Simpson (DPI&F Horticulture and Forestry Science) and Dr David Lamb and Dr Susanne Schmidt (University of Queensland) for their insightful comments on earlier drafts of this manuscript. Field and glasshouse trials were conducted with funding assistance from Australian Centre for International Agricultural Research, the Joint Venture Agroforestry Program, CSIRO and FORSPA (Forestry Research Support for Asia and South Pacific - UNDP/FAO).

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III

Growth and Management of Rainforest Timber Trees

6. Species performance and site relationships for rainforest timber species in plantations in the humid tropics of Queensland

Mila Bristow, Peter D. Erskine, Sean McNamara and Mark Annandale

Abstract

The performance of 32 tropical rainforest and eucalypt tree species grown in private, mixed species plantations was examined. There were two objectives: 1) to summarise the growth of species by soil and rainfall classes, 2) to investigate the degree of variability in growth rates with respect to environmental variables. Data were collected from 112 plots established in the Community Rainforest Reforestation Program (CRRP) plantations across sites in the humid tropics of central and north Queensland. Sites ranged from sea level to 1160 m above sea level, with annual rainfall from 800 mm to 4300 mm, on soils derived from basalt, metamorphic and granite parent material. Species performance was significantly related to climatic and edaphic variables but the strength of these relationships differed among taxa.

Introduction

Foresters involved with timber plantation development in the tropics have traditionally focused on fast-growing species with good form and desirable wood characteristics that can yield a marketable commodity (Evans 1992). Throughout most of the twentieth century Australia followed this trend, establishing fast growing softwoods in plantations while there was a plentiful supply of hardwood timber from native forests. While there is a growing trend to privatisation and private ownership (Wood *et al.* 2001), the plantations, on the whole, have been publicly owned and established on crown land. In Queensland a large estate of tropical exotic conifers (*Pinus* species) and smaller areas of the native *Araucaria cunninghamii* (hoop pine) have been established under this approach. More recently, establishment of hardwood plantations and plantations of rainforest and other high-value species has gained momentum following the cessation of logging in rainforest areas throughout Queensland. Importantly, private interests have, to some extent, driven this development on privately owned land.

Historically, foresters tried a wide range of species in plantations in north Queensland (Anon. 1983), and there has been some analysis and integration of the results of this experience from older (Cameron and Jermyn 1991, Russell *et al.* 1993) and more recent plantings (Applegate and Bragg 1989, Keenan *et al.* 1995, Keenan 1998, Keenan and Annandale 1999, Annandale and Keenan 2000). However, there has not been a planned, well-coordinated and replicated set of trials as is required to match species to site (e.g. see Butterfield 1995, Butterfield 1996, Harwood *et al.* 1997a, Lee *et al.* 2001) for Australian tropical rainforest timber species grown in plantations. A number of surveys have predicted growth rate using expert opinions (Russell *et al.* 1993, Herbohn *et al.* 1999, Herbohn *et al.* 2000) but growth rates and site suitability are not well known for many of these species.

The considerable area of plantations established under the CRRP (1780 ha, Skelton and Sexton pers. comm.) provides an opportunity to investigate the performance of species across a wide range of sites. Preliminary descriptions of growth in CRRP plantations across regions highlight promising species (Keenan and Annandale 1999), and have alluded to relationships between climatic and edaphic factors and early growth rates of rainforest species (Bristow 1996, Merkel 1996, Keenan and

Annandale 1999). However, growth is not uniform over time and there is considerable risk in basing species selection on growth performance during the plantation's establishment phase, where trees are experiencing relatively free-growing conditions (Evans 1992, Haggar and Ewel 1995). This study uses a dataset extended from McNamara (2003) to assess performance across more site types, for eight year old trees. At this age, the faster-growing, early successional species will have concluded their accelerated juvenile growth phase. Indeed by age eight, many species planted in the CRRP will have captured the site and growth rates of individual trees may well be slower than in the first three to five years. At age eight years, growth patterns are affected by between-tree competition and species are beginning to differentiate into crown classes. By using these measurements we are likely to more accurately predict annual growth increments for mature trees.

Knowledge about the influences of genetics, altitude, soil, climate and competition on the growth of a species is crucial for a successful plantation program. For most Queensland rainforest timber species the legacy of 100 years of timber harvesting provided knowledge of timber properties, but very little was known about the silvicultural requirements of these species before the CRRP plantations were established (Lamb and Borschmann 1998, Bristow *et al.* 2000). The CRRP nevertheless provides a range of sites and species to begin considering climatic and edaphic influences on species performance across the landscape. Plantations were established between Mackay and Cooktown, along the coastal lowlands and foothills, and on the tropical upland areas of Atherton and Ravenshoe (see Figure 1).

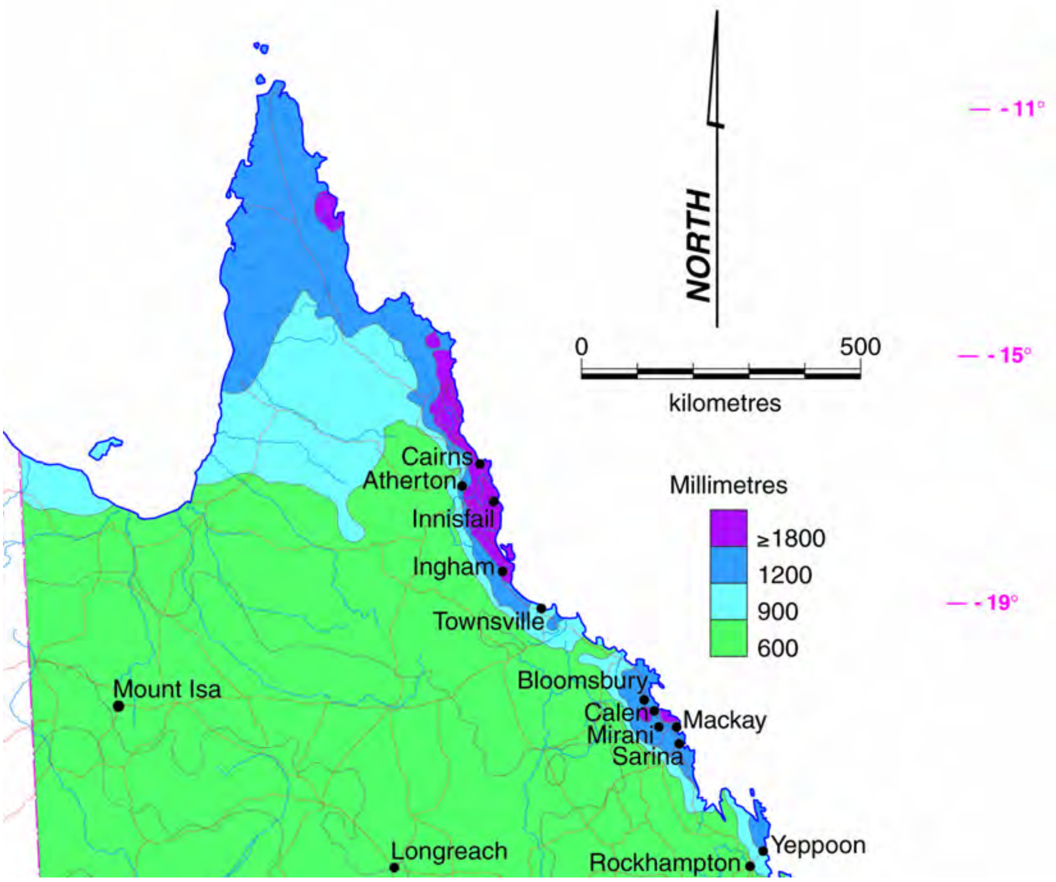

Figure 1 Higher rainfall regions of the humid tropics where rainforest timber species are grown in plantations.

Sites ranged in altitude from 10 m to 1160 m.a.s.l., mean annual temperature varied from 19 to 26°C, and mean annual precipitation from 800 to 4300 mm (Table 1). Soils in this region are derived from basaltic, granitic and metamorphic parent materials of a range of ages (Isbell and Edwards 1988, Murtha and Smith 1994). Previous land use on these sites varied considerably. Many CRRP plantations were located on agriculturally marginal land or subdivided farmland and hobby farms. In some cases, trees were planted as windbreaks and in wide-spaced plots with the intention of grazing cattle under the trees. Further variability is introduced to CRRP plantations through the use of a wide range of species and species mixes, provenances and seedling sources, and variable stocking rates and silvicultural inputs.

Table 1 Locations and climatic ranges of sites sampled from the CRRP.

Parameter	Minimum	Maximum
Latitude	15° 26’	18° 51’
Longitude (East)	146° 13’	145° 02’
Altitude	10 m	1160 m
Mean annual temperature	19° C	26° C
Maximum annual temperature of the warmest week	28° C	33° C
Minimum annual temperature of the coldest week	8° C	15° C
Annual precipitation	800 mm	4300 mm
Precipitation in the wettest week	39 mm	169 mm
Precipitation in the driest week	0 mm	20 mm

Source: ANUCLIM (Houlder et al. 2000).

A study commenced by Queensland Department of Primary Industries and Fisheries’ Agency for Food and Fibre Sciences (DPI&F-AFFS) Forestry Research (formerly QFRI) and Rainforest CRC established a series of permanent sample plots to measure growth of trees across a range of sites in CRRP plantations across the region. The growth and performance of species in CRRP plantation plots is reviewed in this paper.

Objectives

Species performance in this study is a simple combination of growth rate and form whereby faster growth is equated with better performance. If growing these species is to become a commercial reality, it will be necessary to develop cost-effective, quality timber plantations. By summarising performance of species, this study aims to identify a range of preferred species for soil and rainfall classes. The effect of site characteristics on growth can be considered using correlation coefficients (Nichols *et al.* 1997, McNamara 2003). This technique was used as a cost-effective method of matching species to site. In short, the objectives of this study are to: summarise growth of species by soil and rainfall classes; and investigate the degree of variability in growth rates of individual species across different sites with respect to environmental variables derived from ANUCLIM (Houlder *et al.* 2000).

Methods

CRRP Silviculture

Most CRRP plantations are mixed species stands consisting of eucalypts or rapidly growing rainforest pioneer species, together with early or late successional rainforest species and historically well-recognised ‘rainforest timbers’, e.g. cabinet timbers (Keenan and Annandale 1999).

In earlier plantings (those established 1992–1994), species were mixed along rows whereas after 1995 the general configuration was a row of a single pioneer species alternating with a row of mixed later-successional rainforest species. A few plantations consisted of single species, mainly eucalypts or mixtures of eucalypt species, or *Araucaria cunninghamii* monoculture stands. As a result of this variable silviculture, tree stocking at the time of measurement plot establishment also varied, where some plots had trees growing at 1100 stems/ha and others had relatively sparse stocking rates of 470 stems/ha. A list of species commonly planted is shown in Table 2, however not all taxa were planted in each site.

The methodology for plantation and measure plot establishment is described thoroughly in Keenan and Annandale (1999).

Increment plots and measurement

112 permanent measure plots were established on a range of sites planted between 1992 and 1997. Sites were selected to represent the range of plantation conditions, soil and rainfall gradients across the region, described further in Keenan and Annandale (1999). Plots were positioned within block plantations and edge trees were avoided. When established, each plot aimed to include 60 trees typically in 6 rows x 10 tree configuration, but occasionally in 4 rows x 15 trees or 3 rows x 20 trees. Tree measurements consisted of diameter of the stem at breast height over bark (DBHOB (cm)); total height (m); and a qualitative assessment of stem form classified into one of five categories: 1- very poor (extensive branching, very twisted and bent bole), 2- poor (significant branching, some twisting or bends in the bole), 3- average (mostly straight with some branching/forks), 4- good (straight bole with few branching/forks), 5- excellent (straight bole with no forking or bending). Individual trees were measured in 1998, 1999, 2000, 2001(incomplete) and 2002, although this study only summarises the most recent interval.

Estimates of growth rates were calculated using a linear regression growth model to standardise age to eight years, either interpolated or extrapolated to take account of the variation in planting years across the dataset. Average growth estimates from sites were then summarised into nine soil and rainfall classes, which on the whole, reflect naturally occurring, distinct site types that forest growers can easily recognise. Specifically, sites were separated by soil parent material; basalt, metamorphic, alluvial or granite, and three rainfall classifications; less than 1500 mm per annum, 1500 to 2500 mm per annum, and greater than 2500 mm per annum. To account for natural variation in individual tree growth rates, species that were poorly represented, or those with fewer than ten individuals in a soil and rainfall class, were excluded from the performance to site summaries.

Pearson correlation coefficients were used to describe the strength and direction of the relationships between the growth of species across all the sites and the mean annual rainfall, mean annual temperature and soil nutrient supply (Mackey 1993). As multiple environmental factors were tested, a Bonferroni correction was used to adjust significance levels.

Table 2 Species commonly planted in the CRRP.

Species	Common Name
Acacia mangium	sally wattle
Agathis robusta	kauri pine
Alphitonia petrei	pink ash
Araucaria cunninghamii	hoop pine
Blepharocarya involucrigera	rose butternut
Cardwellia sublimis	northern silky oak
Castanospermum australe	black bean
Cedrela odorata	West Indian cedar
Corymbia citriodora	lemon-scented gum
Corymbia torelliana	cadaghi
Elaeocarpus grandis	silver quandong
Eucalyptus acmeniodes	white mahogany
Eucalyptus camaldulensis	river red gum
Eucalyptus cloeziana	Gympie messmate
Eucalyptus drepanophylla	grey ironbark
Eucalyptus dunnii	Dunn’s white gum
Eucalyptus pellita	red mahogany
Eucalyptus resinifera	red mahogany
Eucalyptus tereticornis	forest red gum
Eucalyptus tetradonta	Darwin stringybark
Eucalyptus urophylla	Timor white gum
Flindersia brayleyana	Queensland maple
Flindersia pimenteliana	maple silkwood
Flindersia schottiana	Queensland silver ash
Grevillea robusta	southern silky oak
Khaya spp.	African mahogany
Melia azedarach	white cedar
Nauclea orientalis	Leichhardt/ cheesewood
Paraserianthes toona	Mackay cedar / red siris
Tectona grandis	teak
Terminalia sericocarpa	damson

Results

Survival

Survival in the growth plots was highly variable. Average tree survival across sites from planting to eight years old was 61%, but ranged from 5% to 100% (19% st. dev). The variations in original planting density and survival have contributed to inconsistent growth conditions between trees, species, sites and regions.

Diameter, height and form growth all sites

Table 3 shows species performance estimated at age eight years and ranked by mean diameter over bark (DBHOB) (where *n*>10 in each defined soil and rainfall class) for 32 of the most commonly planted taxa. Growth estimates of DBHOB, mean height and mean form across all soil and rainfall classes are shown in this table. The total numbers of individual trees (*n*) and sites used in this calculation varied and species that occurred in limited plantings are marked.

The ten fastest growing species (based on diameter) include five eucalypts and five rainforest taxa. The fastest growth was recorded for the Indonesian/Timorese eucalypt *Eucalyptus urophylla*, although this species was planted on only one site type represented by a small number of trees (n = 11). As expected, the fastest growing rainforest timber species were generally the early pioneer species such as *Acacia mangium* (ranked 2), *Elaeocarpus grandis* (ranked 8) and *Alphitonia petrei* (ranked 12). Well-known for their cabinet timber properties from native forests, the mid successional species *Grevillea robusta*, *Melia azedarach* and *Flindersia brayleyana* also showed rapid growth ranked 6, 7 and 14 respectively. Similarly, the native conifers, *A. cunninghamii* and *Agathis robusta* had consistently moderate growth and good form across sites. However, other mid to late successional species featured amongst the slowest growing species and included *Castanospermum australe* (ranked 31) and *Flindersia pimenteliana* (ranked 32). Other than *E. urophylla*, there were four exotic cabinet timber species, *Cedrela odorata*, *Khaya nyasica*, *Tectona grandis* and *Khaya senegalensis*, with overall diameter growth ranked 15, 24, 28, and 30 respectively.

The poorest average form was that of the slow-growing *Paraserianthes toona* (average form score 2.7) closely followed by the fast growing *A. mangium* (3.0). Damage by insect pests (such as borers) and pathogens were regularly recorded and at least partially responsible for poor form in these species. The eucalypts exhibited good to excellent form, apart from the two *Corymbia* species and *E. drepanophylla*. These eucalypts have broad natural distributions (Boland *et al.* 1992, Brooker and Kleinig 1994), that have recently been separated into a number of different taxa with noted differences in form across provenances (Nikles *et al.* 2000, Lee *et al.* 2001). It is probable that across different nurseries, planting regions and planting years, different provenances were used. However, it is not possible to test inter-provenance differences in this study.

Preliminary species to site matching

Table 4 demonstrates preliminary species to site matching where sites were grouped into nine broad soil and rainfall classes. Mean annual DBHOB increment was classified as either fast (> 2.0 cm per year), moderate (1.0 to 2.0 cm per year) or slow (< 1.0 cm per year). Growth rate is ranked in descending order both within and between these categories.

Some species were represented by relatively few individuals, growing on only a few, or even one site (e.g. all *E. urophylla* trees are on one site). Consequently comparison between species is confounded by number of individuals, number of sites and variability across sites. Table 4 therefore only provides a general guide to species which have potentially compatible growth rates at a particular site. Thus, to establish a plantation at a site with alluvial soils receiving more than 2500 mm annual rainfall, a potentially compatible combination of moderately growing species would be *Eucalyptus pellita*, *Flindersia brayleyana* and *Araucaria cunninghamii.*

Table 3 Mean of estimated growth rates, form and numbers of individuals (*n*) represented for all species across all site types ranked by mean diameter (where *n*>10 in each soil and rainfall class) generalized to age 8 years. Species with an asterix (*) occur in limited plantings, on few site types (this is not necessarily the same as a low *n*), results for which should be interpreted with care.

Rank	Species	Mean DBHOB (cm)	Mean Ht (m)	Form	n
1	*Eucalyptus urophylla**	26.9	21.6	4.3	11
2	*Acacia mangium*	26.0	15.7	3.0	93
3	*Eucalyptus dunnii**	19.9	16.8	4.5	21
4	*Eucalyptus resinifera*	18.5	13.7	3.5	71
5	*Eucalyptus pellita*	17.8	14.6	4.0	565
6	*Grevillea robusta*	17.7	12.0	3.8	46
7	*Melia azedarach*	17.7	13.2	3.2	25
8	*Elaeocarpus grandis*	17.6	13.0	4.2	248
9	*Nauclea orientalis*	17.0	9.8	4.1	38
10	*Eucalyptus cloeziana*	16.9	15.3	3.9	409
11	*Eucalyptus camaldulensis*	15.6	14.0	3.5	135
12	*Alphitonia petrei*	15.0	9.9	3.4	27
13	*Eucalyptus acmeniodes**	15.0	10.0	3.2	46
14	*Flindersia brayleyana*	14.7	12.1	4.0	393
15	*Cedrela odorata*	14.2	9.2	3.2	57
16	*Eucalyptus tereticornis*	13.9	12.3	3.5	194
17	*Eucalyptus drepanophylla*	13.3	12.5	3.7	58
18	*Araucaria cunninghamii*	12.5	8.3	4.2	307
19	*Cardwellia sublimis*	12.5	9.6	3.8	13
20	*Terminalia sericocarpa*	12.1	8.8	3.6	53
21	*Corymbia torelliana**	11.8	8.3	3.3	78
22	*Corymbia citriodora**	11.3	12.8	3.7	57
23	*Eucalyptus tetradonta*	10.8	8.5	3.9	20
24	*Khaya nyasica*	10.6	9.2	4.1	48
25	*Blepharocarya involucrigera*	10.6	7.0	3.3	31
26	*Agathis robusta*	9.2	6.6	4.1	291
27	*Flindersia schottiana*	9.2	7.4	3.7	74
28	*Tectona grandis**	9.1	7.8	4.3	10
29	*Paraserianthes toona**	8.1	5.9	2.7	80
30	*Khaya senegalensis**	7.8	5.3	3.5	55
31	*Castanospermum australe**	7.6	7.4	3.5	134
32	*Flindersia pimenteliana**	7.5	7.0	3.5	21

Table 4 Species to region matching: species are ranked in descending order of performance of DBHOB increment both within and between these classes of soil and rainfall. The number of trees used to calculate this value is shown in brackets. Cells that are blank show where no growth measure plots were established, or where n<10, or where no CRRP plantations occur.

Soil type	Diameter growth rate	< 1500mm	1500 – 2500mm	> 2500mm
Basalt	Fast >2.0 cm yr^{-1}		E. dunnii [21] Ela. grandis [77] E. pellita [123] E. cloeziana [85]	E. urophylla [11] Ela. grandis [21] E. pellita [186] E. cloeziana [35]
	Moderate 1.0-2.0 cm yr^{-1}	E. cloeziana [99] E. resinifera [15] E. drepanophylla [45]	A. petrei [17] T. sericocarpa [12] A. cunninghamii [141] F. brayleyana [63] C. odorata [21] B. involucrigera [15] A. robusta [197]	C. odorata [11] F. brayleyana [77] A. cunninghamii [52] C. sublimis [10] A. robusta [38] C. australe [38]
	Slow <1.0 cm yr^{-1}		F. schottiana [32] C. australe [25]	
Metamorphic	Fast >2.0 cm yr^{-1}	E. pellita [49] E. cloeziana [16]	A. mangium [12] Ela. grandis [10] F. brayleyana [44] E. pellita [41] C. torelliana [10]	
	Moderate 1.0-2.0 cm yr^{-1}	F. brayleyana [50] K. nyasica [19] E. tereticornis [41] Ela. grandis [44]	C. odorata [12] F. schottiana [12] E. tereticornis [65] E. tetradonta[17] T. grandis [10]	
	Slow <1.0 cm yr^{-1}	C. torelliana [36] Aga. robusta [14]	K. nyasica [10] P. toona [16]	
Alluvial	Fast >2.0 cm yr^{-1}	G. robusta [25] E. camaldulensis [91] E. cloeziana [63]	A. mangium [70] Ela. grandis [51] E. resinifera [46] E. pellita [91] G. robusta [18] E. cloeziana [86] E. tereticornis [88] C. torelliana [30]	N. orientalis [11] Ela. grandis [29] E. cloeziana [17]

	Moderate 1.0-2.0 cm yr^{-1}	E. pellita [59] A. cunninghamii [30] E. acmeniodes [28] F. brayleyana [43] A. robusta [12]	F. brayleyana [87] N. orientalis [26] E. drepanophylla [10] E. camaldulensis [44] T. sericocarpa [31] A. robusta [19] B. involucrigera [10] C. citriodora [38] P. toona [27]	E. pellita [16] F. brayleyana [22] A. cunninghamii [17]
	Slow <1.0 cm yr^{-1}	K. senegalensis [54] C. australe [14]	C. australe [45]	
Granite	Moderate 1.0-2.0 cm yr^{-1}		Ela. grandis [13] F. schottiana [14] A. cunninghamii [60] P. toona [28]	

Environmental influences on growth

For species that were planted in sufficient numbers across several sites the CRRP provides an opportunity to investigate the influences of environmental factors on growth. Earlier studies have shown there is significant covariation of soil, rainfall classes and temperature across the study region (Bristow 1996, McNamara 2003). For example, high rainfall sites with alluvial soils are located on the coastal lowlands and experience warmer mean annual temperatures, while lower rainfall metamorphic sites are often found in upland areas and have cool mean annual temperatures. Significant relationships describing the amount of variation in diameter growth that can be attributed to mean annual rainfall, mean annual temperature, and soil nutrient supply are displayed in Table 5. Species with no significant correlations between growth and environmental factors are not shown.

Highly significant relationships with mean annual rainfall were found for five species: *Acacia mangium* ($r = -0.39$, $p < 0.001$), *Agathis robusta* ($r = 0.23$, $p < 0.001$), *Elaeocarpus grandis* ($r = 0.34$, $p < 0.001$), *Eucalyptus resinifera* ($r = 0.52$, $p < 0.001$), *Eucalyptus tereticornis* ($r = 0.27$, $p < 0.001$), with all but *A. mangium* showing increased growth with increased rainfall. The other environmental factors, soil nutrient supply and mean annual temperature, describe significant trends in the growth of nine and eleven species respectively.

Most significant relationships between diameter growth and temperature are positive, suggesting that these species grow better on sites with warmer mean annual temperatures. For *A. cunninghamii*, the variability in diameter growth is highly correlated with lower mean annual temperature ($r = -0.51$, $p<0.01$), with better growth on cooler sites. Interestingly, for several species the variation in growth has a negative relationship with the soil nutrient supply factor derived by Mackey (1993), suggesting these species grow faster on poorer sites. *G. robusta* has a highly significant negative correlation with nutrient supply ($r = -0.57$, $p< 0.001$). This is also the only species in Table 5 which has proteiod roots, a root type which are adapted to nutrient poor soils (Lamont 2003).

Comparisons with earlier studies

In their survey of performance of rainforest timber species in 1991, Cameron and Jermyn sourced growth rates from both long-term native rainforest species grown in manipulated natural stands (in Queensland) and some exotic species tested in early Australian and international plantation research. This review also highlighted species that warranted further attention and many of these were included in the CRRP.

Table 6 shows the range of annual diameter increments reported in Cameron and Jermyn (1991), compared with the mean DBHOB annual increment at all CRRP study sites, and the mean DBHOB increment of the best ten trees observed for some key rainforest species at age eight years in this study. Priority listings are those suggested by the authors (Cameron and Jermyn 1991). The mean growth rates of species fell within the range reported by Cameron and Jermyn (1991), however the ten best trees of local species in CRRP have growth rates up to twice those reported by Cameron and Jermyn (1991).

Discussion

Four eucalypts (*E. pellita*, *E. cloeziana*, *E. tereticornis* and *E. camaldulensis*) and five rainforest cabinet timber species (*F. brayleyana*, *A. cunninghamii*, *A. robusta*, *Elaeocarpus grandis* and *C. australe*) were widely planted within the CRRP and the number of individuals in the growth plots (Table 3) are broadly indicative of the relative importance, or popularity, of these species in the CRRP plantations. For these species there is reasonable confidence in the reliability of the figures presented. For species represented by a low number or only recorded in one or two regions, growth figures must be interpreted with caution as these data are estimates of growth despite varied silvicultural and genetic inputs.

Many species have performed well across a range of sites. In the early years of the CRRP, the selection of species for planting and their matching to sites were often determined by factors such as availability of seedlings (see Lott *et al.* Chapter 3). After the Program became better established and managers gained more experience, site selection criteria were introduced, and plantation establishment reportedly became more successful (Creighton and Sexton 1996a, Vize and Creighton 2001). However, the measure of ‘success’ in these earlier reports does not necessarily relate to survival rates. The average survival of trees in growth plots at age eight years (61%) was significantly less than the 85% described by Vize and Creighton (2001) and did not change significantly between establishment years (data not shown).

The widely planted *E. pellita* and *E. cloeziana* consistently grew well across most sites in the CRRP and in a range of rainfall classes and soil types (Tables 3 and 4), thus reflecting these species’ wide natural distributions (Boland *et al.* 1992, Brooker and Kleinig 1994). While earlier studies (Dickinson and Sun 1995, Semple *et al.* 1999) have recommended *E. pellita* for more fertile soils (basalt and alluvial), and *E. cloeziana* for poorer soils, these distinctions were not observed in this study. This could be due to the précis inherent in the factor ‘soil nutrient supply’ derived by Mackay (1993).

Otherwise, as other studies have shown, the variation in growth of these species could be correlated with genetic or provenance differences (Harwood *et al.* 1997a, Harwood *et al.* 1997b, Semple *et al.* 1999, Nikles *et al.* 2000, Lee *et al.* 2001).

Even though not planted across many sites, *E. dunnii* and *E. urophylla* were the fastest growing species on basalt soils in the medium and high rainfall classes, respectively (Table 4). These species have been included in tree improvement and preliminary wood properties studies and, as has been suggested elsewhere, they may warrant further study on other sites (Dickinson *et al.* 2000, Nikles *et al.* 2000, Muneri *et al.* in review). *Corymbia torelliana*, a eucalypt that grows naturally on metamorphic soils with higher rainfall on the margins of rainforests (Boland *et al.* 1992), displayed similar growth rates in comparable CRRP plots (Table 4).

Table 5 Pearson correlation coefficients for environmental variables and DBHOB of at age eight years for key species. How much of the variation in growth is governed by a factor, is summarised for a number of species using correlation coefficients. The closer the coefficient value is to 1.0, the more the variation in diameter growth is related to that variable. Positive or negative correlations are shown and significance levels are shown by asterix markings.

Species	Mean Annual rainfall	Mean annual temperature	Soil nutrient supply
Acacia mangium	-0.39 ***		-0.29 *
Agathis robusta	0.23 ***	0.31 ***	0.20 **
Araucaria cunninghamii		-0.51 **	0.53 **
Castanospermum australe		0.39 ***	
Cedrela odorata		0.31 *	
Elaeocarpus grandis	0.34 ***	0.26 ***	0.30 ***
Eucalyptus cloeziana		0.26 ***	0.26 ***
Eucalyptus pellita		0.14 *	-0.13*
Eucalyptus resinifera	0.52 ***	0.41 ***	
Eucalyptus tereticornis	0.27 ***	0.47 ***	0.59 ***
Flindersia brayleyana		0.34 ***	
Flindersia schottiana		0.34 **	-0.29 *
Grevillea robusta			-0.57 ***

*Significance adjusted for Bonferroni = *p<0.05, **p<0.01, ***p<0.001*

Table 6 Comparison of performance results from this study and Cameron and Jermyn (1991) for annual diameter increment (cm yr^{-1}) of rainforest timber species in plantations.

Species	Cameron and Jermyn (1991)*	This study age 8 years: Mean of all sites	This study age 8 years: Mean of 10 best trees
Priority 1 Species*			
Castanospermum australe	1.0	0.9	2.1
Cedrela odorata	1.3 – 3.9	1.8	3.1
Elaeocarpus grandis	1.2 – 3.0	2.2	4.2
Flindersia brayleyana	0.6 – 1.7	1.8	3.4
Grevillea robusta	0.7 - 3.0	2.2	3.0
Tectona grandis	1.2 – >3.0	1.1	1.1
Priority 2 Species*			
Flindersia pimenteliana	0.6	0.9	1.2
Flindersia schottiana	0.8 - 1.2	1.1	2.4
Khaya nyasica	1.3 – 1.9	1.3	2.2

**Cameron and Jermyn (1991) growth figures were sourced from literature (both domestic and international) and data extracted from Queensland databases (priority levels suggested by Cameron and Jermyn).*

As expected, eucalypts had the fastest growth on the drier sites (e.g. *E. cloeziana* and *E. resinifera* on basalt soils, *E. pellita* and *E. cloeziana* on metamorphic soils, *E. camaldulensis* and *E. cloeziana* on alluvial soils). Also, the cabinet timber species *G. robusta* was the fastest growing species on alluvial soils with rainfall less than 1500 mm/annum (Table 4). Smaller numbers of some eucalypts that were planted on particular sites, achieved moderate to fast growth rates, i.e. *E. camaldulensis* (low rainfall alluvial soils, northern Atherton Tablelands region), *E. drepanophylla* (low rainfall basalt soils, southern Atherton Tablelands, and medium rainfall alluvial soils Ingham region), *E. tetradonta* (medium rainfall metamorphic soils, Cooktown region) and *E. acmeniodes* (lower rainfall alluvial soils, Ingham region). As a result of their site-specific plantings we are unable to compare these species across sites.

The native softwoods *A. cunninghamii* and *Agathis robusta* were widely planted across site classes and showed, as expected, moderate to slow growth. *A. cunninghamii* has been considered somewhat a generalist in its natural distribution, extending from northern New South Wales in scattered forest patches along the entire coast of Queensland, and into the uplands of Papua New Guinea (Webb and Tracey 1967, Boland *et al.* 1992). *A. cunninghamii* was originally prized as a plantation species for its tolerance of a wide range of environmental conditions including drought (Webb and Tracey 1967, Holzworth 1980). Even though its natural distribution covers a broad rainfall gradient, previous studies of *A. cunninghamii* indicate that low rainfall may be a major factor causing low site indices when this species is grown in plantations (Holzworth 1980). In this study rainfall may have been a less important factor as all sites where *A. cunninghamii* was planted received >1200 mm annual rainfall and the only significant correlations were between diameter growth of *A. cunninghamii* and temperature and soil nutrient supply. This suggests that *A. cunninghamii* prefers cooler, more fertile sites such as the uplands where it is most commonly planted. *A. robusta* is not as well researched as *A. cunninghamii*, but has recognized growth and timber properties that justified its inclusion in the CRRP. *A. robusta* does not occur naturally higher than 900 m elevation (Boland *et al.* 1992), which may explain why its growth was positively correlated with warmer sites.

Among the cabinet timber rainforest species *Elaeocarpus grandis* showed reliably good performance on the higher rainfall sites, with greater diameter growth than *E. pellita* and *E. cloeziana* wherever it was planted. This is consistent with earlier studies which included this species (Cameron and Jermyn 1991, Bristow 1996, Keenan 1998, Ibell *et al.* 2001, McNamara 2003, Bristow *et al.* 2005).

Another successful species of the CRRP is *F. brayleyana*. On some sites, metamorphic soils in particular, *F. brayleyana* displayed good growth rates and form when compared with the more traditionally planted eucalypts. The mean diameter increment across all sites for this species is greater than that reported by Cameron and Jermyn (1991); the mean of the best ten trees across all sites is twice as large as earlier reports (Table 6). Furthermore the growth of *F. brayleyana* is positively correlated with temperature, with better growth at warmer mean annual temperatures, and we can therefore recommend it for humid tropical, coastal lowlands sites (Keenan *et al.* 1995, Keenan 1998, Keenan and Annandale 1999, Bristow *et al.* 2003, Bristow *et al.* 2005).

Other studies have noted that *F. brayleyana* was very site specific, requiring sites within the higher rainfall areas (Creighton and Sexton 1996b, Brown 2001), that are fertile and well drained (Creighton and Sexton 1996b). However this study did not find any relationship between this species and rainfall or nutrient supply.

In comparison, *F. schottiana* and *F. pimenteliana* are slower growing. *F. schottiana* had generally slow growth (rank 27, Table 3), but grew moderately fast on the metamorphic and granite derived soils (Table 5). There is a significant correlation between the variability in diameter growth and increasing temperature and decreasing nutrient supply, which might be expected: It is these sites where it has been more commonly planted, such as the poorer soils of the coastal lowlands around the Mackay (central Queensland) region. Like other species in this genus *F. pimenteliana* was included in the CRRP for its beautiful, highly prized cabinet timber. It was the slowest growing of all the 32 species examined and was not planted widely enough to be used in further species to site analysis (n = 21). However the growth of the ten best of these trees across all sites is twice as fast as expected by Cameron and Jermyn (1991) (see Table 6), and deserves further attention.

Table 4 suggests that *C. australe* showed consistently slow growth across sites. This species was widely planted in the CRRP and some of the variation in growth rates across sites is related to temperature (Table 5); at warmer temperatures this species grows faster. This is consistent with the photosynthetic characteristics of *C. australe* – the optimum temperature for photosynthesis has been determined be between 23.7 ºC and 25.6 ºC (Swanborough *et al.* 1998). Warmer temperatures are experienced more often on the coastal lowland areas, where the mean diameter increment of the top ten trees of *C. australe* was relatively fast (Table 6).

For young trees competition with weeds and grasses, especially *Brachiaria decumbens*, which has been established in many improved pastures, appears to be particularly strong. In plantations that are well maintained grasses and weeds are removed from around the young trees to reduce competition. Slower growing species like *C. australe* require weed control for longer than faster growing species.

Small numbers of some rainforest species were only planted on one or two soil types, and it is not possible to compare their performance across sites in this study. More sites are needed to determine whether these species perform differently in other conditions, that is, whether they may be regarded as specialist site species. On basalt soils with medium rainfall, *A. petrei*, *Terminalia sericocarpa* and *Blepharocarya involucrigera* grew moderately fast, as did *Cardwellia sublimis* on high rainfall basalt soils. On some lower rainfall, poorer soil sites around the Mackay region, *Melia azedarach* and *G. robusta* performed very well, although the form of *M. azedarach* is not satisfactory. Corresponding well with its natural habitat, the riparian-zone early pioneer rainforest tree *Nauclea orientalis* is well suited to plantations on very high rainfall alluvial coastal sites (Table 4). *Paraserianthes toona* was included in the CRRP for its beautiful cedar-like timber and its tall, straight form when grown in native forest from Cooktown to Mackay. In CRRP growth plots it was one of the worst performing species with slow growth rates and poor form (resulting at least partially from insect attack) across all sites. Rather than excluding this species from plantations, it may be that *P. toona* may not be suited to this style of plantation; it could benefit from nurse crops or perhaps there are mycorrhizal associations that are unknown for this species.

Previous studies have recommended a number of exotic rainforest timber trees for investigation in tropical Australia (Cameron and Jermyn 1991, Russell *et al.* 1993, Herbohn *et al.* 1999). Four exotics species were measured in this study, three from the Meliaceae family (*Cedrela odorata*, *Khaya nyasica*, *K. senegalensis*) and *Tectona grandis*. They were planted in low numbers and on few sites. Compared with the native species, none had “fast” growth rates (Table 4). Excluding *K. senegalensis* (not discussed in Cameron and Jermyn (1991)), they grew within previous expectations (Table 6) and similar to other studies in this region (Keenan 1998, Annandale and Keenan 2000).

Conclusions

The choice of plantation species is dependent on a range of factors including timber markets, management costs, site factors, land availability and species attributes such as seed availability, propagation costs, growth rates and timber properties. To support a processing plant or export business, plantation growers need to have large estates or a critical mass of timber in a region is required. To achieve this, tree species that perform relatively well across a wide range of sites are preferred. In this study, species that grew consistently across sites include *E. pellita*, *E. cloeziana*, *Elaeocarpus grandis*, *A. cunninghamii*, and *C. australe*. Where there are ‘niche markets’ or diverse demands for timber and other values (e.g. habitat or site protection), particular species may be preferred. Site specialists are more difficult to define at only eight years of age, but results from this study indicate that *F. brayleyana*, *F. schottiana*, *G. robusta*, *A. mangium* and potentially some of the exotic species can grow well at particular sites.

After four remeasures of growth plots on these sites, observations by various researchers confirm that only the better maintained CRRP sites have the potential to produce timber, and the usefulness and viability of poorly maintained sites is questionable (Bristow 1996, Keenan and Annandale 1999, McNamara 2003).

Notwithstanding the variable nature of this dataset, it is useful to ascertain trends in species performance across sites. Results should ideally be confirmed with a further set of replicated trials. Continued measurement and maintenance of these increment plots would allow further investigations of silviculture of mixed rainforest timber species plantings. Permanent growth plots may, in time, provide opportunities to forecast harvests, and plan sustained flow of timber (and other products) into the market place (Vanclay *et al.* 1995).

Acknowledgements

Growth plots were established with financial support from the Queensland Department of Primary Industries and the Joint Venture Agroforestry Program (RIRDC Project No. DAQ-240), in collaboration with the Rainforest CRC and University of Queensland. We thank CRRP landholders for repeated access to sites. Drs Rod Keenan and David Lamb contributed to experimental design. Thanks are also due to the various DPI staff and volunteers who have assisted with tree measures. Drs Mark Hunt and Susan House are gratefully acknowledged for their comments on earlier versions of this manuscript.

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7. Growth performance and review of wood quality concerns for rainforest timber species in subtropical eastern Australia

Kevin Glencross and J. Doland Nichols

Abstract

The early growth performance of rainforest trees in plantations in northern New South Wales was assessed and a brief review of wood quality concerns for these species was undertaken. Plantations assessed contain a mixture of more than twenty species from 5-9 years of age, across 14 sites. Nine species with some history of high value commercial timber utilisation have been included in the growth analysis. The performance of 1265 trees has been assessed with regard to survival, tree height, stem diameter, canopy diameter and stem form. Among the more successful species are Elaeocarpus grandis *(2.0 m/yr- mean annual height increase),* Flindersia brayleyana *(1.7 m/yr),* Grevillea robusta *(1.5 m/yr) and* Flindersia schottiana *(1.4m/yr). Preliminary wood quality assessments of rainforest species grown in plantations are reviewed and considerations for quality wood production from these plantations are discussed*.

Introduction

Australian rainforests are broadly grouped into temperate, subtropical, dry or tropical forests. The subtropical rainforests occur in patches along the coast of eastern Australia from New South Wales (NSW) to the uplands of far north Queensland (Lat 36^{o} S to Lat 17^{0}) (Floyd 1989). Rainforests that originally grew in the area of this study were characterised by trees with plank buttressing, compound leaves, and dense canopies often covered with epiphytes and woody vines (Baur 1986). Subtropical rainforests often grow on kraznosem soils (Oxisols in USDA system) (Grunwald 2004) over weathered basalt, producing a deep friable soil of good fertility and drainage. The demand for these rich soils has resulted in clearing of large areas of subtropical rainforest for agriculture. In northern NSW and Queensland these rainforests contained some of the finest furniture timber species found anywhere in the world (Bootle 1983, Sewell 1997). Despite this high value, rainforest cabinet timber trees have been largely ignored as potential plantation species until recently (Russell *et al.*1993, Lamb 1998, Herbohn *et al.*1999).

The only native rainforest tree on which significant research efforts have been made to improve plantation performance, and which is planted on a commercial scale in Australia is *Araucaria cunninghamii* (Aiton ex D. Don), commonly known as hoop pine (Cameron and Jermyn 1991). *Grevillea robusta* (A.Cunn.) (southern silky oak) has a long history of planting in South Asia and east Africa for shade and fuel (Harwood and Booth 1992). The potential for production of high quality wood from this species is not clear, despite the rapid growth and good form (Harwood *et al.* 2002). However, Owino (1992) describes the wood from *G. robusta* grown in east Africa as having “notable drawbacks”, due to its low durability, attack by borers and low economic value.

Increasing community interest in rainforest regeneration and cabinet timber production over the last ten years has stimulated a number of plantings on cleared ex-rainforest land in eastern Australia. Data from young mixed species rainforest plantations across a range of sites in northern NSW has been collected over the last ten years (Specht 1998, Emtage and Specht 1998, Specht *et al*. 1999, Glencross and Nichols 2002). A number of studies have identified *Elaeocarpus grandis* (F. Muell.)

(silver quandong), as a plantation species worthy of investigation, especially in terms of form, volume and height growth (Cameron and Jermyn 1991, Russell *et al.*1993, Keenan 1996, Specht *et al.*1999). According to Borshmann and Lamb (1996) the speed at which this species grows, as well as the high value of the timber, may make it an excellent plantation candidate species on suitable sites.

Estimates of the potential economic performance of rainforest plantations have been made using surveys of experts (Russell *et al.* 1993, Herbohn and Harrison 2000) and computer modeling (Herbohn and Harrison 2000). The lack of data on the nature of the wood produced from rainforest plantations makes predictions of returns very difficult. Therefore, the potential for solid wood production from rainforest species grown in plantations is uncertain. Expense of establishment and management, and uncertainty about rotations lengths, wood quality, and markets create considerable risk for the potential grower of rainforest species (Herbohn *et al.* 1999).

The future prices paid for high value timbers are difficult to predict but prices in the global market may be driven up as wood availability declines (Keenan 1998). A study by Morell (2001) represented the views of a group of FAO staff on expected changes in world forestry over the period to 2050. The study concluded that solid wood will be at a "premium", especially rare, high quality hardwood. These high predicted prices are specific to wood grown in natural forests and harvested from mature trees. Predicted global increases in premium timber prices may not be realized for plantation-grown wood. Plantation-grown wood needs to be seen as a 'new' resource with unknown properties (Harris 1993). The suitability of these fast-grown plantation timbers for high value uses such as joinery remains unknown. Therefore, the growers of high value hardwoods in plantation need to remember that market prices depend on the quality of the wood produced.

The objectives of this paper are to provide forest growers with basic information on early growth performance of a number of key rainforest species in northern New South Wales and to review wood quality concerns for those species when they are grown in plantations.

Review of wood quality

Wood quality is a broad term encompassing the physical properties of wood such as density, strength, colour, stability, shrinkage, defects, durability and working properties. There is a great deal of variation in wood qualities between and within species and individual trees so characterizing properties is difficult. The young age of most recent plantings of rainforest species presents a significant challenge when trying to answer questions about future wood quality from a plantation-grown resource. Wood from young plantations can however, provide early indications of the potential wood qualities that may be of interest although it is well known that wood properties also vary over time as the tree matures (Bootle 1983).

The demands of the end users and the factors that affect market prices need to be considered at all levels of the wood production process. Wood properties that processors and end-users of rainforest timbers may consider important include uniformity, density, heartwood and juvenile wood, growth stresses, knots and defects and reaction wood. After cost, uniformity is the most important criterion for end-users (Hillis 1978). Uniformity is concerned with the similarity of wood properties throughout the product 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.

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 Australia produce some very dense hardwoods, such as *Flindersia australis* (945 kg/m^3), to comparatively light hardwoods (*Toona ciliata* 450kg/m^3) (Sewell 1997). Generally, high value processes such as joinery favour species with moderate density 450-600kg/m^3, where the wood is sufficiently strong, yet easy to work and not too heavy (Hillis 1978).

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).

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.

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 lead to the production of reaction wood, which creates higher internal stresses (Walker 1993). The formation of reaction wood can increase the shrinkage during drying and result in collapse (Bootle 1983).

Therefore an understanding of species growth rates and response to site conditions, together with appropriate stand management is important to produce timber of maximum uniformity and minimum defect. Market price and end use should also be taken into consideration when choosing species to plant, and how to manage them in plantation.

Wood properties from small samples of a number of rainforest species were investigated in the early part of the Community Rainforest Reforestation Program (CRRP) (Clause 1995). This research focussed on the recovery and utilisation of wood from species produced in plantations. Most of these plantations were 28 years or older although an eight year old *Elaeocarpus* stand was also included.

The grade of sawn boards was assessed using the Queensland Timber Industry Specification for appearance-graded Queensland hardwoods for furniture use. Better performing species included *Khaya*, *Swietenia*, and *Flindersia brayleyana* (Table 1) with recovery rates over 40% and greater than 80% of sawn boards in the highest grade (Grade 1). Wood from a 28 year old *Flindersia brayleyana* appeared to have a higher recovery rate than from an older (63 year old) stand.

The encouraging growth performance of *E. grandis* in mixed species rainforest plantations over the last ten years led to a preliminary study investigating the properties of young plantation-grown wood of this species (Ibell *et al.* 2001; Table 1). The wood properties of eight-year old *E. grandis* were compared with the properties of mature wood as outlined by Bootle (1983). The young wood was similar in a number of ways to the mature wood, being straw coloured, stable, and easy to work (see Bootle 1983, Sewell 1997). The density of young wood was close to that of mature wood, and mechanical properties closely resembled those of mature wood sourced from native forests (Ibell *et al*. 2001).

Results from these studies should be considered as preliminary groundwork only due to the small sample sizes (Table 1). More comprehensive analyses of wood from plantation-grown rainforest timbers are currently being undertaken by the authors, funded by the Joint Venture Agroforestry Program through Southern Cross University. The results will be reported at a later date.

Table 1 Wood properties and recovery rates of high value subtropical and tropical timber species (source: Clause 1995 and Ibell *et al*. 2001).

Standard Trade name	Botanical Name	Sample Size (logs)	Age (years)	Density (kg/m^3)	Tangential Shrinkage	Radial Shrinkage	Sawn Recovery (%)	Graded Recovery
African mahogany	*Khaya spp.#*	3	37	571	5.4	1.9	41	88% grade 1, 0% grade 2, 8% grade 3.
American mahogany	*Swietenia spp.#*	5	28	650	4.9	2.6	40	82% grade 1, 7% grade 2, 10% grade 3.
Gympie messmate	*Eucalyptus cloeziana#*	5	31-35	910	3.4	2.1	39	88% grade 1, 6% grade 2,
Red mahogany	*Eucalyptus resinifera#*	5	47	921	4.1	2.7	39	94% grade 1, 2% grade 2, 2% grade 3.
Silver quandong	*Elaeocarpus grandis#*	3	NS *	453	4.4	1.3	40	97% grade 1, - grade 2, 2% grade 3.
Silver quandong	*Elaeocarpus grandis***	3	8	427	3.4	2.5	-	Not graded
Queensland maple	*Flindersia brayleyana#*	6	28	-	-	-	-	88% grade 1, 3% grade 2, 5% grade 3.
Queensland maple	*Flindersia brayleyana#*	3	63	498	6.9	3.4	46	72% grade 1, 12% grade 2, 13% grade 3.

(NS- Natural stand in north Queensland - age not known)*
(# Source- Clause 1995)
*(** Source- Ibell et al. 2001)*

Methods – Growth in plantations

We analysed growth performance of nine rainforest species across 14 sites in subtropical northern New South Wales. The sites were in mixed-species plantings established between 1994 and 1996 (Table 2). The data collected for individual trees was both quantitative and qualitative. Measurement of height, diameter (over bark at breast height 130 cm), and canopy diameter was used to determine the growth performance in quantitative terms. The form of the tree was assessed qualitatively to score individual trees on stem straightness and degree of branching. The qualitative assessments of tree form were collected to help identify those species that are most suitable for plantation production.

The selection of the 14 study sites from a total of 19 was made on the basis of adequate replication of target species and suitability of the sites for establishment of rainforest species. Initial measurements were undertaken in October 1996 and December 1997, with a further round of measurement carried out in August and September 2000 (that is, the trees were 5-9 years of age). The growth of over 2000 individual trees at these sites has been followed since planting. From the larger data set, the growth of nine species that are well replicated (minimum of 100 individuals per species) was analysed in detail.

Table 2 Location, planting date and dominant soil type at the fourteen sites sampled in northern New South Wales.

site no.	name	date planted	Soil	Locality
1	Harvey jones	Mar-96	Krasnozem	Eureka
2	Dorey	Oct-96	Krasnozem	Bangalow
3	Truswell	Jan-96	Krasnozem	Federal
4	Kemsley	Nov-94	Krasnozem	Dorroughby
5	Andreason	May-97	Chocolate basalt	Nimbin
6	Lascelles	Oct-96	Krasnozem	Rosebank
7	Doric Order	Sep-96	Chocolate basalt	Billinudgel
8	Etheridge	1997	Krasnozem	Mullumbimby
9	Jervis	Oct-95	Krasnozem	Eureka
10	Mutimer	Apr-96	Krasnozem	Rosebank
11	Richmond	Feb-96	Krasnozem	Bangalow
12	Van Kleef	May-94	Chocolate basalt	Dorroughby
13	Dugeon Bros.	Nov-94	Krasnozem	Dorroughby
14	Griffiths	Apr-97	Chocolate basalt	Wiangaree

Sites

Most sites were located within or near to the original range of the Big Scrub subtropical rainforest, a 75,000 ha area of rainforest now almost entirely cleared and converted to pasture, horticulture or suburban blocks (Table 2).

There is a considerable variation between sites in terms of soil, aspect, climate and topography. These variables were not assessed and did not form part of the analysis. However, all selected sites have adequate mean rainfall (1300 mm+) and soil quality (basalt derived soils) for rainforest regeneration. Management interventions varied widely; pruning and thinning had not taken place so many trees that would be thinned under conventional plantation management were retained and have been measured.

'Measure' trees were located in either permanent plot transects 20m wide and 50m long or in clearly identified sub-populations within each plantation. The sampling strategy was designed to account for any environmental gradients that could influence growth across the site (e.g. changes in soil type, slope, aspect and management). Measurements undertaken on each 'measure' tree included: diameter of the stem at breast height over bark (DBHOB (cm)); total height (m); height to lowest live branch (free bole height); canopy diameter (m) in four compass directions. A qualitative assessment of stem form was also noted for each tree. Stem form was classified into one of three categories: 1- poor (crooked or multi-stemmed), 2- fair (slightly curved), 3- good (straight- very straight).

Analysis of growth was based on measurements from 1,265 individual trees across the nine species (Table 3). Each of the species was located on a minimum of 7 of the 14 sites, with a minimum of 100 individuals measured to ensure adequate replication between and within sites. Tree survival was recorded for each species and shown as a percentage of total individuals planted of each species (Table 4). Age differences between individual trees was standardised by calculating a mean annual increment in height (m/yr), canopy growth (m/yr) and diameter (DBHOB) (cm/yr) for each of the nine species.

Table 3 Number of each species measured, their representation at the several sites and the estimated current value of sawn dried timber.

Species	Code	Common Name	Total no. Individuals (n)	No. Sites	M^3 $ Value*
Araucaria cunninghamii	*Ac*	hoop pine	135	10	1500
Elaeocarpus grandis	*Eg*	silver quandong	151	11	1500
Flindersia australis	*Fa*	Crows ash / teak	135	11	2500
Flindersia brayleyana	*Fb*	Queensland maple	120	8	2100
Flindersia schottiana	*Fs*	silver ash / cudgerie	172	12	2100
Gmelina leichhardtii	*Gl*	white beech	104	8	2400
Grevillea robusta	*Gr*	southern silky oak	181	13	1800
Melia azedarach	*Ma*	white cedar	117	7	1800
Rhodosphaera rhodanthema	*Rr*	deep yellow wood	150	11	1500

** Aus $ Value – sawn dry boards, Select Grade (Herbohn et al. 1996, DPI 1998, SFFA 1999)*

Results – Growth in plantations

Survival

Table 4 shows that the species with the highest survival rates were *Flindersia brayleyana* (97.5%), *E. grandis* (94.7%) and *Flindersia schottiana* (93%). The species with the poorest survival was *Melia azedarach* (76%).

Table 4 Growth of nine rainforest species measured between 1996- 2000 at 5-9 years of age.

	Mean Annual Height Increment						
Sp. Code	Mean (m/yr)	St. Dev	Worst site	Best site	CV[#]	Canopy diameter increment (m/yr)	Survival %
Ac	0.97	0.52	0.24	1.51	.54	0.6	90
Eg	2.01	0.86	1.02	3.51	.43	1.3	95
Fa	0.6	0.31	0.52	0.71	.52	0.3	84
Fb	1.71	0.73	0.72	2.31	.43	0.7	98
Fs	1.41	0.76	0.44	2.09	.54	0.7	93
Gl	1.08	0.54	0.42	1.42	.50	0.7	90
Gr	1.55	0.64	0.91	2.26	.41	0.7	90
Ma	0.61	0.36	0.13	0.84	.59	0.5	76
Rr	1.08	0.49	0.41	1.65	.45	0.9	83

[#] *CV is coefficient of variation*

Mean Annual Height Increment (MAHI m/yr)

Mean tree heights and standard error at five years of age are presented in Figure 1. The mean annual height increment (calculated by dividing total height by the age at time of measurement) and standard deviation are shown in Table 4. *Elaeocarpus grandis* grew the fastest across all sites. *Flindersia australis* (crows ash) generally grew slowly, and early growth of this species does not seem to be affected by increases in site quality or improved management. The three fastest growing species

E. grandis, Flindersia brayleyana and *G. robusta* also show the lowest coefficient of variation (Table 4).

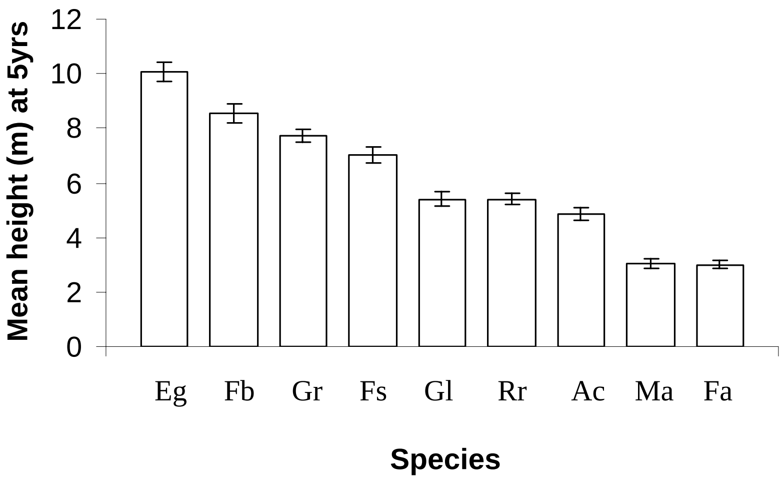

Figure 1 Height growth (m) with standard error at five years for nine rainforest species in north eastern NSW. The abbreviations used to identity each species are given in Table 3.

Canopy growth

The growth of the tree canopy will indicate those species that will be strong competitors for light and space. By monitoring canopy growth, farm foresters can estimate time taken to achieve site capture and potential interactions between species planted in mixtures. Mean annual canopy diameter increment was recorded, with the most rapid annual canopy growth being found in *E. grandis* (Table 4).

Mean Annual Diameter Increment (DBHOB cm/yr)

The annual increase in the mean DBHOB (cm/yr) for each species was calculated across all sites (Figure 2). *E. grandis* had the largest mean annual diameter increment. The poorest performing species in diameter at five years was *F. australis* which had grown at only 0.5 cm/yr. There was a change in the ranking of the species when comparing the annual diameter increment with the annual height increment. *F. brayleyana* was ranked second in height increment and third in the diameter increment, indicating a tendency to form taller thinner stems relative to the other species in the analysis.

Form

A qualitative assessment of tree form indicates stem straightness and degree of large low branching, both of which will influence timber production potential and wood quality. Individuals from each species have been classified into one of three classes; poor, fair or good (Figure 3). The species with the best form, across all sites, is *A. cunninghamii* while the species with the poorest form was *Melia azedarach*.

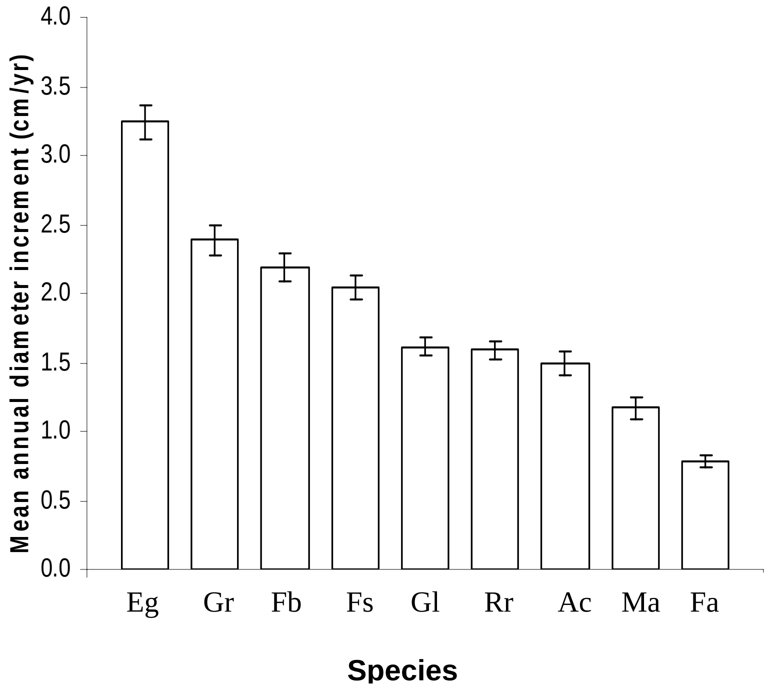

Figure 2 Mean annual diameter increment (cm/yr) at breast height over bark for all sites over five years. The abbreviations used to identity each species are given in Table 3.

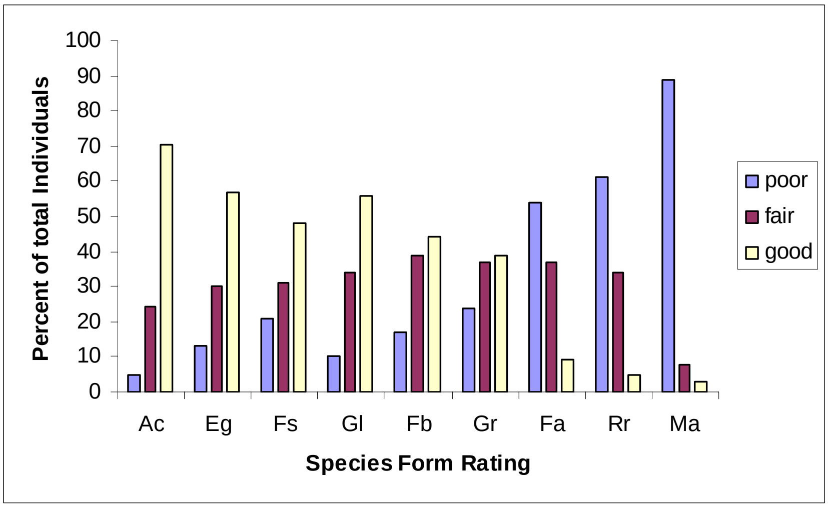

Figure 3 Form ratings for nine rainforest species in northeastern NSW, presented as the percentage of all individuals scored for that species. The abbreviations used to identity each species are given in Table 3.

Discussion

A major concern about any new plantation species is ascertaining its ability to survive and grow in the field. Rainforest species established in cleared pasture sites often endure harsh climatic conditions, degraded soils, competition with weeds and browsing by domestic and wild fauna. The period over which this growth assessment has been carried out included extreme drought seasons. Given the range of sites and climatic conditions, the excellent survival rates of some rainforest species at this early stage is encouraging for growers.

The growth data presented provides an indication of the species performance across a wide range of environmental conditions and management regimes. The variation between sites in this assessment provides a challenge in terms of data analysis. The plantations at the selected sites have been established as farm forestry plots rather than as managed experiments and there is a great deal of variation in terms of biophysical characteristics and management across sites. This provides an indication of the best and worst case scenarios for the nine species discussed. Some sites were of very high quality to begin with and a number of sites were extremely degraded. Management inputs have also been a very significant source of variability; some plantings have been managed extremely well and others totally neglected since establishment. The lack of adequate site description and inventory of management inputs reduces the inferences that can be drawn from this data set. However, the results are valuable for assessing and comparing species performance across such diverse conditions.

A number of high value rainforest timber species have performed well in terms of tree height and diameter growth in the young (less than eight years) mixed plantations sampled. The best performers were *Elaeocarpus grandis*, *Flindersia brayleyana*, *Grevillea robusta* and *Flindersia schottiana*. Annual height increment is a particularly valuable indicator of early plantation performance as it is less influenced by any variation in stocking density across the sites (West 2004). Therefore, height may be the best parameter to compare species performance across sites.

Previous estimates of growth for rainforest species appear very conservative, but some are based on older-age stands. Cameron and Jermyn (1991) reported Mean Annual Increment (MAI) of 3.4 m^3 ha^{-1} yr^{-1} and mean DBH of 29.3 cm at 24 years in *Elaeocarpus grandis* trials in the Atherton area of North Queensland. Another analysis of rainforest growth potential, made on the basis of a Delphi survey without the aid of hard data, estimated *E. grandis* average growth at 8.2 m^3 ha^{-1} yr^{-1}, *Grevillea robusta* at 8.33 m^3 ha^{-1} yr^{-1} and *Flindersia brayleyana* at 5.33 m^3 ha^{-1} yr^{-1} (Russell *et al* 1993).

Trials of rainforest species at Mt. Mee, near Brisbane (Borschmann and Lamb 1996, Lamb and Borschmann 1998), showed similar growth performance results to those found in this study in NSW. At six years of age *Elaeocarpus grandis* was performing very well, both in form and growth, with a mean DBH of 18.5 cm at six years (Borshmann and Lamb 1996). The mean diameter growth of the same species across all our sites in NSW was 3.2cm /yr at five years.

The growth performance of a given species in plantation is not the only important criterion when considering commercial potential. Timber production returns are affected by the quality of the wood and form of the stem as well as by growth rates. The ideal plantation species would have the ability to produce straight stems with few large lower branches without major management inputs. Of the species assessed *Elaeocarpus grandis* combines good growth with good form and stands out as a potentially successful plantation species on suitable sites. *Flindersia brayleyana* showed good early growth but has poorer form and is more prone to retaining heavy branches. The potential high value of the timber may compensate for the cost of measures taken to improve form, such as pruning. *Flindersia schottiana* has slower early growth, however the excellent straight stems, lack of heavy branching and high value of the timber may provide some commercial opportunity for growers.

Slower-growing species with high timber value and good form, especially *Gmelina leichhardtii*, may deserve further attention by growers who are considering longer rotation systems. The diameter growth of *Rhodosphaera rhodanthema* appears good, however, the form of these species is relatively poor. Therefore, *Rhodosphaera rhodanthema* will require significant management (pruning) to produce a straight stem free of major branching that has some value as a timber resource.

The slower growing species in this assessment, such as *Melia azedarach,* have been severely affected by pests. The annual defoliation, loss of growing tips and damage to bark to this species has reduced growth and may also be contributing to poor form. The poor overall performance of *Flindersia australis* in terms of form and growth would seem to limit its application in timber plantations in north-eastern NSW.

To ensure good early plantation growth it is important to achieve adequate canopy growth rates to capture the site. Early site capture provides important benefits in terms of improving microclimate for trees, and reduced competition from weed species. Selecting species with rapid canopy growth will assist in achieving early site capture and assist in designing efficient plantation designs. The radial canopy growth of *Elaeocarpus grandis* is rapid in the first five years. However, this rapid growth has created a situation on some densely planted sites where slow-growing trees in the mixtures are being suppressed by the faster growing species.

Many of the sites studied have been planted with moderate to high densities of stems, initially 1200-1600+stems/ha, and not thinned up to years 7-8. There may be some initial advantages to dense stocking initially for early site capture and genetic diversity (Kooyman 1996, Specht *et al*. 1999). However, when growers are developing timber production systems, the initial high costs of rainforest seedlings and the excessive competition between trees can seriously erode economic performance. If timber producers wish to ensure that growth is maintained well beyond canopy closure, thinning must be undertaken. It is easy to understand why thinning has been avoided, with significant difficulties in terms of selecting trees for removal, safe work practices and the costs of hiring qualified labour.

Wood quality

The small scale and variability within the existing rainforest species plantation estate presents a significant challenge when attempting to develop markets for wood. The wood grown in plantations will vary significantly from that harvested from native forests (Bootle 1983, Walker 1993). In order to understand some of the general issues for growers relating to the quality of plantation wood it may be valuable to draw on the experience of better developed plantation systems. The relevance of such comparisons is not known, but areas of concern that have emerged from other plantation systems are worthy of consideration.

The international effort to grow teak (*Tectona grandis*) provides an example of a well-established, high value plantation system that shares some characteristics with local rainforest plantation systems. Teak has a unique position in the world timber market primarily based on the colour and durability of the heartwood (Bhat 1998). The current international teak market requirements are centered on wood quality and dimensional characteristics, with the best prices paid for larger logs with high proportions of defect free heartwood (Cordero and Kanninen 2003). Fast grown plantation wood is not likely to achieve the prices paid for old growth teak, due to differences in the color, durability and texture of the young wood (Bhat and Ma 2004). The proportion of teak heartwood at ten years is 33-37% (Acre 2001), and at 30 years heartwood is 55% of the total volume (Cordero and Kanninen 2003). The lessons from the teak experience are that production of higher value timber will require good silvicultural management and long rotation lengths.

According to a recent analysis of the cabinet timber market by ANU (2003), any positive change in product price will help profitability. The main conclusion of the report was cautionary: “before investing in these potentially profitable but highly risky plantations, it is advisable for farm forest growers to give very careful attention at the outset to key factors such as species selection, silviculture and marketing”.

The analysis of growth of high value species carried out over the last decade helps to inform decisions on species selection. Good plantation silviculture including pruning to remove unwanted characteristics such as defects and bends, and thinning throughout the rotation to create enough growing space, will help improve wood quality. The major challenge that remains relatively unexplored is the marketing of high value plantation timber.

Conclusion

Growth data from young rainforest plantations gives an indication of the performance of nine species across a range of environmental gradients in NSW. The most promising species was *Elaeocarpus grandis*, with rapid early growth, good form and survival rates. Other performers that show good early height growth were *Flindersia brayleyana, Grevillea robusta* and *Flindersia schottiana.* The potential to generate high value solid products from plantation wood provides a very significant challenge for researchers. Future monitoring of the wood properties of species such as *Elaeocarpus grandis* from trees grown in plantations may provide a clearer indication of the commercial opportunities for these new plantation systems. Wood samples from several of the species measured in this study are currently being analysed by the authors as part of a project funded by the Joint Venture Agroforestry Program.

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. Growers and managers of rainforest species in plantations need to carefully select species and management systems that improve wood quality and meet the expectations of potential end users.

Acknowledgements

We would like to acknowledge the generous support of the Joint Venture Agroforestry Program (JVAP) (RIRDC project USC-7A) and the landholders who provided information about and access to their plantations. We thank Mila Bristow, Peter Erskine, Rosemary Lott and an anonymous reviewer for comments on an earlier version of the manuscript.

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8. Insect pests and diseases of rainforest timber species grown in plantations

Judith King and Simon Lawson

Abstract

The Community Rainforest Reforestation Program (CRRP) and other planting programs included in their aims the long-term expansion of forest industries in north Queensland with the production of high quality rainforest timbers in plantations. Plantation productivity (survival, growth rate, form and yield) and quality of the timber product are influenced in part by plantation health which can be adversely affected by insect pests and diseases.

Plantation development planning should include an assessment of the potential risks due to pests and diseases and site-related problems, facilitating appropriate species choice. Once established, regular plantation health surveillance should be incorporated into the management program, enabling early intervention where appropriate. A plantation health surveillance program: identifies pathogens, insect pests and their parasites and predators; enables early recognition of health change; identifies predictive patterns of pest and disease activity; facilitates the correlation between plantation productivity and pests and diseases; and contributes to a valuable bank of knowledge.

Hardwood plantation research has recognised serious pests such as tip moths of the Meliaceae family as well as wood boring beetles and moths, sap sucking bugs and beetle defoliators associated with several tropical and subtropical eucalypts. Diseases such as Cylindrocladium *leaf blight,* Phellinus noxius *and phytophthora root rot are also potential threats to rainforest replantings.*

Risk assessments and health surveillance were not conducted in the CRRP plantings, missing an opportunity to identify and manage the threat of pests and diseases in rainforest reforestation programs. Examples of appropriate risk assessment and health monitoring in hardwood plantation programs are the Department of Primary Industries' Joint Venture scheme and Hardwoods Queensland project.

Introduction

The Community Rainforest Reforestation Program (CRRP) was one of a number of federal and state government initiatives for tree planting, founded on economic, environmental, and social considerations. Others included the Joint Venture Scheme (Department of Primary Industries (DPI), Forestry) and Hardwoods Queensland project (DPI, Agency for Food and Fibre Sciences, Forestry Research).

The CRRP, which began in 1993, included in its aims the growing of high value cabinet woods and hardwoods to provide a sustainable timber industry, and support for the development of a private plantation industry. This industry would provide employment and future growth in areas where logging of native forests ceased.

The development of a private plantation industry requires high-level, long-term investment. To secure such a commitment of funds, potential investors must be certain of a reasonable return on capital, and the value of the return in part, is directly related to the productivity of the plantations and the quality of the end product. To achieve this, plantations should include species best suited to the site (and to the market), and should be managed to provide optimum growing conditions for the selected species, so that the end product meets market expectations in minimum time.

Pests and diseases, and their effect on tree health, can be major limiting factors influencing plantation productivity and the quality of the end product, especially where native or endemic species are to be grown.

Tree health

Tree health is dependent on many factors, including: the genotype of the tree, which determines whether it is vigorous or weak stock; environmental and climatic influences at the planting site; competition with weeds and direct losses due to pests and diseases. Accurate matching of tree species to site promotes tree vigour, and so enhances tree tolerance and resistance to pest and disease attack. In plantations where tree species are well matched to the site, weed competition and pests and diseases can be the most important determinants of plantation health and productivity. If trees are not matched to the site pest and disease effects may be exacerbated.

Previous experience in Queensland has shown that pests and diseases can have major impacts on the health of individual trees and plantations (Heather and Schaumberg 1966; Wylie and Peters 1993; Speight and Wylie 2000; Griffiths *et al.* 2001). When trees are being chewed, sucked on, bored into, defoliated or decayed by pests and diseases they will not grow well, and the end product will be of a low standard, or non-existent. Incorporating pest and disease considerations into the planning of plantation projects is essential to obtaining successful long-term outcomes (see Speight and Wylie 2000). However, during the planning and implementation stages of the CRRP the potential effects of pests and diseases on the required outcomes of the project were not recognised, and entomologists and pathologists were not consulted.

Effects of pests and diseases on tree health

Pests and diseases can affect tree survival, growth rate, form and yield:

Survival – Severe and/or repeated damage caused by insects or diseases can kill trees, or can weaken them sufficiently to make them much more susceptible to adverse abiotic factors.

Growth rate – Defoliation and loss of growing points reduces the tree's ability to photosynthesise, and reserves are depleted in producing a new crown. Subsequent defoliations can compound the problem and stop growth. Some examples of defoliators are:

- Sap-suckers, such as psyllids which suck sap from leaves and soft stems or form galls, causing chlorosis, necrotic patches on the leaves, distortion and leaf fall;
- Leaf chewers that singly, in groups or swarms chew off leaves and growing tips. These include sawfly larvae, adults and larvae of leaf-eating beetles and various caterpillars. Leaf chewers in this case includes leaf miners, tiers, etc, many ways of chewing on a leaf;
- Leaf and shoot blight diseases that cause necrosis of leaf tissues, shrivelling and distortion of twigs and growing points; and
- Root rots, which slowly destroy the root system and starve the tree, causing chlorosis, defoliation and often tree death.

Form – Loss of leaders and growing tips, and damage to the stems of young trees, can lead to development of multiple growth points, bushy form and distorted stems, instead of a single, straight trunk which will later yield a high quality saw log. Some examples are:

- Tip and shoot moths that chew out growing tips;
- Tip-sucking bugs which pierce and suck sap from just behind the growing tips and cause them to shrivel;
- Longicorn beetles, either stem borers or branch pruners, and wood moths that kill off branches; and

- Diseases, including cankers, stem and leaf blights and bacterial wilts that can have a detrimental effect on form.

Quality and value of timber produced - These are directly affected by pests and diseases in the trunk. Some examples include:

- Branch-pruning longicorn beetles that also prune young stems, often close to ground level, resulting in loss of growth increment or multiple leaders;
- Longicorn borers and wood moths which leave tunnels filled with frass, gum veins and/or large holes;
- Bark and ambrosia beetles that colonise wound sites and stain the timber; and
- Termites, root rots and heart rots that are associated with cavities, pipes and decaying wood.

Pests and diseases can be a primary cause of poor health, but they can also be secondary agents, 'taking advantage of' and compounding an existing problem. For example trees which are stressed by competition with weeds, or have suffered storm damage, may be more susceptible to, and less able to recover from a subsequent insect or disease infestation.

Often more than one pest or disease or other stress factor can be active at one time. Emergence of holes in the trunk can act as entry points for fungal diseases; dead, ring-barked branches can be infested by termites and the damp 'mudguts' surrounding their nests facilitates decay in the branches and trunk. As a field example a *Eucalyptus urophylla* plantation near Cardwell suffered storm damage, then was trampled by cows and then defoliated by caterpillars (probably *Doratifera* sp. cup moths) and the disease Cylindrocladium leaf blight (Pomeroy pers. comm.).

CRRP plantations

CRRP plantations were often established on cleared agricultural land that was originally rainforest and so could be considered extremely vulnerable to attack by a wide range of tree pests and diseases. These sites were spread over a wide geographic and climatic range. Extensive plantings of mixed species were made in an area that has a high level of biodiversity, especially rich with regard to herbivorous insects and fungal pathogens, and where there was comparatively little recorded information on health problems of some of the rainforest species to be planted. From entomological and pathological perspectives the project would have been an opportunity to increase our knowledge of pest and disease interactions with trees in northern Queensland, particularly in plantation situations.

Cameron and Jermyn (1991), in their review of the performance of rainforest species, recommended future directions for research and testing to improve the performance of selected species in plantations. In their list of 'High Priority' recommendations, which should be addressed early in any program of growing high value rainforest trees, they included research into pests and diseases. They acknowledged the lack of information on health problems of these trees, and made particular mention of problems with *Hypsipyla robusta* in *Toona ciliata* and *Cedrela odorata*, and pests and diseases of *Gmelina arborea*.

In their list of 'Low Priority' recommendations they included long-term experiments monitored by multidisciplinary teams as one of the 'key ingredients' for successful plantation trials. Based on their 'High priority' recommendations, monitoring teams should have included forest health specialists in entomology and pathology.

Plantation health risks in the CRRP

The CRRP would have benefited from the inclusion of pest and disease specialists as permanent members of the project team. During the planning stages entomologists and pathologists would have provided valuable input into species selection and species/site matching by identifying some potential and actual threats to tree health from existing information. Information on potential pest and disease problems of some of the species and sites selected for the CRRP was available from previous trials, specific research projects and field experience. Some of these previously described problems did then occur in the CRRP and other plantations may have been preventable. Consideration of potential problems could have saved time and money either by a decision not to plant particular high-risk species, or by regular monitoring and early intervention. Examples of previously recognised problems include the following:

Cedar Tip Moth

Red cedar, *Toona ciliata*, is attacked by the cedar tip moth, *Hypsipyla robusta.* There have been several unsuccessful attempts to grow Queensland red cedar in plantations in northern and southeast Queensland (Cameron and Jermyn 1991; DPI Forestry records), and in New South Wales (Griffiths *et al* 2001). All trials failed because the trees were attacked by the cedar tip moth, resulting in multi stemming, bushy growth and sometimes tree death. Yet red cedar was planted in several places, with predictable results; in one plantation near Mackay all the trees were severely affected, none were of any value and many died (see Figure 1).

Figure 1 Red cedar severely damaged by *Hypsipyla robusta*.

White cedar moth

Similarly, white cedar, *Melia azedarach* L., is frequently defoliated by caterpillars of the white cedar moth (*Leptocneria reducta* (Walker)). Caterpillars of this moth cluster together at the base of the tree or on the lower trunk during the day and move into the crown at night to feed. They are voracious feeders, and when all the leaves have been eaten they will move in procession from the defoliated tree to a new tree. This pest reached such high numbers in some areas that eggs were being deposited on seedlings in the nursery. White cedar moth is usually not found in nurseries of north Queensland.

Eucalypt pests and diseases

Several pests and diseases of eucalypts and acacias were recorded during a series of hardwood taxa trials in northern and south eastern Queensland in the late 1980's. During these trials the devastating disease Cylindrocladium leaf blight (*Cylindrocladium quinqueseptatum* Boedijn and Reitsma), which defoliates eucalypts, was recorded on *Eucalyptus pellita* F. Muell. at Lannercost and Murray Upper (see Figure 2).

Figure 2 Cylindricladium leaf blight causing leaf and stem distortion and defoliation of *Eucalyptus*.

Also recorded were longicorn borers (including *Penthea macularis*) and wood moths tunnelling in trunks of some eucalypts and acacias (see Figures 3 and 4), sap sucking bugs and scarab beetle defoliators (see Figure 5) of some eucalypts (Wylie and Peters 1993).

Yet some of the species severely damaged in these trials (e.g. *E. urophylla* and *E. grandis*), were subsequently used in CRRP plantings and other north Queensland plantations.

Other diseases

Research on the fungus *Phellinus noxius* (Corner) G. Gunn., a lethal pathogen of many tree species, has shown that it can persist in infected stumps and roots in cleared rainforest sites for many years and can infect new hosts through root contact (see Figure 6) (Bolland 1984, Ivory 1996).

The fungus is endemic to rainforests in tropical and subtropical Queensland, and has long been recognized as a serious disease of hoop pines and other rainforest species (Bolland 1984, Ivory 1996). Another well-researched lethal fungus with a wide range of hosts is *Phytophthora cinnamomi* Rands, phytophthora root rot (Keane *et al.* 2000). An initial assessment of sites by a pathologist

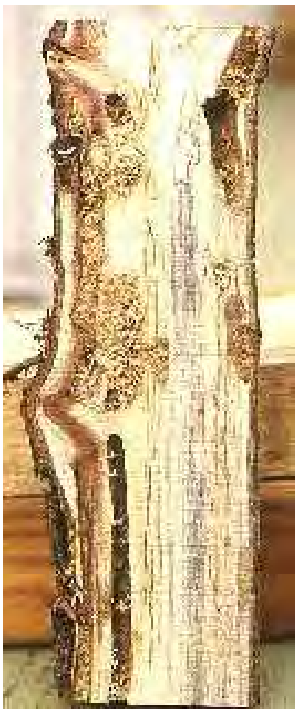

Figure 3 *Acacia aulacocarpa* stem extensively damaged by longicorn borer *Penthea macularis.*

Figure 4 *Acacia mangium*, Kuranda seed orchard, with wood moth damage. Growth rate and form are affected, the trees will not produce marketable timber.

Figure 5 *Epholcis bilobiceps*, a swarming scarab beetle which can defoliate some eucalypts.

Figure 6 *Phellinus* root rot ‘stocking’ on the trunk of *Argyrodendron* sp. The tree will die and timber will be affected by decay.

would have indicated whether these diseases were likely to be present at the sites, and the likely long-term effects and planting options. This was not done.

These pests and diseases, and others subsequently recognised as potentially serious problems, are included in Table 1 at Appendix One.

Plantation health

During the life of the CRRP, entomologists and pathologists were not asked to inspect the trees until damage and disease were obvious and/or severe. They visited only a few of the plots, although many other plots were affected by pests and diseases (P. Pomeroy, G. Sexton, M. Bristow, A. Sturrie pers. comm.). This is sometimes referred to as the 'fire fighting' approach to pest and disease management, whereby control measures are undertaken once visible symptoms are severe, rather than sampling for pests and diseases before they reach critical levels. A health surveillance program would have facilitated early recognition of health problems and significantly increased knowledge of pests and diseases, knowledge which could be utilised in planning and managing future plantations. In addition, field staff who travelled with the surveillance team would have increased their knowledge and awareness of this aspect of plantation development.

Health Surveillance.

A regular health surveillance program, with frequent inspections and meticulous record keeping, should be an integral part of plantation management (e.g. Stone *et al.* 2001, Candy and Zalucki 2002).

Benefits of health surveillance include:

- Identification of pests and diseases;
- Identification of parasites and predators of insect pests - these may be useful pest controllers;
- Standardised and consistent methods of measuring and expressing damage and effects;
- Early recognition of developing problems and changes in health. This will allow timely remedial action to be taken if such action is appropriate or possible. For example, remedial measures such as weed control and fertilizer application can significantly improve tree health following pest or disease damage episodes (Stone and Birk 2001, Wardlaw pers. comm.);
- Recognition of patterns of pest and disease activity. This can have predictive value for some pests and diseases, once activity patterns have been determined. For example, some scarab beetle species swarm in the spring, often following storm rain, and defoliate some eucalypt species. If those beetles are known to be present, extra surveillance at the appropriate time, and early intervention, can reduce or prevent damage. As well, the grower learns which pests and diseases are always present, and can select tree species with low susceptibility to pests and diseases for future planting;
- Development of a database. A database of information on pests and diseases is crucial for planning future plantations, eg. matching species to site: a eucalypt species devastated by leaf blights in some locations would not be replanted and would not be planted in other sites with similar parameters;
- Potential for regular exchange of information with colleagues, widening the knowledge and experience base; and
- The creation/development of a known source of assistance and information as needed.

A health surveillance program should include nursery inspections and nursery staff should be trained to be aware of problems so that recognised nursery pests and diseases can be managed effectively. Nurseries also need to ensure that healthy seedlings are supplied for planting out and that high populations of pests and diseases are not introduced into the plantation at this early stage. High economic costs can be associated with treatment or replacement of unhealthy stock once planted out. Quarantine is also an issue – nurseries from one region supplying plants for another region (e.g. north Queensland nurseries supplying plants for southeast Queensland) can spread pests and diseases into areas where they previously did not occur.

A final inspection of standing trees and some destructive sampling at the end of the CRRP would have provided information on the longer-term effects of damage to trees previously inspected – did they survive, if they survived how well did they recover, what were the outcomes for each plantation? As well, overall health, and the effects of pests and diseases on stand quality across sites could have been assessed.

Hardwoods Queensland – A case study

An example of a planned health research and development program for plantations is provided by the Hardwoods Queensland project (www.dpi.qld.gov.au/hardwoodsqld). This project represented an integrated, multidisciplinary approach to research and development in support of a new plantation industry. This project focused upon eucalypt plantations in southeast Queensland which comprised part of the South East Queensland Forests Agreement (SEQFA) of 1999. From the conception of this project, pests and diseases were recognised as key limiting factors in plantation productivity, and research into their management was appropriately funded and resourced for the four years of the project. Additionally, systematised health surveillance has been a part of the operational plantation program since 1999 and has contributed much to our understanding of the distribution and impact of pests and diseases in eucalypt plantations, as well as providing early warning of new problems when they arise and assisting in targeting research into the most needed areas. This close linkage between surveillance and research should be an essential part of any plantation program.

From its inception, forest health specialists contributed to the selection process for species to be used in the planting program, with some species (notably *Eucalyptus grandis*) being rejected and cautions given for others with known problems. Because these plantations are being established mainly for solid timber values, *E. grandis* was excluded due to its extremely high susceptibility to stem borers such as *Endoxyla cinerea* (the giant wood moth) and longicorn beetles (*Phoracantha* spp.), which have rendered timber from older plantations of this species virtually valueless from a solid timber point of view. From previous experience plantation managers were advised of the possible impact of *Quambalaria pitereka* (J. Walker and Bertus) J.A. Simpson (Ramularia shoot blight) on *Corymbia citriodora* ssp. *variegata* (spotted gum) based on plantings in northern New South Wales. When problems did occur, provenance trials of this species had been established from which more tolerant genotypes could be selected and then used in the plantation program.

Several other projects such as the Department of Primary Industries' (DPI) Forestry Joint Ventures scheme and the Australian Centre for International Agricultural Research (ACIAR) and Shell trials of the 1980's included pest and disease specialists in their planning and management programs such that many emerging pests and diseases were identified early on, such as *Epholcis bilobiceps* swarming scarabs, Cylindrocladium leaf blight, stem borers such as giant wood moths (*Endoxyla* spp.) and *Phoracantha* spp. longicorn beetles, and Ramularia shoot blight. Where possible, remedial action could then be taken (Wylie and Peters 1993).

Harvest and post-harvest health

For future projects some consideration should be given to health issues during and after harvest. Problems are caused almost exclusively by insect pests. Primary fungal infestations in newly felled logs are prevented by rapid harvesting and processing.

Of greatest concern are ambrosia beetles, which are major timber pests world wide. Ambrosia beetles are pests of unseasoned timber. Adults bore in the sapwood and heartwood of unhealthy, wounded, dying or recently dead trees, freshly felled logs or, occasionally, newly sawn timber. Their tunnels and the associated fungal staining of the wood can rapidly and severely degrade the timber (Peters *et al*. 1996).

Disinfestation of borer-affected logs is extremely difficult. Therefore, for high value logs the emphasis should be on:

- Care in logging - to prevent wounding and infestation of remaining trees;

- Rapid processing - logs taken to the mill and processed as soon as possible, not left lying in the bush, at the logging ramp or in the mill yard; and
- Kiln or air drying - sawn product should be kiln dried where possible, or air dried in a protected environment.

Conclusions

Long-term management of pests and diseases in plantations of native species should be an integral part of a project from planning to harvest. It is a complex issue demanding tailored rather than ‘broad brush’ measures. This is because the pests and diseases are already present and large-scale planting, either mixed or monoculture, provides substantial new habitats and resources.

Good plantation health management practice is about:
- identifying the end-use of each species, including sawlogs, cabinet timber, veneer, pulp, environmental restoration (biological damage is much less significant for some uses); and
- having knowledge of: the potential pest organisms and an understanding of their biology; the effects of these organisms on the host tree in relation to the end-use; and whether effective and appropriate management (for example natural enemies, pheromone trapping) is practically and economically possible.

Where available, all this information should be incorporated into plantation project planning by pest and disease specialists. Where information is not available it should be collected. An informed decision can then be made about which species to include.

After planting, trees should be inspected regularly (at least twice a year) for pest and disease problems by experienced personnel, and appropriate remedial action should be taken as necessary.

The CRRP plantings would have been an opportunity for entomologists and pathologists to increase the knowledge bank of pests and diseases of trees in north Queensland, as well as providing an opportunity for CRRP staff and other stakeholders to access knowledge and information needed to execute sound plantation health management practices, as achieved by Hardwoods Queensland and the Joint Venture scheme where immediate benefits for growers and the collection of information for the long-term benefit of an expanding industry resulted.

Recommendations

Several principles of sound plantation health management can be recommended for future planting programs for rainforest timbers:
- Forest health specialists need to be involved in any planting program from its inception to advise on the health risk aspects of species selection and to have inputs in planning the management of known pests and diseases;
- A systematised health surveillance of plantations must be put in place. This is essential to assess the incidence and severity of pests and diseases over time and to evaluate the impacts on plantation productivity;
- Field staff should be trained to recognise and record health problems, and request assistance as necessary between scheduled health surveillance visits from specialists;
- Our current knowledge of pests and diseases in north Queensland should be reviewed, and a comprehensive health data base developed to record pests, diseases, impacts, geographic and temporal occurrence and other factors in relation to the tree species grown in plantations;
- A final inspection of at least some of the CRRP plantations should be conducted to assess and record the outcomes of the project; and
- Harvest and post-harvest pest problems of logs for cabinet timbers and veneers require greater recognition in the overall health risk to timber production in native hardwood plantations.

Acknowledgements

We thank Dr Manon Griffiths, Dr Susan House, Geoff Pegg and Dr Ross Wylie for their assistance in preparing the manuscript.

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Appendix One

Table 1 Some insects and diseases causing severe damage to trees in north Queensland. Note: pest and disease occurrence and effects differ at different localities.

Tree species	Insect	Type of Damage
Acacia aulacocarpa Cunn. ex Benth.	*Calomela crassicornis* Fabricius. Coleoptera	Leaf chewer
	Cryptocephalus iridipennis Chiapuis. Coleoptera	Leaf chewer
	Cryptocephalus gracilior Chiapuis. Coleoptera	Leaf chewer
	Rhyparida discopunctulata Blackburn. Coleoptera	Leaf chewer
	Penthea pardalis (Newman). Coleoptera	Tunnels in trunk
	Dicranosterna sp..Coleoptera	Ring bark branches,
	Xyloryctidae, unidentified species. Lepidoptera	Stem and branch borer
A. auriculiformis Cunn. ex Benth.	*Calomela crassicornis*	Leaf chewer
	Cryptocephalus speciosus Guerin. Coleoptera	Leaf chewer
	Dicranosterna sp.	Ring bark branches
	Mictis profana (Fabricius). Hemiptera	Tip sucker: shoot dieback, stunting, bushy growth
A. mangium Willd.	*Calomela crassicornis*	Leaf chewer
	Cryptocephalus iridipennis	Leaf chewer
	Cryptocephalus gracilior	Leaf chewer
	Dicranosterna sp.	Ring bark branches
	Platyomopsis sp. Coleoptera	Ring bark branches
	Calcarifera sp. Lepidoptera	Leaf chewer
	Xyloryctidae, unidentified species	Stem and branch borer
	Cryptophlebia sp. Lepidoptera	Tip borer: shoot dieback, stunting, bushy growth
Agathis robusta (C. Moore ex F. Muell.) Bailey	*Geloptera miracula* Lea. Coleoptera	Leaf chewer, surface and margins
	Conifericoccus agathidis *Brimblecombe* Hemiptera	Sap sucker
Alphitonia petrei	No information	
Blepharocarya involucrigera	No information	
Cardwellia sublimes F. Muell.	No information	
Castanospermum australe Cunn. ex C. Fraser ex Hook	No information	
Cedrela odorata L	*Hypsipyla robusta* (Moore). Lepidoptera	Tip and stem borer: shoot dieback, stunting, bushy growth

Tree species	Insect	Type of Damage
Corymbia citriodora (Hook.) K.D. Hill and L.A.S. Johnson	*Cryptocephalus speciosus*	Leaf chewer
	Phoracantha acanthocera (Macleay). Coleoptera	Tunnels in trunk
	Phoracantha solida (Blackburn). Coleoptera	Tunnels in trunk
Corymbia torelliana	*Monolepta australis* (Jacoby) Coleoptera	Defoliator
Elaeocarpus grandis F. Muell.	Unidentified processionary caterpillars. Lepidoptera	Defoliator
Eucalyptus acmenoides Schauer	*Epholcis bilobiceps* (Fairmaire). Coleoptera	Defoliator
Eucalyptus camaldulensis Dehn.	*Epholcis bilobiceps*	Defoliator
	Liparetrus discipennis (Guerin-Meneeville). Coleoptera	Defoliator
	Hyalarcta huebneri (Westwood). Lepidoptera	Defoliator
	Endoxyla cinerea (Tepper) Lepidoptera	Tunnels in trunk
Eucalyptus cloeziana F. Muell.	*Paropsis atomaria* Olivier Coleoptera	Defoliator
	Liparetrus sp. Coleoptera	Defoliator
	Hyalarcta huebneri	Defoliator
	Phoracantha solida	Tunnels in trunk
Eucalyptus drepanophylla F. Muell. ex Benth.	*Epholcis bilobiceps*	Defoliator
Eucalyptus dunnii Maiden	*Chrysophtharta cloelia* Stal. Coleoptera	Leaf chewer
	Paropsis atomaria	Defoliator
	Xylotrupes gideon (L). Coleoptera	Bark chewer
	Creiis lituratus (Froggatt) Hemiptera	Defoliator
	Endoxyla cinerea	Tunnels in trunk
	Phoracantha solida	Tunnels in trunk
E. grandis W. Hill ex Maiden	*Epholcis bilobiceps*	Defoliator
	Endoxyla cinerea	Tunnels in trunk
	Phoracantha acanthocera	Tunnels in trunk
	Phoracantha solida	Tunnels in trunk
	Cossidae, unidentified species. Lepidoptera	Tunnels in trunk
	Eriococcus coriaceus Maskell. Hemiptera	Damage and distortion of small branches and twigs, chlorosis.
	Chrysophtharta cloelia	Leaf chewer
	Cardiaspina fiscella Taylor Hemiptera	Defoliator
	Cardiaspina maniformis Taylor. Hemiptera	Defoliator

Tree species	**Insect**	**Type of Damage**
E. microcorys F. Muell.	*Phoracantha acanthocera* *Phoracantha solida* Scarabaeidae, unidentified species. Coleoptera *Pergagrapta polita* (Leach) *Hymenoptera*	Tunnels in trunk Tunnels in trunk Defoliator Leaf chewer
Eucalyptus pellita F. Muell.	*Chrysophtharta cloelia* *Epholcis bilobiceps* *Geloptera miracula* *Phoracantha acanthocera* *Phoracantha solida* *Pergagrapta polita*	Defoliator Defoliator Leaf chewer, surface and margins Tunnels in trunk Tunnels in trunk Leaf chewer
Eucalyptus pilularis Smith	*Cryptocephalus speciosus* *Epholcis bilobiceps* *Hyalarcta huebneri* *Phoracantha solida* *Paropsis atomaria*	Leaf chewer Defoliator Defoliator Tunnels in trunk Defoliator
Eucalyptus resinifera Smith	*Phoracantha acanthocera* *Phoracantha solida*	Tunnels in trunk Tunnels in trunk
Eucalyptus robusta Smith	*Epholcis bilobiceps* *Phoracantha acanthocera* *Phoracantha solida*	Defoliator Tunnels in trunk Tunnels in trunk
Eucalyptus tereticornis Smith	*Endoxyla cinerea* *Phoracantha solida* *Chrysophtharta cloelia* *Glycaspis* sp. Hemiptera	Tunnels in trunk Tunnels in trunk Defoliator Sap-sucker
Eucalyptus tetradonta F. Muell.	No information	
Eucalyptus urophylla S.T. Blake	*Epholcis bilobiceps* *Phoracantha acanthocera* *Phoracantha solida* *Doratifera* sp. Lepidoptera	Defoliator Tunnels in trunk Tunnels in trunk Defoliator
Eucalyptus spp., specific name not recorded	*Cardiaspina* sp. Hemiptera *Amorbus* sp. Hemiptera Microhymenoptera, Hymenoptera *Perga* sp., *Pergagrapta* sp., Hymenoptera	Sap sucker: leaf necrosis, defoliation Tip sucker: shoot dieback, stunting, bushy growth Galls on leaves and stems, distortion, stunting Defoliators
Flindersia spp	*Strongylurus thoracicus* (Pascoe). Coleoptera	Branch girdler

Tree species	Insect	Type of Damage
Grevillea robusta Cunn. Ex R. Br.	No information	
Khaya spp.	No information	
Melia azedarach L.	*Strongylurus thoracicus* (Pascoe) *Leptocneria reducta* (Walker).Lepidoptera	Branch girdler Defoliator
Nauclea orientalis (L.)	No information	
Paraserianthes toona	No information	
Tectona grandis	*Hyblaea puera* Cramer Lepidoptera	Leaf chewer
Terminalia sericocarpa F. Muell.	No information	
Toona ciliata M. Roemer	*Hypsipyla robusta*	Tip and stem borer: shoot dieback, stunting, bushy growth
Araucaria cunninghamii Aiton ex D. Don	*Phellinus noxius* (Corner) G. Gunn	Root decay, death
Acacia mangium	*Ganoderma sp.* *Atelocauda digitata (G. Wint.) Cummins and Y. Hiratsuka*	Root decay, death Leaf and stem galls, distortion, leaf loss
Most rainforest species	*Phellinus noxius*	Root decay, death
Many hardwoods and softwoods	*Phytophthora cinnamomi* Rands	Root decay, poor growth or death
Eucalyptus spp.	*Cylindrocladium quinqueseptatum* Boedijn & Reitsma *Mycosphaerella* sp.	Defoliation, shoot, branch and stem damage in young trees and nursery stock Shriveled leaves, defoliation.
Corymbia spp.	*Quambalaria pitereka* (J. Walker & Bertus) J.A. Simpson	Shoot distortion, dieback, bushy growth.

9. Designing mixed-species plantations: Progress to date

David Lamb, Huynh Duc Nhan and Peter D. Erskine

Abstract

Mixed species plantations are much more complex than traditional monocultures. The problem of designing appropriate systems is made even more difficult because of our comparatively limited knowledge of most of the tree species of interest. Random mixtures are unlikely to be successful but there is evidence that some carefully selected, multi-species plantations are likely to be more productive than simple monocultures. Evidence presented here suggests that:

- *pairings of two dominant and fast growing species (e.g. Eucalyptus pellita and Elaeocarpus grandis) are likely to be less successful than pairings of two less dominant species;*
- *pairings of a species having a persistent green crown (i.e. having some shade tolerance) with species that are shade intolerant and have shallow crowns can sometimes be complementary; and*
- *species with contrasting rooting depths are likely to be complementary.*

Introduction

Most state governments in Australia have sponsored tree growing schemes at one time or another. However, the Community Rainforest Reforestation Program (CRRP) in north Queensland, sponsored by both the Queensland and federal governments, was different from most of these other schemes in two important respects. One was that it focused on rainforest tree species. The other difference was that it sought to grow these in mixed species plantations rather than in the more traditional plantation monocultures.

There were several reasons for encouraging the use of rainforest species. One of these was economic. Previous government programs had encouraged farmers in north Queensland to plant *Pinus caribaea* (Caribbean pine). This species was then being widely grown in the Queensland government's own plantations because it was fast growing and could tolerate the poorer soils usually available to the then Forestry Department for plantation establishment (most of the better soils being used for agriculture). But few of these north Queensland farm plantations could be regarded as successful. Only small areas were ever reforested and the value of the trees at commercial maturity was low. In fact, disappointingly few sawmillers were interested in purchasing the logs. While high-quality timbers could be supplied from the natural forests and the state-owned plantations provided a benchmark price for lower value *Pinus caribaea,* farm plantations were always likely to remain unattractive. This situation changed when logging in natural rainforests in north Queensland ceased and the supply of the higher value timbers began to decline. This meant there was a possible market niche for plantations of these quality species, and for the expansion and development of this industry, especially on some of the more fertile soils in the region that were available for planting.

The other reason why the CRRP was based on rainforest species was because these were seen to have a greater "conservation" value. This was also the reason why more complex planting designs such as mixed species plantings were used. Timber production was important for some farmers but many also wanted additional benefits such as improved catchment and biodiversity protection. These preferences were probably a consequence of the vigorous debates over forest conservation and the World Heritage listing of the Wet Tropics rainforests that took place in north Queensland in the late 1980's.

Both of these new approaches represented rational choices. The market prices of the timbers of many rainforest species at the time were usually many times greater than that of *Pinus caribaea*. Likewise, there are several reasons (outlined below) why mixed-species plantations can sometimes have advantages over traditional tree monocultures. These advantages are in addition to any catchment or biodiversity benefit a mixture may provide. But multi-species plantations are much more complex systems to design and manage, and at the time the CRRP commenced the problem was how to develop appropriate multi-species plantations utilizing species about which very little was known.

Potential advantages of mixed-species plantations

One potential advantage of a multi-species plantation (where overall density is kept constant but where two or more species are used) is that the overall production may be greater because between-tree competition is less than in a traditional monoculture (Kelty 1992). In these circumstances the stand productivity is higher because individual trees are able to grow faster because of differential resource use. This reduced competition can be caused by the component tree species having different phenologies, meaning they place their demands for site resources at different times of the year. As a consequence, there is reduced competition with their neighbours. Alternatively, they may have different root or crown architectures resulting in reduced between-tree competition through separation in space. For example, one species might have a shallow root system while another has mostly deeper roots that explore a different section of the soil profile. There is some evidence this is the case with mixtures of *Araucaria cunninghamii* and *Flindersia brayleyana* (Lamb and Lawrence 1993). Similarly, a difference in crown depth or shade tolerance may allow better partitioning of light resources than when neighbouring trees are identical.

A second possible advantage of mixtures is that overall tree nutrition is improved. This might come from the inclusion of nitrogen-fixing trees in the mixture that improve the overall supply of nitrogen to the plantation (Forrester *et al.* 2004). Or it may come from the faster decomposition and nutrient cycling that occurs when a more diverse range of leaf litters are mixed together.

A third possible advantage of mixtures is the potential reduction in insect and disease problems. This occurs because individual trees of a particular target species are dispersed in space and are more difficult for insect pests to find or diseases to reach. The evidence for this is equivocal; there are examples of mixtures where there is no apparent advantage but others where there is (Montagnini *et al.* 1995). Perhaps the best local example of a benefit is the case of *Toona ciliata* (red cedar) where a tip moth borer *Hypsipyla robusta* normally attacks trees grown in the open in plantation monocultures. These attacks were significantly reduced in a mixture created by underplanting the red cedar beneath *Grevillea robusta* (Keenan *et al.* 1995). The reason for this is still unclear but may be due to some kind of disadvantage suffered by the tip moth borer caused by the micro-climate created by the shade of the *Grevillea* overstorey. In this particular case the higher survival rates of trees grown in the understorey were matched by much slower growth rates. At some point the *Grevillea* would have to be removed if satisfactory *Toona* growth was to be achieved. This might be done when the *Toona* had safely reached some threshold height.

Such temporary mixtures can also be advantageous to species needing some early shade from a “nurse” tree to become established. There is evidence of this being important for some South East Asian species (Appanah and Weinland 1993) although there is no good evidence to date that the same is true of any Australian rainforest species.

Finally, mixtures can be beneficial for financial reasons. When plantation rotations are long and future markets are difficult to predict it can be useful to use more than one species as a form of insurance. Likewise, a mixture including a species able to be harvested early in the rotation and a slower growing species might provide an early cash flow for the grower (especially if the trees were planted in rows enabling thinning to be carried out without damaging the remaining trees) while also acting as a thinning to improve the growth of the longer lived trees (Larson 1992).

Do these possible mechanisms mean that mixtures are always better than monocultures? The answer is no. Mixtures of randomly chosen tree species are unlikely to be successful and are more likely to end with one species out-competing and excluding another. This means there are several silvicultural problems to be solved before a multi-species plantation system can be designed. The first of these is to identify which species are likely to form complementary mixtures and which species should not be grown together.

Choosing complementary species

There are several ways this question might be approached. The first is by trial and error and this was the approach used by the CRRP. Apart from the commercial values of the timbers, little was known about the ecological or silvicultural attributes of most rainforest species from Queensland's rainforests and the timing of the CRRP meant the reforestation program had to begin with very limited information. Figure 1 demonstrates that only 32 out of a total of 646 sites planted by the CRRP were monocultures and most farms had many species in their plantations. Indeed, an 'average' farm in the CRRP had 11 species planted and 55 sites had more than 20 species (Figure 1).

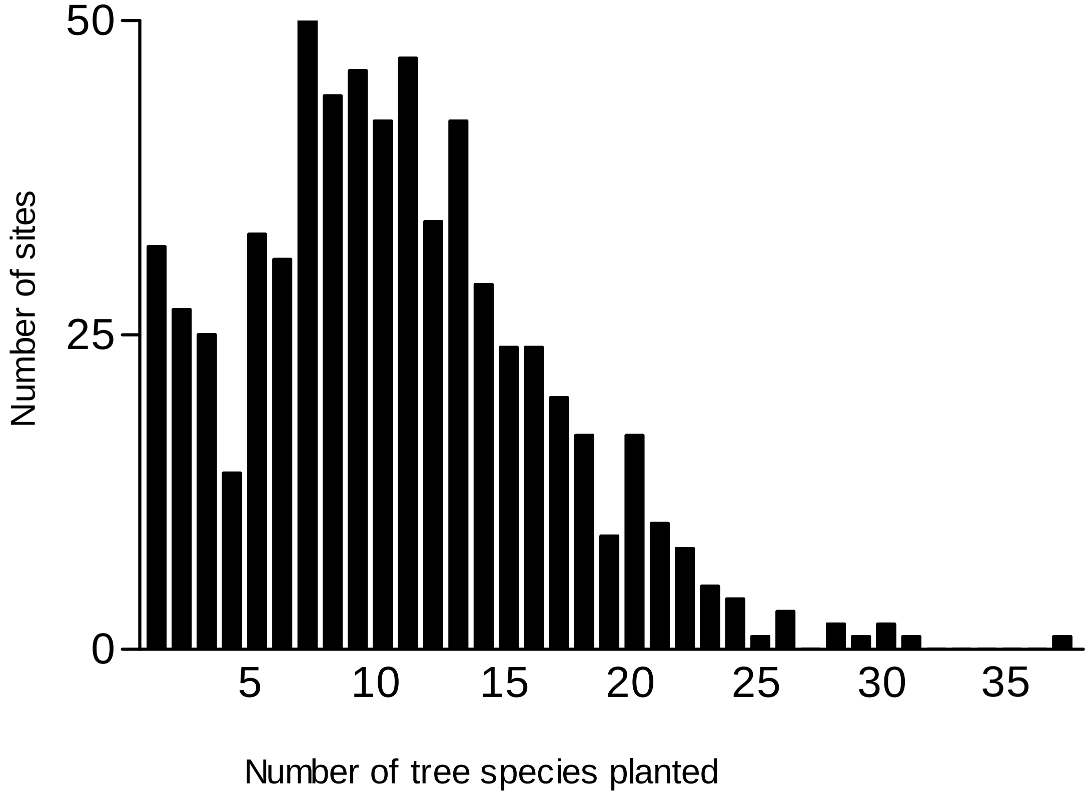

Figure 1 The frequency distribution of the number of tree species planted in all CRRP sites.

The spatial arrangement of these 'mixed species' plantations included sections of monocultures, rows of single species, and/or arbitrary plantings of species in and between rows. This random configuration and the variable spacing of the plantations across the region has meant that attempts to find replicated combinations to determine which species in the CRRP were complementary has had limited success.

A different approach would have been to establish replicated mixture trials to assess the overall competitive abilities of the different commercially attractive timber species and to use this knowledge to identify complementary mixtures. A start on using this approach was made using observations carried out at an experimental planting established in 1990 at Mt. Mee in southern Queensland (Lamb and Borschmann 1998). This trial included 16 species grown in plots containing 16 trees. Each plot had one individual of each of the 16 species and there were 28 plots in the trial (i.e. there were 28 individuals of each species). The location of each species within the plot was randomised. This meant that each individual of each species was surrounded by a random assortment of trees of four competitor species. The growth of each tree was then assessed via a "Competition Index" that expressed the sum of the competition offered by these four neighbours derived by the following formula (also see Figure 2).

$$CI_s = \sum_{k=1}^{n} (H_k - H_s)$$

Where:
CI_s = Competition index of subject tree
H_k = height of neighbour k
H_s = height of the subject tree
n = four

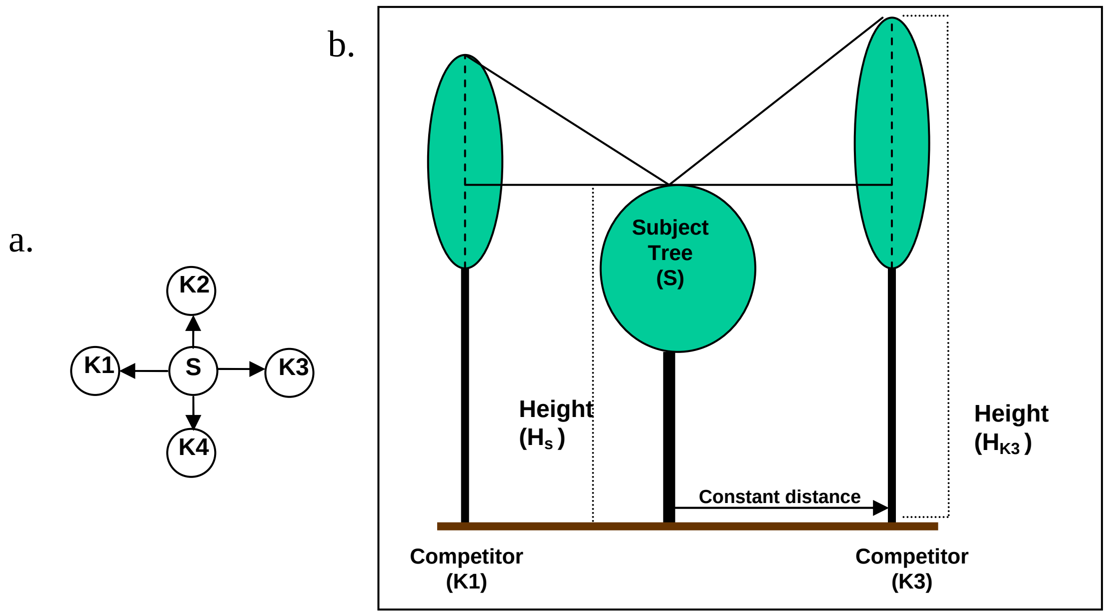

Figure 2 The basis of the Competition Index used to assess the relative competitive abilities of trees in a multi-species plantation at Mt. Mee (a) The top view of the subject tree (S) surrounded by four competing trees (K1 to K4). (b) The principle of calculating the Competition Indices (CIs) for a tree with Hs the height of the subject tree and Hk the height of the competing trees.

The relationship between the growth of each individual of a particular species and the competition offered by the neighbours of each of these (expressed by the Competition Index) could then be examined and the slope of the regression linking the two parameters measured. Examples of some of these regressions are shown in Figure 3. Note that the slopes of some of these regressions drift over time as the plantation ages and the competitive relationships alter.

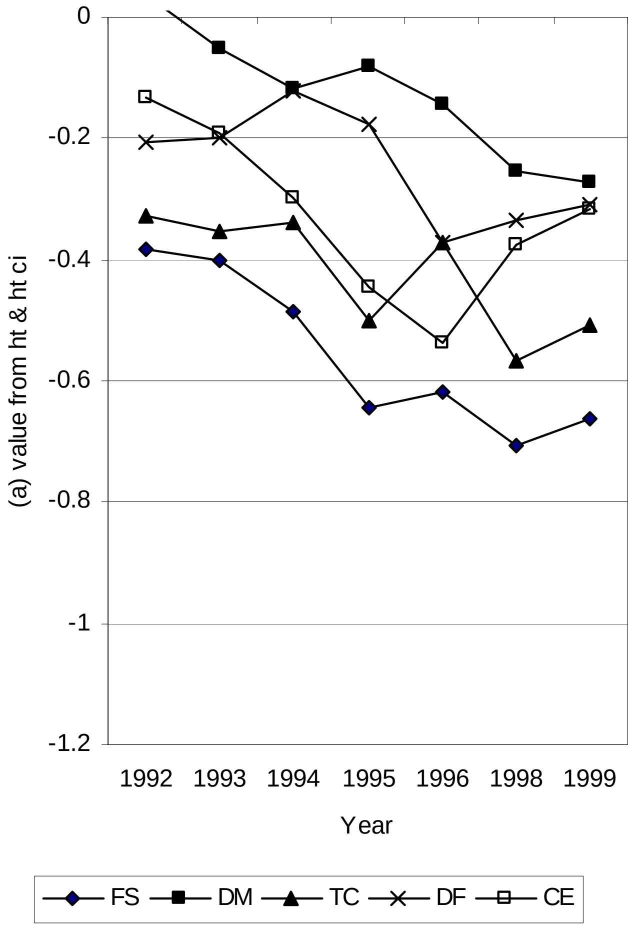

Figure 3 Examples from Mt. Mee of the relationship between tree height growth and the Competition Index (CI) showing how the slope (a) of the regression can vary between different species and that it can vary over time as the plantation ages. Species codes are: FS, *Flindersia schottiana*; DM, *Dysoxylum mollissimum*; TC, *Toona ciliata*, DF, *Dysoxylum fraserianum*; CE, *Cryptocarya erythroxylon.*

There are several ways in which these observations can be used to identify potentially complementary species. One is to simply choose species that have similar growth rates up until a particular age. This is a good first approximation but it is necessarily rather site specific – trees of species A may grow faster than trees of species B at one site but grow worse than species B at another. An alternative is to choose species with broadly similar overall growth rates but which also have similar slopes for the regression of height against the competition index.

An example of this is shown in Figure 4. This shows that some species with commercially attractive timber are probably too slow to grow in plantations designed to provide, in part at least, commercial benefits. Because of this, these species are probably not useful to include in multi-species mixtures. But the example also shows there are some species may be simply too fast-growing and dominant to be attractive components in mixtures. In this particular case *Elaeocarpus grandis* is an example of such a dominant species.

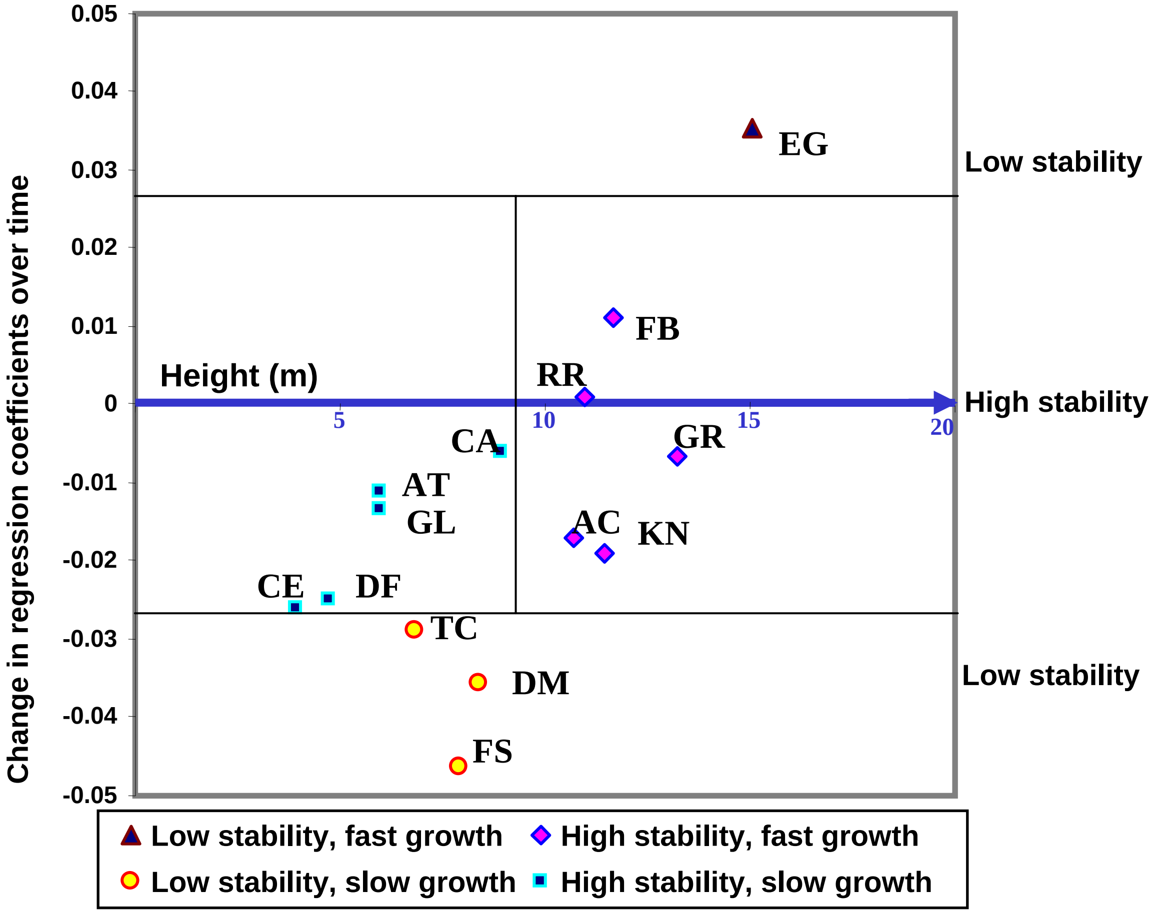

Figure 4 The growth rate and competitive stability of 16 species grown in the mixed species trial at Mt. Mee. The horizontal axis is the species height at 10 years while the vertical axis is the regression coefficient tracking the changing relationship between height growth and Competition Indices (CI) over time. Species abbreviation are: AC *Araucaria cunninghamii*, AT *Argyrodendron trifoliolatum, CA Castanospermum australe, CE Cryptocarya erythroxylon, DF Dysoxylum fraserianum, DF Dysoxylum mollissimum, EG Elaeocarpus grandis*, FB *Flindersia brayleyana*, FS *Flindersia schottiana*, GL *Gmelina leichhardtii, GR Grevillea robusta*, KN *Khaya nyasica, RR Rhodosphaera rhodanthema, TC Toona ciliata.*

A third approach could be to choose species with similar overall growth rates but which have Competition Indices that remain stable over time showing that they are able to adapt to any changes over time in the competition offered by neighbours. Again, dominant species that overtopped their neighbours and began suppressing them (shown by a drift in the Competition Index) would not be appropriate components in multi-species mixtures.

It is one thing to identify these patterns and relationships but it is another to identify the silvicultural or physiological causes underpinning the competitive abilities of the particular species. Are they related to shade tolerance? Or to nutrient acquisition strategies? Or are some other factors involved? If we knew this it might be possible to generalise more widely from the particular suite of species being studied in this trial and identify other species that might form complementary mixtures.

Is there any production gain from using mixtures?

Species grown in mixtures may simply grow well together or the stands may, potentially, provide production gains over monocultures for the reasons outlined above. But which species gain an advantage from being grown in mixtures and which groups of species provide the biggest gains? To examine the first question the database (see Bristow *et al* Chapter 6) containing growth information for 100 plots in the CRRP, including monocultures and multiple species mixtures, was examined.

After investigating the database only three species, *Agathis robusta*, *Araucaria cunninghamii* and *Eucalyptus pellita*, were found to be growing in plots in monoculture and mixtures under similar environmental conditions. Growth data from mixtures were grouped for each species, even though there was a range of planting densities and a diversity of species surrounding these 'target species' in the different plots. Results for the three species, from sites that were on basalt derived soils and in similar rainfall zones (1600 to 2500 mm), are presented in Table 1. The mean height and diameter at breast height over bark (DBHOB) of each of these three species were always higher when they were grown in mixtures. However, the difference was only statistically significant in the case of *E. pellita* which was taller when grown in mixture than when grown in a monoculture. These results suggest that these species may obtain some production gains from being grown in mixtures but that the benefits appear to be relatively marginal after eight years of growth.

Table 1 Comparisons of the height and Diameter Breast Height Over Bark (DBHOB) at age eight years of three species growing in monocultures and random mixtures established by the Community Rainforest Reforestation Program. All plots containing these species were growing on basaltic soils. Values are means (±one SD).

	Agathis robusta	*Araucaria cunninghamii*	*Eucalyptus pellita*
Height in monoculture (m)	5.7 (1.7)	9.7 (2.1)	11.8 (2.8)
Height in mixture (m)	6.8 (2.1)	10.2 (2.6)	15.4 (2.8)*
DBHOB in monoculture (cm)	8.3 (3.2)	14.0 (2.9)	16.1 (5.6)
DBHOB in mixture (cm)	9.5 (3.8)	14.1 (3.4)	17.3 (4.9)

** Significantly different at $p < 0.01$*

The CRRP growth plots do not appear to offer any particular answers to the question of which groups of species provide the biggest production gains as pair-wise mixtures were uncommon in the CRRP growth plots. Most experimental work on species groups has generally been done in simple two-species mixes (Harper 1977) and the traditional experimental approach has been to hold plant density constant and vary the proportion of species A and species B. In the case of a 50:50 mixture, for example, the comparative value of the mixture can be judged by assessing the Relative Yield of each species. The Relative Yield is the ratio of the yield of species A in a mixture relative to the yield of species A in a monoculture. If the sum of the Relative Yield for species A plus the Relative Yield for species B (i.e. the Relative Yield Total) > 1.0 then the mixture of these two species is beneficial (Kelty 1992).

A carefully designed field trial was carried out at Babinda in north Queensland to test the consequences of growing paired mixtures of various high-value tree species. Four species were used yielding six pair-wise comparisons (plus the four monocultures).

The species chosen (*Flindersia brayleyana, Elaeocarpus grandis, Eucalyptus pellita, Acacia aulacocarpa*) had quite contrasting silvicultural attributes in terms of growth rates, green crown depths (an expression of shade tolerance), nitrogen fixing abilities, canopy architectures, etc.

The mixtures were created by growing the species in alternative rows of trees such that a row of species A was planted with rows of species B on either side. Likewise, a row of species B was established with rows of species A on either side. The controls were a row of trees of species A with adjoining rows of trees of A and a row of trees of species B with adjoining rows of trees of species B (Huynh Duc Nhan 2001).

After three years it was clear that some combinations were more productive than others and that some combinations were comparative failures (Table 2). For example the mixture of *Flindersia brayleyana* and *Eucalyptus pellita* had a summed Relative Yield of 1.62 suggesting it was significantly better than monocultures of either species. By contrast, the mixture of *Elaeocarpus grandis* and *Eucalyptus pellita* had a summed Relative Yield total of only 0.90 suggesting this mixture was much less successful and grew more poorly than if these two species were grown alone in monocultures.

Table 2 Relative Yields based on biomass after three years of growing various paired mixtures of tree species in alternate rows.

Mixture		Relative Yield		Total Relative Yield
		First species	Second species	of Mixture
Flindersia	*Eucalyptus*	0.71	0.91	1.62
Flindersia	*Acacia*	0.73	0.66	1.39
Flindersia	*Elaeocarpus*	0.56	0.64	1.20
Acacia	*Eucalyptus*	0.54	0.83	1.37
Acacia	*Elaeocarpus*	0.53	0.65	1.18
Eucalyptus	*Elaeocarpus*	0.56	0.34	0.90

Source: Huynh Duc Nhan (2001)
Note: The Relative Yield is the ratio of the yield of a species in a mixture and the yield of a species in a mixture. A Total Relative Yield of 1.0 would indicate trees grew equally well in a mixture and in both monocultures. A Total Relative Yield >1.0 indicates the mixture is more productive than either monoculture.

Subsequent studies (Huynh Duc Nhan 2001) to explore the reasons for these differences suggested the trees of *Flindersia brayleyana* and *Eucalyptus pellita* had complementary attributes that reduced inter-tree competition in the mixture. The *Flindersia* had a deeper green crown and produced taller trees when grown in the mixture in comparison with its growth in a monoculture. The *Eucalyptus pellita* also had a deeper root system than the *Flindersia* which allowed it to explore deeper soil resources. By contrast the *Elaeocarpus grandis* and *Eucalyptus pellita* were both shade intolerant species with similar crown and root characteristics. This made them essentially identical competitors with no niche differentiation.

One of the well known beneficial mixtures is that where a nitrogen fixer, such as *Facaltaria moluccana* or *Acacia mearnsii*, is mixed with non-nitrogen fixing Eucalypts (e.g. Khanna 1997, Binkley *et al.* 1992). These benefits are only likely to occur where nitrogen deficiencies are present and where nodulation occurs and nitrogen fixation is rapid. This was not the case with *Acacia aulacocarpa* at the Babinda field site and may not be the case at many of the comparatively fertile sites in north Queensland where other rainforest tree plantations have been established (but see Webb *et al.* Chapter 5).

Are all mixtures stable and long-lasting?

The studies described above are necessary descriptions of what happens in the early stages of plantation development. This is a crucial period when canopy closure occurs, when competitive relationships are established and when dominance or suppression commences. What happens to these multi-species stands in the longer term? Are the patterns observed in these crucial early years maintained in the longer term or do subsequent changes take place? Unfortunately we have no good data to answer such questions although Vanclay (1994) noted that in natural rainforests in north Queensland the relationships between growth rates of various species remained stable once trees were established. Part of the difficulty in answering this question lies in the fact that so little is known of the ecology and plantation silviculture of most rainforest species irrespective of whether they are grown in monocultures or mixtures (Lamb and Keenan 2001). However, continued detailed observations at the Mt. Mee site have revealed that unexpected developments may sometimes occur, suggesting some caution is needed.

The Mt. Mee trial included species representing early as well as late successional stages. It had been assumed that the species normally found in later successional stages would be slower growing and this was indeed the case (Erskine *et al* In Press). It had also been assumed, however, that while these species might be overtopped by their neighbours, they would persist as members of the sub canopy. While this was true of some of these secondary successional species it was not true of two of the mature phase species, *Argyrodendron trifoliolatum* and *Cryptocarya erythroxylon* (Table 3). These two species did decline after being planted in the open but their numbers also subsequently declined following canopy closure which occurred four years after planting. Some unexpected early losses also occurred with some of the fast growing early successional species. The most obvious example was *Acacia melanoxylon* which was expected to live for at least 40 years but died out after 10 years (Table 3).

Table 3 Survival of four species over 12 years in a multi-species plantation at Mt. Mee in south-east Queensland.

Species	Successional stage	Survival (%) 4 years	8 years	12 years
Acacia melanoxylon	Early	96	89	0
Argyrodendron trifoliolatum	Mature	82	71	57
Cryptocarya erythroxylon	Mature	54	43	14
Toona ciliata	Secondary	86	75	57

Most of the species (including those identified in Table 3 above) which were planted at the Mt. Mee site were present in nearby rainforest and were presumably adapted to local environmental conditions. This demonstrates that it is imperative that the trees planted in the CRRP and other experimental farm forestry systems be carefully monitored into the future to learn as much of their silviculture as possible, and to determine why these species were not successful in the controlled environment.

How many species should be used in a mixture?

Mixed species plantings were used in the CRRP because they were seen as a more “natural” way of growing trees normally found in very species-rich forests. But there was an unstated limit to just how much diversity should be included in a multi-species plantation when timber production was also a management goal. Most CRRP plantings had more than ten species and only fifteen percent had less than five (see Figure 1).

It is difficult to find any basis for these necessarily empirical decisions and, so far, ecological science has little to say on the matter even though this topic has been one of intense discussion in recent years (eg. Mittelbach *et al.* 2001). Just what is the functional consequence of biodiversity? How many species are needed to maximise an ecological function like productivity? Early results using grasses suggest there may be some benefits from having up to 16 species in a mixture (Kinzig *et al.* 2002) but there are no useful results to date from studies using trees.

It is important to differentiate ecological productivity and commercial productivity. While it may be possible that a mixture of, say, five tree species still leaves part of the niche space under-utilized, the financial gains to be made from using five or more tree species will depend very much on the relative market values of these species. If the value of the third, fourth and fifth species are much less than the market values of the first and second species then adding more than two species to the mixture dilutes the overall financial return (ie. there are fewer individuals of the most valuable trees per hectare).

There is no easy solution to this problem because it depends on the trade-offs being made by the plantation manager. Productivity gains may occur if complementary species are used but, at some point, these advantages are likely to be outweighed by the financial dilution effect (above). On the other hand, more tree species are likely to increase environmental complexity and provide other benefits such as improved wildlife habitats, improved watershed protection etc. Of course not all tree species need be represented by equal numbers of trees and some biodiversity benefits may be generated by even modest population sizes. Understorey development can occur beneath even simple monocultures if intact forest is nearby (see Wardell Johnson *et al.* Chapter 11). In such cases the biodiversity gains may come irrespective of the initial plantation design. These issues need much further work to resolve.

Conclusions

Rainforest plantations made up of a random mixture of species are difficult to manage and are unlikely to be more productive than traditional monocultures. However, there is evidence that carefully selected multi-species plantations of species with contrasting growth forms and rooting depths are likely to be more productive than simple monocultures.

There is limited knowledge to date of the growth phenology of many species and, consequently, no evidence that differences in phenology can be used to guide the choice of species to use in mixtures. Similarly, with the exception of *Toona* and the tip moth borer *Hypsipyla robusta*, there is no evidence to date of mixtures offering significant protection from insect damage or disease. In both cases, future studies may provide more information about these possibilities.

The stability of multi-species plantations and the numbers of species to include in plantations established for timber production are both matters about which we currently have limited data and both deserve further study. Careful monitoring of the current CRRP plantations could help provide future guidance.

Multi-species reforestation should be seen as just one approach to growing high-value rainforest trees in plantations. Plantation monocultures, including a mosaic of monocultures of different species spread across a landscape, are another. Mixtures represent a way of balancing a need for generating a financial outcome with a desire to also create some ecological services on the one site. As such, they are possibly the only way by which some degree of ecological complexity will be restored to large areas of cleared tropical forest landscape. But the silvicultural tools to establish these plantations are still being created and the means by which a land owner can make the trade-offs involved have not yet been developed.

Acknowledgements

The field trials referred to in this chapter have involved a variety of people over the years as well as a variety of funding sources and we are grateful to all of these. The Mt. Mee trial was established on land owned by Don and Audrey Pickering who have been generous in allowing us to work on their property over many years. The initial funding came from the Federal Government's Rainforest Afforestation Program and subsequently from grants from the Joint Venture Agroforestry Program. The site was established with the assistance of volunteers from Greening Australia and has been measured annually by a large number of students from the University of Queensland. Most of the early site management was supervised by Geoff Borschmann. The Babinda trial was established on land owned by Errol Wiles. Errol has been an enthusiastic supporter of all work that has been carried out at that site. Funding for the establishment of the trial and the work carried out at on Errol's land was mostly provided by the Rainforest CRC. The trial was established with the considerable assistance of the Queensland Forestry Research Institute and much of the early site management was carried out by Rod Keenan and Mila Bristow and their colleagues.

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10. Stand density management in rainforest plantations

Rodney J. Keenan, David Doley and David Lamb

Abstract

Trees in plantations established for timber production are usually grown at a sufficiently high density that canopy closure occurs within a relatively short time after planting. The trees then shade and out-compete most herbs, shrubs or grasses growing at the site. The closer the spacing (i.e. the greater the density) the faster this will occur. Subsequently, as the trees grow larger, this between-species competition is replaced by within-species competition. If unmanaged, this competition can reduce the commercial productivity of the plantation. Thus, there are two management dilemmas. One is knowing the best initial planting density. The second is knowing how to management the subsequent between-tree competition in order to optimize overall plantation timber productivity. In this chapter we consider initial spacing and thinning for high value timber trees grown in single and mixed species plantations. From growth studies in stands of different ages recommendations are proposed for managing both types of plantations where the primary objective is timber production. It seems that many rainforest species will require more space to achieve optimal growth than most eucalypts and conifers. On the other hand many rainforest species do not have strong apical dominance. Care will be needed to balance these two attributes.

Introduction

Growth of plantation trees and stands is determined by site factors (solar radiation, temperature, topography, water balance, soil nutrient status) and the genetic and physiological characteristics of the planted species (Oliver and Larson 1996, Landsberg and Gower 1997). Management can affect some site characteristics. For example, significant and long-lasting increases in stand growth are often achieved through intensive site preparation, weed control, and nutrition management in the establishment phase (Evans 1992, Nambiar and Brown 1997)). Adding nutrients later in stand development can also produce significant growth responses in treated stands (Maggs 1985, Nambiar and Brown 1997). Following establishment and crown closure, tree and stand development can be manipulated by pruning and thinning (Evans 1992). Selection of initial stocking and thinning regimes will depend on stand management objectives, markets for different size classes, species characteristics and site conditions.

Initial plantation spacing

In the early years of plantation silviculture, trees were planted at relatively high densities, and thinned frequently to produce final crop stems (Troup 1952). This approach is expensive (due to seedling and planting costs and the cost of labour for thinning) and growth rates of individuals under these conditions are usually low. Markets are also often not available for thinnings. It is now more common to plant trees at wider spacings and thin less frequently but more heavily (Fenton and Sutton 1968, Hogg and Nester 1991). Wide planting spacings have been possible in coniferous species because they have strong apical dominance independent of spacing. Hardwood species, such as eucalypts, commonly develop persistent ascending branches when grown at wide spacing (Florence 1996). This can result in a very short merchantable bole and unacceptable form even if diameter growth rates are high.

Comparatively few studies of initial tree spacing and tree growth have been carried out on rainforest tree species in plantations. The influence of planting spacing on subsequent tree dimensions is illustrated by an experiment using *Eucalyptus grandis* in southern Queensland (details can be found in Cameron *et al*. 1989). *E. grandis* is a light-demanding species that regenerates naturally in even-aged stands (Florence 1996). It sheds branches naturally, and the stems in this trial were not pruned, so the bole length reflects the effect of side shade on branch survival. Trees were planted into an established pasture at spacings ranging from 1.7 to 21.3 m in a Nelder spacing design (Nelder 1962) of nine concentric circles and 18 radii, measured in 1996 at age 13 years.

The greatest mean diameter at breast height (DBH) was recorded at the widest spacing but there was no significant difference between mean DBH at 22 and 42 trees per hectare. In contrast to DBH, largest mean tree height was associated with an intermediate planting density of 305 trees ha^{-1}. The longest mean bole length (height to the lowest persistent branch) was observed for trees spaced at about 600 trees ha^{-1} (Table 1). Mean bole lengths were much shorter in trees at the two widest spacings, where branches survived almost from the first year of growth, than in the more closely spaced parts of the trial.

Table 1 Tree dimensions in a 13-year-old unthinned stand of flooded gum (*Eucalyptus grandis*) planted at different densities. Shaded numbers indicate the maximum value of each attribute.

Initial spacing m	Initial density Trees/ha	Dbh cm	Height m	Bole length m
1.7	3580	11.7	17.7	8.7
2.2	2150	13.4	18.8	10.1
3.0	1140	16.7	21.1	11.1
4.1	595	20.3	21.9	12.2
5.7	305	23.3	23.0	11.5
8.0	158	27.0	21.7	6.8
11.0	82	30.1	21.3	5.2
15.4	42	31.5	19.9	3.1
21.3	22	31.6	18.9	2.6

Assuming that the stems were conical in shape, the largest mean total stem and bole volumes per tree occurred in trees planted at 82 stems ha^{-1}, equivalent to a tree spacing of 11 m (Table 2). However, these very wide spacings (greater than 10 m) will only yield a relatively small commercial return per hectare from timber production. Such wide spacings are only likely to be applied where plantation management is aimed at objectives are other than timber production, for example providing shade for cattle. Total stand volume production is a function of DBH, bole length and stocking.

At the time of the last measurement, about one-quarter of the trees had died at the closest spacing. Surviving trees at this spacing had few, very small branches and small bole volumes, but the total bole volume per hectare was the greatest recorded in the trial. Trees planted at an initial spacing of 4.1 m had the greatest mean bole length, close to the largest total height (Table 1) and bole volume per tree, mean bole volume equal to almost 90 percent of total stem volume, and a relatively high bole volume per hectare (Table 2).

Table 2 Individual stem and bole volumes, and bole volume per hectare in an unthinned 13-year-old stand of *Eucalyptus grandis* planted at different densities. Shaded numbers indicate the maximum value of each attribute. The outlined row indicates the spacing associated with the best forest growth form (see Cameron *et al*. 1989 for experimental details). Stem volume was calculated using conical volume. (This may not accurately indicate the true volume.)

Initial spacing m	Entire Stem volume m^3/tree	Bole volume m^3/tree	Bole volume % stem	Bole volume per ha m^3/ha	Mean bole increment m^3/ha/yr
1.7	0.082	0.078	95	217	16.7
2.2	0.102	0.100	98	167	12.8
3.0	0.186	0.163	88	165	12.7
4.1	0.291	0.260	89	146	11.2
5.7	0.357	0.304	79	93	7.1
8.0	0.482	0.326	68	48	3.7
11.0	0.616	0.353	55	29	2.2
15.4	0.598	0.231	38	10	0.8
21.3	0.584	0.201	34	4	0.3

Selection of the optimum initial spacing requires knowledge of the relationship between stocking and individual tree, and stand, growth. This can be a function of crown diameter in relation to growing space. Where trees were planted at closer than 6 m spacing, crown diameter was approximately equal to the tree spacing (Table 3). A ratio of crown diameter to tree spacing of 1.0 indicates the tree crowns occupied all the available space while values less than 1 indicate gaps between crowns. Crowns of trees grown at spacings of about 15 m did not appear to interact at all and they produced very large branches and very short boles. Death of lower branches up to age 13 years appeared to be associated with a ratio between crown diameter and spacing of more than 0.9. This ratio is likely to vary with tree species, being lower for species that are intolerant of shading.

Trees with the most desirable form for timber production (i.e. straight boles with no retained branches) occurred with an initial spacing of 4.1 m. Branch shedding at this spacing had occurred while branch diameters were small, but the crowns were generally vigorous. Trees in this trial could be expected to continue height growth for several years and a relatively small crown is likely to be less important to maintain height growth than retaining branches that limit bole extension.

Thinning

Thinning is generally carried out for the following reasons (Evans 1992, Florence 1996, Oliver and Larson 1996) :

- to remove dead, dying or suppressed trees and reduce potential infestation by pathogens;
- to utilise commercial material that would die through self thinning;
- to remove trees with stem defects or inferior form that are competing with final crop trees;
- to provide remaining trees with greater access to growing space and resources and to accelerate their diameter growth;
- to reduce the time for trees to reach a commercial size and to enhance the profitability of the plantation; or
- to provide greater light, nutrients and water to understorey vegetation such as grasses and forbs for grazing or wildlife habitat, or crops in agroforestry systems.

Table 3 Crown conditions and tree attributes in an unthinned stand of *Eucalyptus grandis* planted at different densities. Shaded numbers indicate the maximum value of each attribute. The outlined row indicates the spacing associated with the best forest growth form.

Initial spacing m	Crown diameter m	Ratio, crown diameter/ spacing	Crown Ratio *	Condition of trees
1.77	1.8	1.08	15	Long bole, suppressed crown, small branches
2.25	2.2	1.02	16	Long bole, suppressed crown, small branches
3.00	3.0	1.01	18	Long bole, weak crown, small branches
4.1	4.0	0.97	20	Long bole, small crown, small branches
5.7	5.3	0.93	23	Long bole, vigorous crown, medium branches
8.0	7.2	0.90	27	Short bole, vigorous crown, large branches
11.0	8.7	0.79	29	Short bole, vigorous crown, large branches
15.4	10.4	0.67	33	Very short bole, very large branches
21.3	10.1	0.47	32	Very short bole, very large branches

** Crown Ratio is the ratio of crown diameter (m) to tree stem diameter (cm)*

As indicated above, silvicultural regimes have changed over time in response to changing market, economic and management requirements. In most modern industrial plantations, planting densities have gradually been reduced and thinnings have become less frequent and more intensive. This is due to tree improvement programs producing a much higher proportion of individuals with commercial potential, to reduce costs associated with thinning and to shorten the time required for final crop trees to reach a minimum merchantable size.

Because of high labour costs, more forest operations are becoming mechanised and thinning systems are being simplified, for example, through the use of row thinning, to suit mechanical operations. Intensive thinning to low stocking may increase risk of wind throw in areas where wind is a problem.

For rainforest trees intended to yield higher-value products such as sawn timber or veneer, the value per unit volume of larger logs is generally considerably greater than that of smaller logs due to processing efficiencies and equipment (Reid 1997, Mason *et al*. 1997). To grow trees to these more valuable, larger sizes in the shortest time, and achieve maximum returns for the forest grower, stand spacing needs to be reduced over time. However, the effect of spacing on growth varies considerably between tree species, thinning operations are often expensive and the market for products from thinnings varies considerably between regions. Consequently, designing stand management regimes and determining the appropriate timing and intensity of thinning can be complex.

The appropriate thinning regime for rainforest species will depend on the management objective. Historically, the wood quality and price per unit volume received for species such as Queensland maple (*Flindersia brayleyana*) has been linked to individual tree size. In the past, sawmillers would not accept logs less than 40 cm DBH and maximum royalties were obtained for logs greater than 80 cm DBH. Currently in north Queensland, there is a very limited market for small-sized logs of any species. If these market conditions continue, it will be imperative to grow rainforest species to a minimum acceptable size in the shortest possible time. Non-structural wood properties such as colour and figure may also be important determinants of log value. Other management objectives, such as retaining or encouraging understorey plant species diversity, will also influence silvicultural choices. Mixed species arrangements used in many of the private hardwood plantations in north Queensland further complicate silvicultural decision making (Keenan *et al.* 1995). However, private forest owners may be less constrained by labour costs than state or industrial forest enterprises and this may increase their management options.

Analysis of alternative thinning regimes generally involves the use of an index of stand density that is independent of site quality and tree age. A variety of such indices have been presented in the silvicultural literature, based on either diameter, basal area or height, but most of these variables tend to be strongly correlated (West 1982, Jack and Long 1996). Reineke's (1933) stand density index (SDI) provides a reasonable predictor:

$$SDI = TPH\ (Dq/25)^{1.6} \qquad (1)$$

where TPH is the stocking in trees per hectare, and Dq is the quadratic mean diameter of the stand in centimetres (diameter corresponding to the mean tree basal area) (Jack and Long 1996). Density management diagrams have been used for a number of dominant forest species in Japan and North America (Newton 1997), and a stand density management decision-support system has been recently published for black spruce (*Picea mariana*) plantations in Canada (Newton 2003). Extension of the SDI principles to multi-aged stands of a single species was described by O'Hara and Valappil (1998), but for tropical species, SDI analyses have only been undertaken for even-aged teak plantations in India (Kumar *et al*. 1995).

A 'theoretical' maximum stand density index value can be calculated using data from unthinned stands, but determining the maximum stand density for a species is problematic. The observed maximum is generally about 85% of the theoretical maximum (Drew and Flewelling 1977). The SDI of different stands can then be related to this theoretical maximum density and expressed as a relative density (percentage of the maximum).

It might be expected that the combinations of tree size and stand density at which individual tree growth slows, self-thinning rates become high, and the upper bound of tree size-density combination is reached will be consistent between species and described by relative density (Long 1985). Jack and Long (1996) refined this concept by allowing for differences in species' responses according to their physiological attributes, particularly tolerance of competition, and canopy architecture. However, the simplicity of Long's (1985) approach has many attractions when physiological information is limited. He suggested that the on-set of competition between trees begins when a stand reaches a relative density of 25%, the site becomes fully occupied at 35%, and mortality induced by competition between trees (self-thinning) increases rapidly above 60%. To maximise stand volume production, but avoid losses due to self-thinning, stand density should therefore be kept within a range of 35-65% of the maximum. Growth of individual trees can be faster at lower densities but this will be associated with some loss to overall stand production. The SDI concept is applied most readily to single-species stands, or to mixed stands as a whole where the species' growth characteristics are assumed to be similar. An alternative approach is outlined later for mixed stands in which the species growth characteristics are less similar.

Stand development in Queensland maple

Long's (1985) principles of stand development were used to construct a stand density management diagram that indicates thinning regimes for Queensland maple in north Queensland. This species was planted at a range of sites across the Atherton Tableland and the Queensland Forestry Research Institute (QFRI) and its predecessors established a substantial number of thinning experiments in these plantations. Most were terminated at relatively young plantation ages and measurement on almost all experiments ceased in the 1970's. Results have been formally presented elsewhere (Keenan *et al*. 1999), but these and other studies (Brown 2002) can provide a guide to future management of rainforest species plantations.

Four thinning experiments were selected for analysis. All experiments were located in north Queensland (latitude 17^o to 17^{o}35'S), in Gadgarra and Danbulla State Forests on the Atherton Tableland (around 700 m.a.s.l.) and Kuranda State Forest (410 m.a.s.l.). Rainfall ranges from 1600 to 2100 mm per annum (see Keenan *et al*. 1999 for full site details).

Most experiments were located in 10 to 20-year-old plantations, with planting dates ranging from 1929 to 1955, and initial stockings from 1100 to 1700 stems/ha (Table 4). Thinning occurred between one and four times, with residual stockings varying from 200-1200 stems/ha. All thinnings were non-commercial as there was no market for small-sized timber. Measurements were collated from field files and the QFRI experimental database. Experiments 46 and 88 were re-measured during 1994. Stem diameter at breast height (1.3 m, DBH) and sometimes bole length (to a minimum diameter of 20 cm) were measured for all trees in each experiment. In general the experiments were set up as observation plots, and the designs did not include replication. Consequently there is confounding of treatment and site variation across the experiments that did not allow statistical analyses of treatment effects. Periodic mean annual increment in diameter over a five-year period (PMAI) following each thinning was calculated for all plots in Experiments 46, 85 and 88.

Experiments were established at different times and had different measurement histories so that comparison across sites at a common age was only possible at age 22 yr (Table 5). In unthinned plots stocking ranged from 842 - 1143 stems/ha; basal area was highest in Experiment 88 at Gadgarra State Forest on basalt soils (41.9 m^2 ha^{-1}), and lowest in Experiments 85 at Danbulla State Forest on granite soils (34.0 m^2 ha^{-1}). Thinning histories prior to age 22 varied considerably, with Experiment 46 thinned once just prior to the measure, Experiment 88 thinned once at age 10, and Experiments 85 twice and 325 four times (Table 4). The substantial reductions in basal area in thinned stands had resulted in greater growth on retained trees, but basal areas in thinned stands remained below those of unthinned stands. Mean diameter increment was greater than 1.0 cm/yr on all thinned plots, with the largest mean diameters (about 27 cm) on the metamorphic soils at Kuranda in plots that had been thinned twice to relatively low levels (40-45% of maximum density). Although Experiment 85 at Danbulla was thinned earlier than, and in one plot to a similar stocking as, the Kuranda experiment, diameter growth at Danbulla was less than that at Kuranda. This is possibly due to lower rainfall and more coarsely-textured soil type resulting in lower water availability at Danbulla.

Table 4 Experiments established to investigate response to thinning of Queensland maple (*Flindersia brayleyana*) on the Atherton Tableland in north Queensland.

State forest	Experiment No.	Date planted	Initial stocking (Stems/ha)	Plot number	Number of thinnings	Thinning Ages (Years)	Stocking prior to first thinning (stems/ha)	Stocking after last thinning (stems/ha)	Year of last measurement
GADGARRA	46	1929	1160	1	1	-	842	786	1994
		“		2	3	21, 28, 36	845	311	“
“		“	“	3	3	“	702	220	“
“		“	“	4	3	“	813	200	“
GADGARRA	88	1941	1500	1	1	10	1318	1006	1994
		“		2	2	10, 24	1204	449	“
		“	“	3	2	“	1290	357	“
		“	“	4	2	“	1339	243	“
DANBULLA	85	1947	1500	1	-	3, 17	1400	1198	1974
		“	1700	2	2	“	1738	631	“
“		“	“	3	2	“	1574	621	“
“		“	“	4	2	“	1573	412	“
KURANDA	325	1955	1500	1	4	-	1107	394	1977
		“		2	4	9, 20	1142	396	“
“		“	“	3	4	“	1413	395	“
“		“	“	4	3	13, 20	1056	483	“

The maximum SDI observed was about 900 in an unthinned plot with 1006 stems/ha and Dq of 23.3 cm at age 24 yr in Experiment 88 at Gadgarra State Forest (Table 4). A number of other unthinned stands were close to this level. From this it was concluded that the potential maximum SDI for maple was 1060. This value was consistent with graphical analysis and was similar to values for other tropical broadleaved species (Kumar et al. 1995), but well below the maximum level for conifers (Long 1985). The crown architecture of maple is similar to many other emergent tropical rainforest species in that once it attains a certain height it develops a broad spreading crown and has relatively high crown diameter to stem diameter ratio (Brown 2002). Consequently, the space required for individual trees to maintain a high diameter increment (>1 cm/year) will be greater than that for species with narrower and deeper crowns such as young eucalypts and conifers.

Table 5 Comparison of thinning experiments in plantations of Queensland maple at four sites on the Atherton Tableland, north Queensland at age 22 years. Maximum relative density was assumed to be 1030 calculated using Reineke's stand density index (Jack and Long 1996). BA is basal area, Dq is quadratic mean diameter, RD is relative density.

Experiment Number	Plot	Stems/ha	BA (m^2/ha)	Dq (cm)	% Maximum RD
46	**1**	**842**	**35.3**	**23.1**	**70**
46	2	604	26.3	23.6	67
46	3	482	23.7	25.0	60
46	4	412	18.1	23.7	62
88	**1**	**1052**	**41.9**	**22.5**	**84**
88	2	880	34.4	22.3	69
88	3	768	31.4	22.8	63
88	4	620	29.1	24.4	66
85	**1**	**1143**	**34.0**	**19.5**	**72**
85	2	604	25.2	23.1	50
85	3	475	19.4	22.8	39
85	4	412	17.3	23.1	34
325	**1**	**1094**	**36.8**	**20.7**	**76**
325	2	394	22.8	27.1	42
325	3	396	22.3	26.8	42
325	4	395	23.1	27.3	43
325	5	483	22.7	24.5	44

For an unthinned plot in Gadgarra State Forest at age 67 years, Dq was 33.8 cm and stand density was 770 canopy stems ha-1 (Brown 2002), resulting in an SDI of 1245. The difference between this value and the theoretical maximum at age 22 years suggests that some caution be used in applying generally the 'theoretical maximum' SDI figure indicated above for maple. Differences in crown and canopy architecture between relatively vigorous 22-year-old and crowded 67-year-old trees may explain the higher density in older stands. The 67-year-old stand contained a large minority of trees with crown ratio of less than 12 that had been able to persist in very crowded conditions with very little growth.

The diameter PMAI of 20-year-old Queensland maple ranged from about 0.2 cm/yr in unthinned stands (relative densities of about 80%) to over 1.2 cm in young thinned stands. Increment declined as relative density increased with a steep decline between 20 and 40% (Figure 1) confirming that the onset of between-tree competition in maple occurs at a relative density of about 25% (Long 1985).

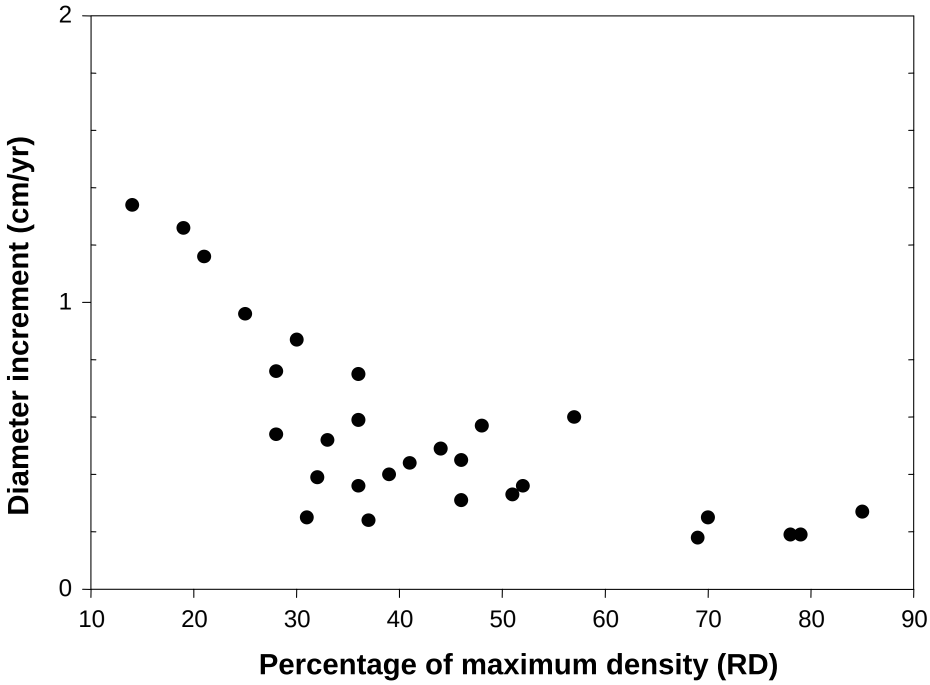

Figure 1 Periodic mean annual diameter increment for five year following thinning versus percentage of maximum relative density and (b) basal area relative growth rate (basal area increment/basal area), for Queensland maple (*Flindersia brayleyana*) thinned to various levels at Gadgarra and Danbulla State Forests, north Queensland.

In a plot of stocking versus Dq for unthinned plots there is a characteristic vertical trajectory as diameter increases, with a curve to the left with the onset of self-thinning (Figure 2). The theoretical maximum stand density (SDI of 1060) is also plotted (the line marked '100'). Three lines are also marked parallel to this corresponding to the threshold relative densities proposed by Long (1985). Visual inspection suggests that the 60% line coincides with the onset of self-thinning.

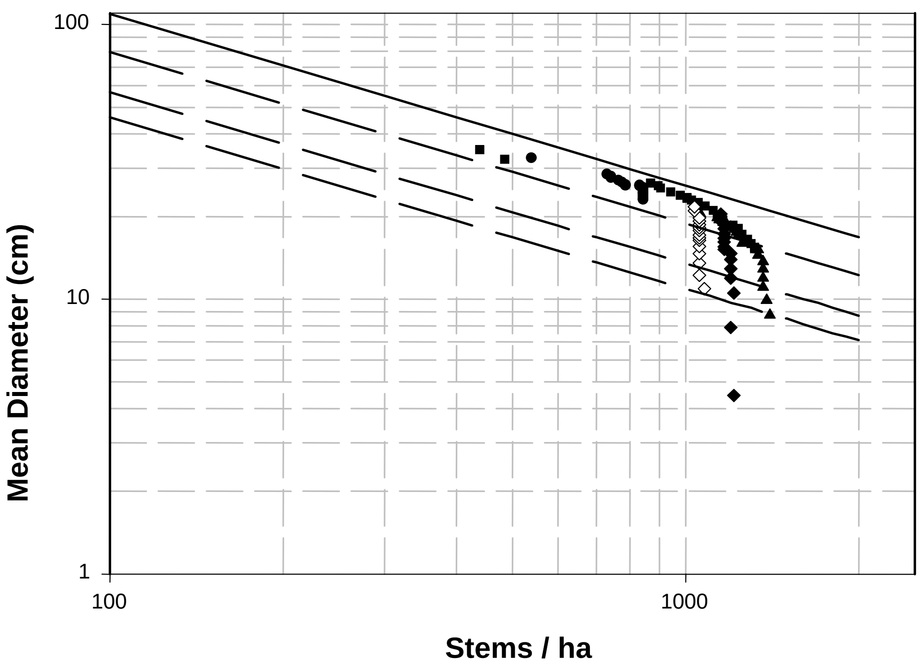

Figure 2 Mean diameter (cm) versus stocking (stems/ha) for unthinned plots of Queensland maple (*Flindersia brayleyana*) from four experiments shown in Table 4. Diagonal lines indicate maximum value of Reineke's stand density index assumed for maple (100), and 60%, 35% and 25% of the maximum value in descending order.

Thinning regimes for monoculture plantations

The stand density diagram was used to develop thinning regimes that could be used in a single-species plantation (Appendix 1). To maintain full site occupancy but avoid losses due to self-thinning mortality, a manager would generally aim to maintain relative density between 35 and 60 percent. However, in the market conditions that exist for maple in north Queensland it may be preferable to apply a 'direct' regime. These regimes involve planting at wide initial spacing and thinning heavily, early and to waste in order to maximise diameter growth rates of individual trees. They have been applied in radiata pine (*Pinus radiata* D.Don) in New Zealand (Fenton and Sutton 1968) and hoop pine (*Araucaria cunninghamii*) in southern Queensland (Hogg and Nester 1991). Such regimes maintain stand density below 35% of maximum SDI, with some loss of overall stand production in return for maximum individual tree growth to a desired minimum size.

However, other factors suggest that low initial stocking and heavy early thinning may not be appropriate for Queensland maple. Lamb and Borschmann (1998) demonstrated in a variable spacing experiment in southern Queensland that planting Queensland maple at relatively high initial stocking (> 1000 stems/ha) resulted in more rapid height growth, smaller branches, more rapid branch shed (and consequently more rapid occlusion of smaller branches), greater bole length and straighter stems than occurs at wider spacing.

Queensland maple has not been the subject of tree breeding or selection programs, so seed is collected from trees in the wild and there is a wide range of tree form and degree of forking and branching in plantations. Planting at higher density allows a greater level of selection to be applied in the thinning operation. It also provides more rapid site capture and shading of competing vegetation, although maple is generally quite shallow-rooted (Swain 1928) and if planted on ex-pasture sites is highly susceptible to competition from grasses. More rapid shading of grasses would reduce the effort required for weed control and reduce the potential impacts of competing vegetation.

Thinning monoculture plantations with dense understoreys

Some plantations established as monocultures can be colonised by a variety of other tree species (Keenan *et al*. 1997). In one case Brown (2002) reported that 30 percent of the stand basal area in an unthinned 67-year-old Queensland maple plantation at Gadgarra was contributed by species other than Queensland maple. This occurred because many tree species colonising the understorey eventually grew up and joined the canopy layer.

Two treatments were imposed in Brown's (2002) study. In one treatment all trees other than Queensland maple trees and understorey plants were removed. In the second treatment the Queensland maple trees were also thinned, leaving only selected crop trees. Before thinning, mean stem diameter was 36 cm, stand basal area was 78 m^2/ha (55 m^2/ha of Queensland maple) and canopy stem density was 770 stems/ha. As a result of the treatment, the total stand basal area was reduced by 53% to 37 m^2/ha (36.5 m^2/ha of Queensland maple) and the residual density to 330 stem/ha.

The presence of understorey and non-Queensland maple trees had a significant negative impact on DBH increment in crop trees. The mean annual diameter increment in the untreated and unthinned control stands was 0.05 ± 0.01 cm/yr. Where only the understorey and non-Queensland maple stems were removed, the mean DBH increment in the remaining Queensland maple was 0.13 ± 0. 02 cm/yr. In the case of the thinned stand the mean annual increment was 0.51 ± 0.028 cm/yr, a nearly ten-fold increase in growth rate.

One of the more interesting features of this study was the ability of different trees to respond to the new resources made available after the thinning operation. The crowns of trees growing in a dense, even aged 67-year-old plantation were mostly quite narrow. A useful way of assessing crown condition is to use the crown ratio:

$$CR = CD\ (m)\ /\ DBHOB\ (m)$$

Where CR is crown ratio, CD is crown diameter, DBHOB is diameter at breast height over bark.

Queensland maple trees in the thinning treatment with a crown ratio less than 12 did not respond significantly to thinning. By contrast, the mean DBHOB increment in trees with a crown ratio greater than 12 was 0.54 cm/yr. That is, the larger-crowned trees tended to respond most. Initial crown diameter was, therefore, the best, albeit imprecise, predictor of thinning response.

In analysing these results, Brown *et al*. (2004) drew attention to the wide range of responses to thinning in all crown diameter and DBH classes that reduced the predictive value of pre-thinning tree dimensions. Therefore, it is likely that very crowded plantations (or native forests) cannot be transformed into uniformly and vigorously growing stands by a single radical silvicultural treatment, and they may require a series of more conservative thinnings to identify potential crop trees (Brown *et al*. 2004).

Thinning regimes for mixed species plantings

Where species mixtures are established and where the species used differ in architecture or growth rate, the relatively simple approach to thinning that is described above for monoculture plantations may not be appropriate. In these situations, planning for thinning and other management activities must be incorporated in the original planting design, as the pattern and intensity of tree removal will need to vary for species with different growth rates. One approach to thinning is to consider both the vigour and architecture typical for a species. Vigour will be indicated by characteristic growth rates, and architecture by an expression such as the crown ratio referred to above. The relationships between these two parameters retain a symmetry that makes a species recognisable. For almost a hundred years, foresters have observed that most species maintain an almost constant relationship between crown diameter, estimated as the average spread of an irregularly shaped crown, when grown under favourable conditions in the forest and stem diameter at breast height (Dawkins 1963). When trees become crowded, the crown ratio decreases, as lateral growth of branches is inhibited by neighbouring trees, but height growth continues and stem thickening may also continue, but at a slower rate. Also, when trees reach old age, crown diameter in most trees does not continue to increase indefinitely, as the branches become too heavy to be supported and break off.

Eucalypts and other shade intolerant species in which the crowns of adjacent trees did not intergrow, maintained crown ratios between 15 and 20, and that this identity could be used to design thinning regimes (Lane-Poole 1936). Jacobs (1955) considered that the optimum crown ratio for free-growing young blackbutt (*Eucalyptus pilularis*) and for several other important eucalypt forest species was about 18. This ratio would result in maximum stem diameter increments for individual trees, but maximum stand volume increment was achieved at a crown ratio of 15. At a crown ratio of 15, stand volume growth of *E. grandis* is at a maximum, but most trees in the stand are non-vigorous at 13 years of age (Tables 2 and 3).

Other work has suggested that the optimum crown ratio for blackbutt (*Eucalyptus pilularis*) and broad-leaved red ironbark (*E. fibrosa*) is 20 or 21 (Mackowski 1985; D. Maloney, pers. comm.). Keenan *et al*. (1995) established that Queensland maple requires a crown ratio of 22 in order to maintain satisfactory stem volume growth, and concluded that the disappointing growth rates in most of the experimental plantings of Queensland maple were due to insufficiently heavy thinning. Volck (1969) derived a similar optimum crown ratio for several other north Queensland rainforest species. Dawkins (1963) concluded that many rainforest trees from Africa maintained crown ratios close to 20, and Samarasinghe *et al*. (1996) reported similar relationships for some mature rainforest trees in Sri Lanka. However, the crown ratio of young *Alstonia macrophylla*, an early successional stage species was greater than 50, decreasing to 20 when dbh reached 25 cm.

Five-year-old trees of a number of rainforest species grown at Mt Mee, southern Queensland, exhibited crown ratios varying from 22 (*Acacia melanoxylon*) to 55 (*Dysoxylum mollissimum*) (Table 6). It is interesting that, at this age, Queensland maple had a crown ratio of 35, whilst in a production forest environment, the optimum crown ratio for mature trees was identified to be 22 (Keenan *et al*. 1995). It is important to recognise that the trees were planted in a square arrangement, at a spacing of 3x3 m (1111 stems ha^{-1}), and the crowns of the most vigorous trees had only just fully occupied the planting space.

Therefore, the crown ratios of young or completely open-grown trees are not relevant to the spacing of trees for timber production, whether this is total wood growth per hectare or the optimum development of individual stems for sawn timber.

Table 6 Crown ratios for selected young trees grown in plantations in southern Queensland and mature forest trees grown in Queensland.

Species	Common name	Crown Young	Ratio Mature
Acacia melanoxylon	blackwood	22	
Araucaria cunninghamii	hoop pine	35	
Argyrodendron trifoliolatum	booyong	48	
Castanospermum australe	black bean	33	
Cedrela odorata	cigar-box cedar	25	
Cryptocarya erythroxylon	southern maple	45	
Dysoxylum fraseranum	rosewood	45	
Dysoxylum mollissimum	redwood	55	
Elaeocarpus grandis	silver quandong	39	
Eucalyptus grandis	flooded gum	35	24
Eucalyptus pilularis[1,2,3,4]	blackbutt		19-21
Eucalyptus fibrosa[4]	broad-leaved red ironbark		21
Flindersia brayleyana	Queensland maple	35	8-22
Gmelina leichardtii	white beech	34	
Grevillea robusta	silky oak	28	
Khaya nyasica	East African mahogany	27	
Rhodosphaera rhodanthema	deep yellow-wood	27	
Eucalyptus gummifera[2]	red bloodwood		18
Swietenia macrophylla[5]	Honduras mahogany	36	16-20

[1] *Lane-Poole (1936);* [2] *Jacobs (1955);* [3] *Mackowski (1985);* [4] *D. Maloney* (pers. comm.)*;* [5] *Samarasinghe* et al. *(1996).*

The definition of optimum crown ratio in forest grown trees does not mean that the greatest crown ratio results in the maximum useful (merchantable) wood volume per tree, as is clear from the example of *Eucalyptus grandis* shown in Tables 2 and 3. Therefore, while the crown ratio is far from constant under all conditions, it is close enough to constant under conditions that result in optimum development of useful timber stems. These conditions appear to be provided by maintaining tree spacings that are slightly greater than crown diameter.

It is important that this constant crown ratio holds for forest-grown trees over the complete size range up to about 1m dbh. For seedlings, there is a minimum height associated with the development of lateral branches, and this is usually about 0.5 m (Lane-Poole 1936; D. Maloney pers. comm.).

It is a relatively simple matter to establish the crown ratio for a new species by sampling at least 20 trees that are growing under conditions that are associated with vigorous growth, but good forest form. Initially, it does not appear to be necessary to sample a wide range of stem sizes, although that would be preferable.

Using Crown Ratio to design thinning regimes

The crown ratio and anticipated DBH increment can be used to plan tree spacings at planting and to select trees for thinning in an established plantation. Planting spacing allows for some growth of trees before the first thinning. Early stand growth is a function of site conditions and species, and the rate of early growth will determine this spacing. Similarly, spacing between crowns remaining at any thinning will be determined by DBH increment and the time to the next thinning. These considerations assume that the species is able to survive and grow satisfactorily in full sunlight, that competition between trees in humid forests can be described by the interactions that occur above the ground and that crown ratio is constant for a species.

A simple spacing guide for trees to avoid crown closure is as follows:

$$S = (CR\ (DBH + INC \times A)) \qquad (2)$$

where
S = spacing (m)
CR = crown ratio (crown diameter/DBH)
DBH = stem diameter at breast height (m)
INC = mean DBH increment expected in the interval to next thinning based on past growth (m/yr)
A = time interval to next thinning (yr)

Values derived using equation 2 provides a guide for using this approach (Table 7). For example, a stand with a crown ratio of 20 (a common figure for eucalypts), an average DBH of 13 cm and growing at an average rate of 1 cm/yr will require an average spacing of 3.6 m to maintain maximum diameter increment for a further five years. Typically, stands are established at about 1111 (3 x 3 m) or 1250 (4 m x 2 m) stems per hectare. The more vigorous species would reach canopy closure after two years of growth, and would require thinning to 770 stems per hectare to provide sufficient space at the end of five years. In contrast, the slower-growing species would achieve canopy closure at a 3 x 3 m spacing after a further 20 years' growth.

Table 7 An example of attributes of two adjacent trees in a mixed-species stand that is to be thinned.

Attribute	Species 1	Species 2
Crown ratio	20	16
Dbh (cm)	13	9
Dbh increment (cm/year)	1.0	0.5
Thinning interval (years)	5	5
Ideal future spacing (m)	3.6	1.8
Optimum combined spacing (m)	2.7	

Application to Non-Uniform or Mixed Stands

For a mixed-species forest the space required between two individuals from species 1 and 2 is:

$$S = [CR_1\ (DBH_1 + INC_1 \times A) + CR_2\ (DBH_2 + INC_2 \times A)] / 2 \qquad (3)$$

where the subscript denotes the attributes for Species 1 and Species 2, respectively.

If Species 1 has a DBH of 13 cm, crown ratio of 20 and DBH increment of 1.0 cm y^{-1}, the crown diameter (and spacing) of Species 1 should be 2.6 m diameter at present and should reach 3.6 m diameter in five years time. For Species 2, with a more compact crown ratio of 16, DBH of 9 cm, and a slower DBH increment of 0.5 cm y^{-1}, the ideal crown diameter (and spacing) in a uniform stand should be 1.4 m at present and should reach 1.8 m in five years time.

The spacing between these two tree species in five years time should be equal to the sum of the crown radii, that is, (3.6+1.8)/2, or 2.7 m. Therefore, the optimum spacing for this pair of trees would be 2.7 m, but 3.6 m would allow an additional four years growth by the larger tree before canopy closure (Table 7).

Table 8 shows that slow-growing species require slightly less space than faster-growing species of the same dimensions. In plantation management, the faster-growing species will require the additional space many years before the slower-growing species. Consider a fast-growing species with a crown ratio of 25 in a mixture with a slow-growing species with a crown ratio of 15. When the faster species has reached a dbh of 60 cm, it will require a spacing of about 16 m, but at the same time the slower species will require a spacing of about 5 m. This disparity in tree size and spacing will provide a challenge to plantation managers who wish to maximise productivity at the same time as they optimise timber harvesting. An even greater challenge arises when natural regeneration of desired species appears in a plantation.

Table 8 Mean tree spacings required to provide sufficient growing space for 5 years growth for stands with varying mean diameter, diameter increment of 0.5 or 1.0 cm/yr and crown ratios (crown/stem diameter) of 15, 20 or 25.

	Diameter increment 0.5 cm/yr Crown ratio		
Mean diameter	15	20	25
10	1.9	2.5	3.1
20	3.4	4.5	5.6
30	4.9	6.5	8.1
40	6.4	8.5	10.6
50	7.9	10.5	13.1
60	9.4	12.5	15.6

	Diameter increment 1.0 cm/yr Crown ratio		
	15	20	25
10	2.3	3.0	3.8
20	3.8	5.0	6.3
30	5.3	7.0	8.8
40	6.8	9.0	11.3
50	8.3	11.0	13.8
60	9.8	13.0	16.3

This example shows that if a single-species stand of a fast-growing species is to be maintained in a vigorous condition, trees need to be spaced widely at thinning. However, if vigorous and slower-growing species are maintained in a mixture, closer average spacings may be maintained, with a possible saving on tending costs. At the end of the cycle and at the time of the next thinning, a selection must be made between the two adjacent trees, and this selection will be influenced by the need to maintain maximum stem volume growth of potential final crop trees or some other tree or site value.

If the vigorous species is selected, the space occupied by the slower-growing species will be filled relatively quickly, but if the slower-growing species is selected, then there will be space in the plantation that is left unoccupied by trees for a longer period after thinning. This space will be occupied by weeds unless the area is tended regularly, so the selection of trees to be removed must be made with great care.

Conclusions

The key conclusions from these studies are that:

1. Some rainforest species may need more space to maintain optimum growth than do eucalypts, which in turn need more growing space than conifers. Consequently, the stand density index at which inter-tree competition will impact on growth in rainforest trees and final stockings to reach a given minimum diameter will both be lower. Some stand production will need to be sacrificed in order to get individual trees to a minimum bole size quickly.
2. Many rainforest species do not have strong apical dominance. Close spacing is needed early in the development of the stand to achieve good height growth and avoid heavy branching.
3. Close early spacing is also desirable for rapid crown closure and to reduce weed competition.
4. Many rainforest species are ‘crown-shy’ and will require an even spacing around them to achieve good growth.
5. Many rainforest species are relatively shade tolerant. They will survive at close spacing and can respond rapidly when released from competition.
6. Once trees have become severely suppressed or overtopped, the crown is unlikely to recover and most of these stems show little response to thinning. Thinning to promote stem volume growth should generally be from below and favour larger-sized stems, although stem size is not a certain predictor of rapid growth.
7. Results suggest that the presence of a dense understorey can impact on the growth of canopy trees and thinning responses will be greatest when the understorey is also removed.
8. These general principles apply to both monoculture and mixed species plantings. More analysis is required in mixed species plantings of rainforest species with other types of trees such as eucalypts and conifers.

Acknowledgments

We would like to thank officers of the Queensland DPI-Forestry and its predecessors in Atherton for establishing the experiments, conducting the treatments and measuring and maintaining the stands. Gary Sexton and Arthur Wright were instrumental in gathering compartment histories and data records and relocating the experiments for measurement. Management recommendations were based in part on an internal Departmental report by Mr. Eddie Volck.

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Appendix 1

Management recommendations for Queensland maple plantations

1. <u>Site selection</u>. Maple appears to perform best on lower slopes on good quality soils (sandy loams, loams or clay loams derived from basalt or metamorphic rock types) with annual rainfall greater than 1500 mm. Coarse-textured soils and ridge or upper slopes should be avoided.
2. <u>Plant</u> at 1000 stems ha^{-1} (3 m x 3 m or 4 m x 2 m spacing) and maintain a 1 m wide weed free strip either side of the planting row for at least one year after planting. Responses to fertiliser application are still uncertain.
3. <u>Pruning</u>. Prune competing leaders at an early age (e.g. when trees are 2 m tall) and persistent branches when the stem is approximately 6 cm DBH. Removal of up to 50% of green crown should not impact on growth. When the stand has reached predominant height of 6 m select 500 stems ha^{-1} and prune selected stems to 3 m. When stand has reached predominant height of 12 m prune selected stems to 6 m.
4. <u>Thinning</u>. The thinning regime will depend on the increase in log value with size. To produce maximum biomass the stand should be left unthinned. Two alternative regimes are shown in Figure 3. The target is a stand of 125 stems ha^{-1} with an average diameter of 70 cm. The time taken to achieve this target diameter (and whether or not the target can be achieved) will depend on site quality. On good sites this might be achieved in 60 years. If the minimum merchantable DBH is 40 cm, growth models suggest that this would yield to a volume of about 400 m^3 ha^{-1}.

Thinning Regime 1

The first regime involves three thinnings, halving the density of the stand at each thinning.

a) Grow until the average DBH for the stand reaches 20 cm (basal area about 31.4 m^2 ha^{-1}, 65% SDI - 700). Thin to 500 stems ha^{-1} with a residual basal area of 27.6 m^2 ha^{-1} and mean diameter of 26.5 cm. SDI is reduced to about 50% of maximum.
b) When the stand reaches an average DBH of 30 cm (basal area of 36 m^2 ha^{-1}), thin to 250 stems ha^{-1} (residual basal area of 31.0 m^2 ha^{-1} and average DBH of 40 cm).
c) When the stand reaches an average DBH of 47 cm (basal area 43 m^2 ha^{-1}) thin to 125 stems ha^{-1}.
d) The final felling may be made when the stand has reached a quadratic mean DBH of 70 cm (basal area of 48 m^2 ha^{-1}) and 60% of maximum SDI.

Thinning Regime 2

The second regime involves two heavier thinnings than Regime 1. This will result in greater individual tree diameter growth but it will involve some loss of overall stand production.

a) Allow the stand to grow until the average DBH reaches 20 cm (basal area about 31.4 m^2 ha^{-1}, 65% SD - 700). Thin to 250 stems ha^{-1} (residual basal area 20.0 m^2 ha^{-1}, mean DBH 32.0 cm, RD 35%).
b) When the stand reaches a mean DBH of 40 cm (basal area 21.4 m^2 ha^{-1}) thin to 125 stems ha^{-1} (residual basal area 23.9 m^2 ha^{-1}, mean diameter 49.0 cm and RD 35%).
c) The final felling may be made when the stand has reached a quadratic mean DBH of 70 cm (basal area 48 m^2 ha^{-1}, RD 60%).

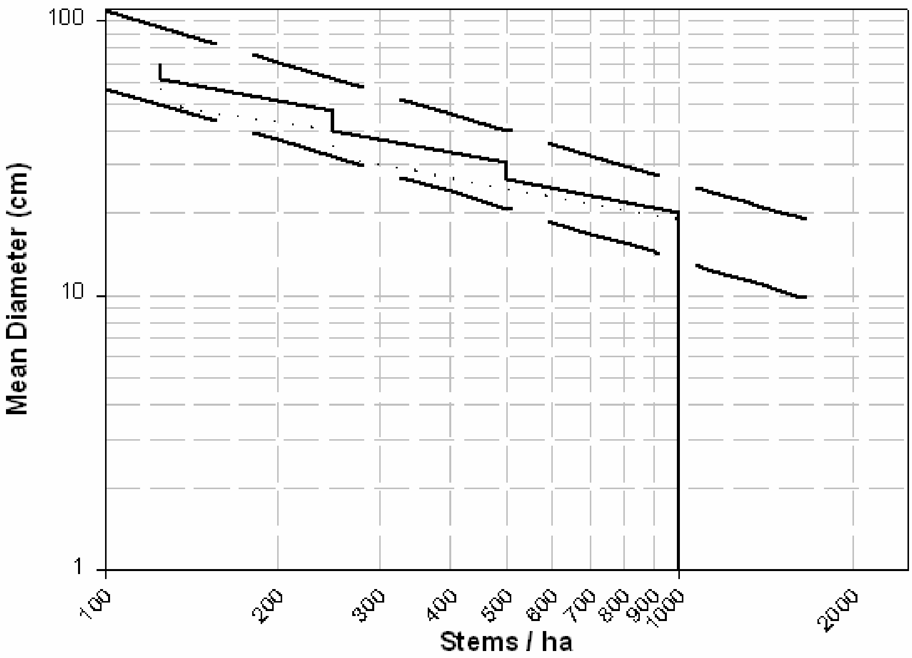


Figure 3 Two alternative thinning regimes for Queensland maple based on the results of this study. Regime 1 (solid line) maintains a higher stand density, while Regime 2 (dotted line) involves heavier earlier thinning and lower stand density.

IV

Rainforest Biodiversity Associated with Tropical and Subtropical Reforestation

11. Rainforest timber plantations and the restoration of plant biodiversity in tropical and subtropical Australia

Grant W. Wardell-Johnson, John Kanowski, Carla P. Catterall, Steven McKenna, Scott Piper and David Lamb

Abstract

We compared the species richness, growth forms and assemblages of vascular plants in five types of rainforest reforestation with pasture and forest reference sites in tropical and subtropical Australia. These types include unmanaged regrowth, young and old monoculture plantations, young rainforest cabinet timber species plantations and plantings designed to restore natural rainforest communities. Patterns of species richness across these reforestation types differed between the tropics and subtropics, although all reforestation types supported fewer species than natural rainforest reference sites. In the tropics similar numbers of introduced (i.e. non-native) species occurred in all types of reforestation (with the exception of old plantations which included few introduced species) and pasture reference sites. This contrasts with the subtropics where the greatest numbers of introduced species were associated with cabinet timber plantings. Greater diversity of growth forms (including epiphytes and vines) occurred in rainforest reference sites than in any type of reforestation. The assemblages of canopy trees (including both planted species and recruits) varied in their resemblance to rainforest reference sites in the different types of reforestation in the two regions. However, there was a tendency for young plantations to be most dissimilar to rainforest reference sites. On the other hand, old (ca. 60 years) plantation sites in the tropics were similar to natural rainforest reference sites. This was due to their close proximity to remnants and low intensity management regimes.

Because species richness and growth form obscures the importance of particular species in reforestation, we targeted eight common species (four native and four introduced) as exemplars of the possible biodiversity future under the different types of reforestation. These species demonstrated the individuality of species behaviour under different types of reforestation. Rainforest timber plantations can lead to increased biodiversity if they are designed to facilitate the colonization of rainforest taxa, and managed to favour processes associated with the development of a rainforest environment. Negative outcomes for rainforest biodiversity follow the establishment of non-rainforest species or processes (e.g. persistent high understorey light levels) not associated with a rainforest environment. Management and designs to minimize the need for ongoing intervention will be important economic considerations in future reforestation efforts aimed at restoring biodiversity.

Introduction

Australian rainforests are notable for their high biodiversity and their distribution over a large latitudinal range (Adam 1994, Barlow 1994, Webb and Tracey 1994). Northern Australian rainforests are noted at a world scale for their diversity of vascular plants, especially trees (Hyland *et al*. 2003). The extent of the rainforest cover in Australia, already diminished to refugial status by long-term climatic trends, was greatly reduced by European settlement (Floyd 1990, Winter *et al*. 1987, McDonald *et al*. 1998, Erskine 2002, Catterall *et al*. 2004).

Remaining areas of rainforest are now well represented in the reserve system, while in recent years there has been increasing interest in reforestation within former rainforest landscapes. This interest has been generated by the twin beliefs that the reserve system is insufficient in itself to conserve biodiversity (Adam 1994, Goosem and Tucker 1995, Turner 1996), and that reforestation can reverse some of the environmental damage caused by clearing (Lugo 1997, Parrota *et al*. 1997, Lamb 1998, Hartley 2002).

Approaches to reforestation in former rainforest landscapes have varied with time (Kanowski *et al*. 2003). The earliest reforestation programs resulted in extensive areas of monocultures of fast-growing native timber trees (Fisher 1980). Most of these plantations were of hoop pine (*Araucaria cunninghamii*). In more recent times, mixed-species plantations using rainforest species which are well-known from native forests for their production of potentially high value, appearance-grade cabinet timbers, and diverse mixtures of trees and shrubs to restore rainforest to cleared land have also been established in humid regions of north and south east Queensland as well as New South Wales (NSW) (Kooyman 1991, Lamb *et al*. 1997, Parrotta *et al*. 1997, Tucker 2000, Lamb and Keenan 2001, Catterall *et al.* 2004).

These have typically been on a relatively small scale (Catterall *et al*. 2004). In addition, extensive areas of cleared land have been allowed to revert to secondary forest, particularly following the decline of the dairy industry in some regions (Kanowski *et al.* 2003). These approaches to reforestation vary widely in their primary objective, costs, potential economic returns and presumably in their use by rainforest fauna (Lugo 1997, Lamb 1998, Harrison *et al*. 2000). Until recently there has been no comprehensive attempt to assess the capacity of different types of reforestation to restore biodiversity and ecological functioning to cleared rainforest lands. However, recent research has provided a framework to allow such an assessment (Kanowski *et al*. 2003, Catterall *et al*. 2004).

In this chapter, we examine the restoration of components of plant biodiversity in a variety of different types of reforestation in former rainforest landscapes in eastern Australia. We compare species richness, growth form and assemblage patterns of plants in different types of reforestation to determine trends in the restoration of plant biodiversity. We also examine the behaviour of particular species (native and introduced) following reforestation. We evaluate the extent to which these different reforestation styles and management systems have produced differing plant biodiversity outcomes.

Methods

Rainforest reforestation plantings

We examined plant biodiversity in the range of sites where reforestation approaches have been used. These approaches include: unmanaged regrowth, monoculture timber plantations, mixed-species cabinet timber plantations and plantings established to restore natural rainforest communities (referred to subsequently as ecological restoration plantings). The methodology used to investigate biodiversity values of reforestation has been described by Wardell-Johnson *et al.* (2002), Kanowski *et al.* (2003) and Catterall *et al.* (2004).

Reference sites of pasture and natural rainforest were used to benchmark the extremes of the rainforest clearing-restoration spectrum, and thereby to provide a context for restoration plantings. All are referred to collectively as land cover types and are described in Kanowski *et al*. (2003). Some attributes of these different approaches and sites are shown in Table 1.

Table 1 Summary of main attributes of the reforestation types and site conditions.

Type of Reforestation or Site	Age (years)	Tree density at planting (trees per ha)	Dominant tree height (m)	Other notes
Pasture reference (P)	80–120	NA	NA	Largely treeless reference sites
Regrowth (RG)	10-20 in tropics; 30-40 in subtropics	NA	< 10	Large variation in composition
Young monoculture plantation (YP)	5-15	1200	< 8	Entirely *Araucaria cunninghamii*
Old monoculture plantation (OP)	38-70	1200	< 35	Mostly *Araucaria cunninghamii* or *Flindersia brayleyana*; many acquire a high understorey diversity if near intact forest
Cabinet timber (Mixed species) plantation (CT)	5-10 years	> 1200	< 8	Most planted with 6-20 tree species per site
Restoration planting (ER)	6-22	4-6000	< 10	Most planted with 20-100 tree and shrub species per site
Rainforest reference (F)	Unknown	NA	30-40	c. 100-150 species per ha.

NA =not applicable

The study was conducted in the extensively modified agricultural areas of two rainforest regions of eastern Australia: the Atherton Tablelands, an upland plateau in tropical north-east Queensland; and the lowland subtropics of south-east Queensland and north-east New South Wales. The two study areas experience a similar climate (due to the lower altitude of the subtropical sites), and rainforests in both areas exhibit structural and floristic affinities (Webb 1968).

The two regions differ with respect to their management history (southern areas cleared for longer), the proportions of the landscape in different land cover types (more plantation in the south) and the extent of rainforest clearance (more cleared in the subtropics (Kanowski *et al.* 2003). Details of the study design and most land cover types are presented in a companion paper (Kanowski *et al.* Chapter 12). We also surveyed unmanaged regrowth that had developed on abandoned farmland. In the subtropics this regrowth was 30-40 years old and dominated by woody weeds, notably camphor laurel, *Cinnamomum camphora*, and broad-leaved privet, *Ligustrum lucidum.* In the tropics, patches of regrowth 10-20 years old comprised dense clumps of vines and scramblers, including the weed species *Lantana camara*, growing amongst pasture with a few rainforest trees and shrubs.

In the tropics, cabinet timber plantings were represented from Community Rainforest Reforestation Program (CRRP) plantations. Cabinet timber plantings in the subtropics were established by a number of different individuals and organisations, but those surveyed in this study resembled the CRRP plantations in terms of plant selection, spacing and management focus (see Harrison *et al*. 2003, Glencross and Nichols Chapter 7).

Sampling procedures

At each site, we conducted surveys of a wide range of ecological attributes, including plants, lizards, birds, soil and litter invertebrates, and forest structure (see Wardell-Johnson *et al*. 2002, Kanowski *et al*. 2003, Catterall *et al*. 2004). Surveys were conducted between 2000 and 2002 on a standardised 0.3 ha transect at each site.

Vascular plants were surveyed on five 78.5 m^2 quadrats at each transect, with species recorded as present or absent in each quadrat in each of three strata: canopy (top 1/3 of the canopy height), midstorey (2 m to 2/3 height of canopy) and understorey, or ground (< 2 m high). Only plants rooted in the quadrat, or growing on plants rooted in the quadrat, were counted. A frequency index (0-5, the number of quadrats in which a species was present) was used to describe the occurrence of each species in each stratum in each site. We also developed a database of ecological attributes (such as seed size, dispersal, growth form and origin) of each species.

Analytical approach

We compared the various land cover types of the two regions in terms of species richness, growth forms and assemblages. Species richness is presented separately for introduced (i.e. non-native) and native taxa, recorded at each of the three strata considered at each site. In this case, data were the total list of each site, presented as a mean and standard error for each land cover type. These land cover types are considered a proxy for successional stages of rainforest restoration from pasture through various planted forests, to reference forest.

Growth form was separated into five categories - canopy tree, shrub, vine, epiphyte and ground story (includes both herbs and low shrubs). In this case, data were the total list of species occurring in at least one site in at least one land cover type. Associations between growth form and land cover types were compared with χ^2 tests of independence.

We considered the assemblage pattern of canopy trees, where the data used were the sum of frequencies across all three strata for all species of canopy tree (including tree seedlings). Some species of shrubs, vines and epiphytes were sometimes detected in the canopy (particularly in regrowth and young reforestation sites). However, in this case, only species within the life form 'tree' and capable of occurring within the top third of the canopy of mature rainforest were included. A maximum score of 15 can be obtained by a canopy-growing tree occurring in the canopy, midstorey and ground layer of all five subplots. Pasture sites contained few canopy trees, and therefore were not included in this analysis. Multidimensional Scaling (MDS) ordination (Shepard 1962, Belbin 1991) was used to summarise and present patterns of similarity between sites in terms of plant-species composition. Kanowski *et al*. (2003) and Catterall *et al.* (2004) outline detailed analytical procedures associated with the use of ordination in this study.

As species can vary in their influence on a site, on the occurrence of other species, or on ecological processes, we consider individually four native species (*Flindersia brayleyana*, *Elaeocarpus grandis*, *Castanospermum australe* and *Argyrodendron trifoliatum)* and four introduced species (*Cinnamomum camphora*, *Panicum maxima*, *Ligustrum sinense* and *Lantana camara*) in relation to their frequency of occurrence in different land cover types.

The mean and standard error of the frequency of each species in each land cover type were plotted and compared by one-way ANOVA, with post-hoc LSD tests to determine significant pairwise differences between land cover types.

Results

Species richness and stratum

When considered over all strata, plant species richness per site was greatest for the natural rainforest reference sites (Figure 1). In the tropics and subtropics species richness was greater in ecological restoration, old plantation and forest reference sites than other land cover types, but the differences were less pronounced in the subtropics than in the tropics.

Overall, there was a trend for increasing species richness of native plants from pasture through young plantations, ecological restoration plantings and old plantations towards rainforest reference sites. Few introduced species were encountered in forest reference sites in either the tropics or subtropics or in old plantations of the tropics. However, there were many introduced species in all other land cover types in both regions. Although similar numbers of native and introduced species occurred in young plantations in the tropics, pasture was the only land cover type where introduced species generally outnumbered native species.

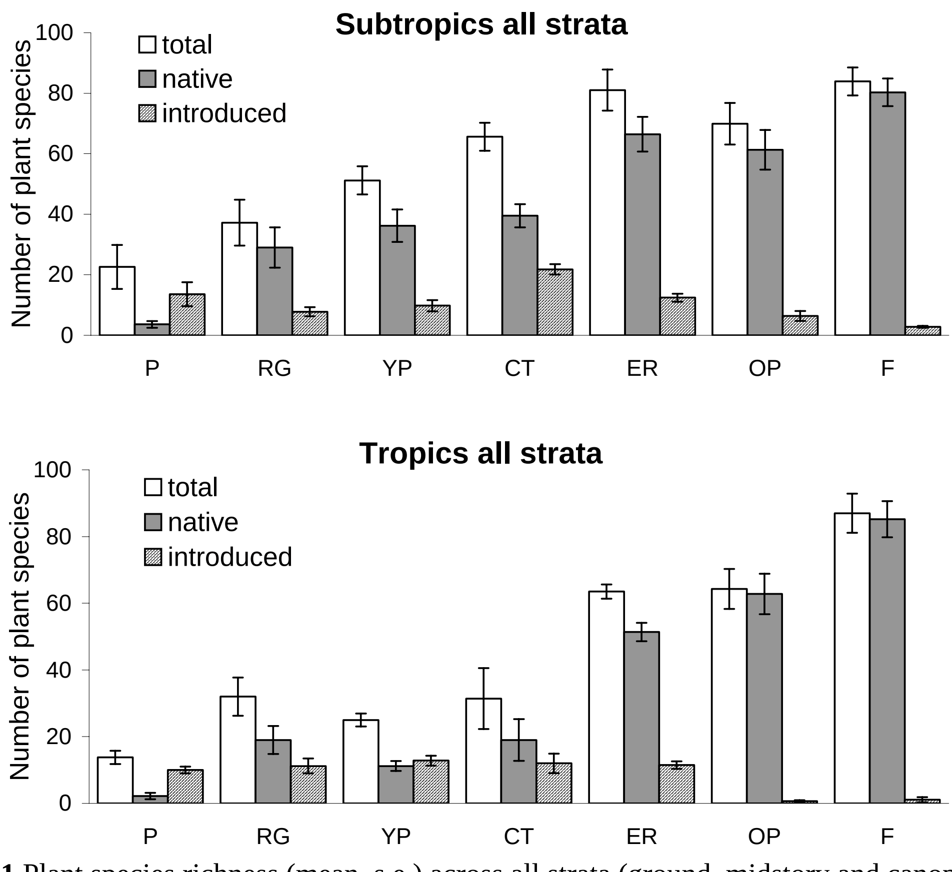


Figure 1 Plant species richness (mean, s.e.) across all strata (ground, midstory and canopy) of all introduced, native and total species in different styles of reforestation. Abbreviations are: Regrowth - RG; Young plantation – YP; Cabinet timber – CT; Ecological restoration – ER; Old plantation – OP; rainforest (F); and pasture (P). Totals include a few (< 1 %) taxa whose origin is uncertain.

When the canopy alone was considered, natural rainforest reference sites were more species rich than any other land cover type, and included fewer introduced species, in both the tropics and subtropics (Figure 2). On average, the canopy of ecological restoration plantings included more species in the tropics than the subtropics. Conversely, the canopy of cabinet timber plantings was more species rich in the subtropics, being similar to ecological restoration plantings in the same region. There was a paucity of species occurring in the canopy of old monoculture plantations, particularly in the subtropics. Relatively few introduced species were associated with the canopy of most land cover types (exceptions were regrowth in the subtropics, and young plantations and cabinet timber plantings in the tropics). Unmanaged regrowth included more canopy-occurring species in the subtropics than in the tropics.

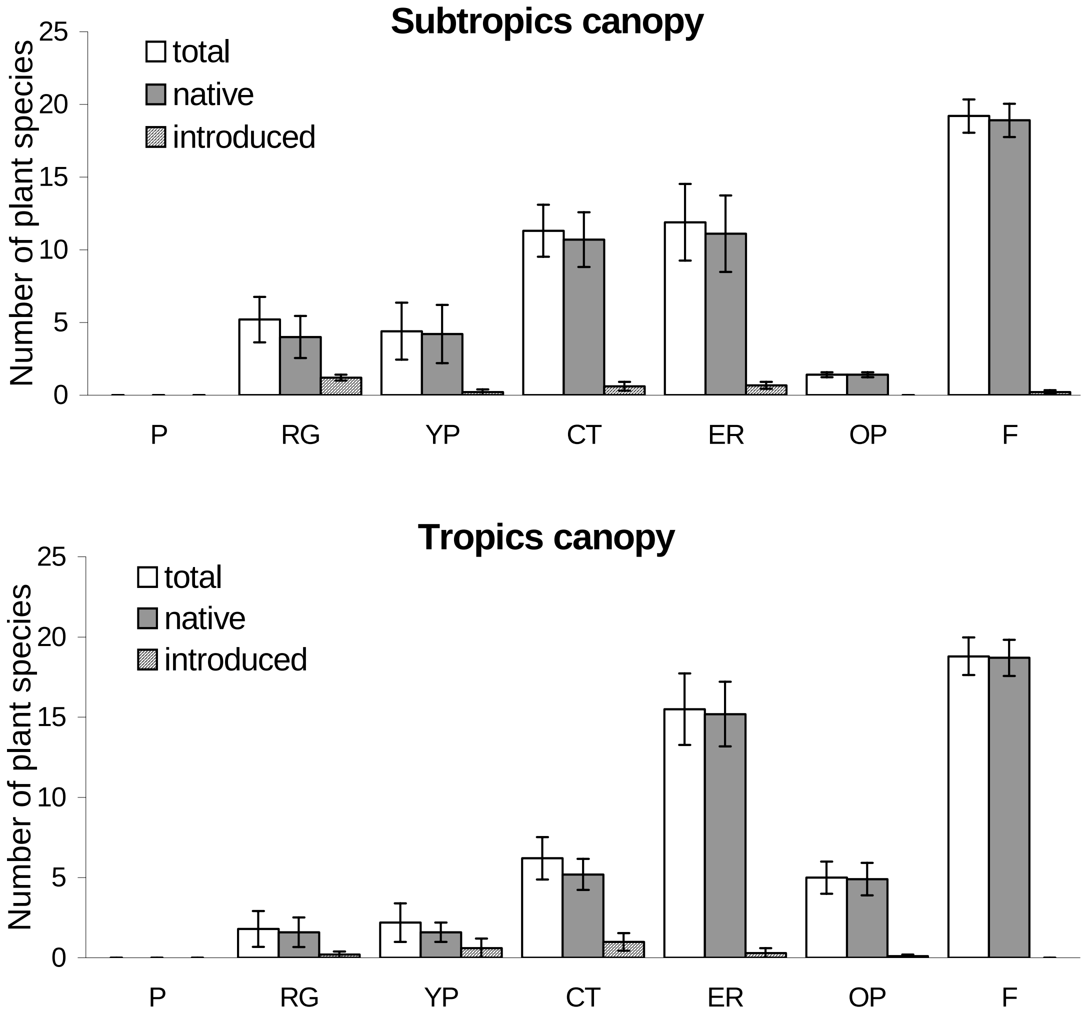


Figure 2 Plant species richness (mean, s.e. of all growth forms combined) in the canopy, of introduced, native and total species in different styles of reforestation Abbreviations are: Regrowth - RG; Young plantation – YP; Cabinet timber – CT; Ecological restoration – ER; Old plantation – OP; rainforest (F); and pasture (P). Totals include a few (< 1 %) taxa whose origin is uncertain.

Origin and growth form

When species were pooled across all sites in each land cover type, the pattern of species richness across different land cover and plantation types followed a similar trend to that observed on a site by site basis (Table 2).

Table 2 Summary of number of sites surveyed, and total numbers of plant species in each of seven different land cover types.

	Subtropics							Tropics						
	P	RG	YP	CT	ER	OP	F	P	RG	YP	CT	ER	OP	F
Number of sites	5	5	5	10	9	10	10	5	5	5	5	10	10	10
No. of native species	12	175	134	165	248	237	282	6	60	34	61	188	230	282
No. of introduced species	40	21	32	70	37	35	19	22	32	29	40	34	4	10

Characteristics of land cover types are shown in Table 1.
Abbreviations are: Regrowth - RG; Young plantation – YP; Cabinet timber – CT; Ecological restoration – ER; Old plantation – OP; rainforest (F); and pasture (P). Totals include a few (< 1 %) taxa whose origin is uncertain.

The two regions showed similar patterns of species; more native than introduced species, and the greatest numbers of native species in forest reference sites. However, because this is complicated by different sampling effort between land cover types or regions, we compared proportions between types and regions. In general, there were proportionally similar numbers of species in different growth form categories within similar land cover types between the two regions (Figure 3).

There was a significant association between growth form and land cover type for native species in both the subtropics (Figure 3, $\chi^2 = 171.5$, $p < 0.001$, d.f. = 24,), and tropics ($\chi^2 = 144$, $p < 0.001$, d.f. = 24). Thus, there were proportionally more epiphytes in regrowth and forest reference sites in the subtropics, and less in the young plantations and cabinet timber plantings in both the tropics and subtropics.

For all land cover types, except regrowth, there were more introduced (i.e. weed) species in the subtropics than the tropics (Table 2). This is especially true for young cabinet timber plantings, although this comparison is complicated by greater sampling effort in the subtropics than the tropics. There was a significant association between growth form and land cover type for introduced species in the subtropics ($\chi^2 = 34.93$, $p < 0.01$, d.f. = 18), but not in the tropics ($\chi^2 = 21.49$, $p < 0.256$, d.f. = 18).

Assemblage of canopy trees

A total of 258 species of canopy trees were detected in the 104 sites surveyed, including 147 species in the subtropics and 163 in the tropics (52 species were in common between the areas). This comprised approximately one quarter of all species recorded in the study (1088). Ordination analysis (Figure 4) showed that of all five reforestation styles, only old plantations and young plantations in the subtropics showed no trend towards difference from one another. The three reforestation approaches; cabinet timber, young monoculture plantation and unmanaged regrowth all trended

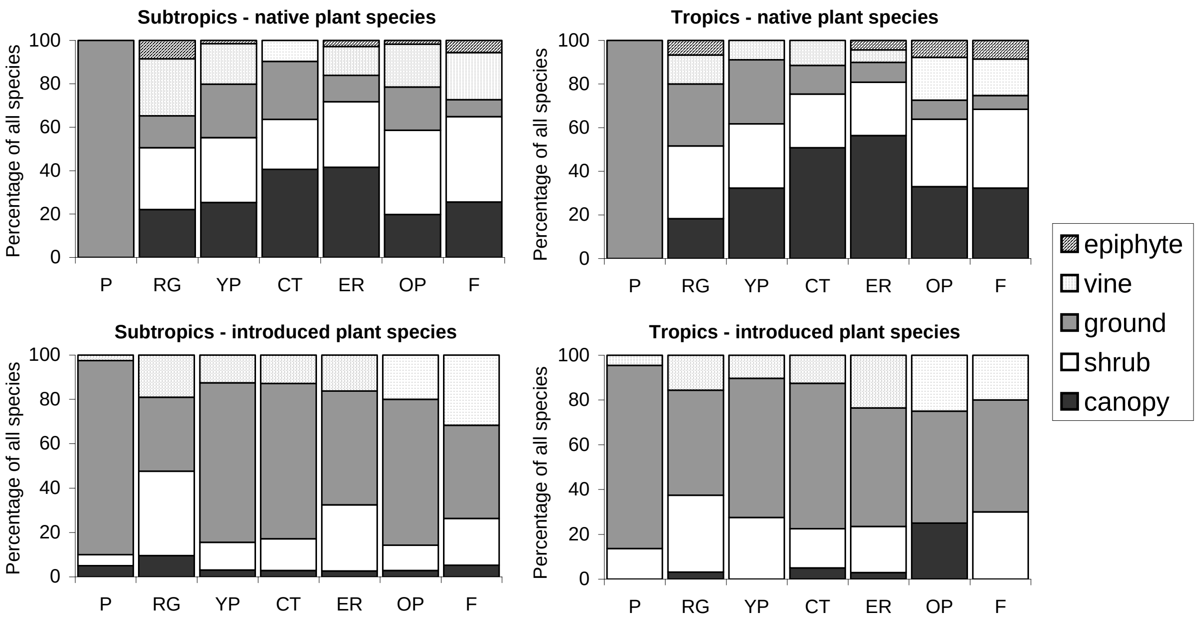


Figure 3 Proportions of species of different growth form in different land cover types Abbreviations are: Regrowth - RG; Young plantation – YP; Cabinet timber – CT; Ecological restoration – ER; Old plantation – OP; rainforest (F); and pasture (P). There are a few (< 1 %) taxa of unknown growth form that were not included in analysis.

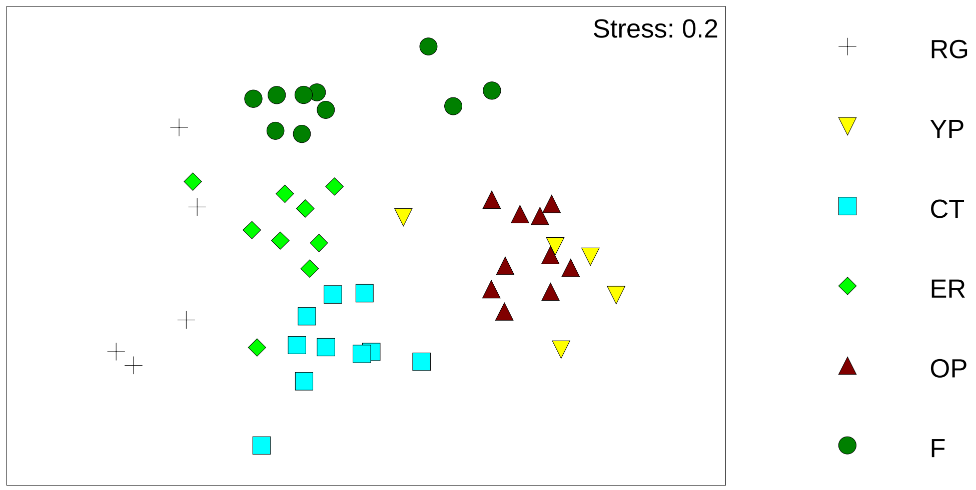
differently in MDS ordination (Figure 4) although few canopy tree species were present in many of the tropical regrowth or young plantation sites.

The assemblage of canopy trees in the rainforest reference sites were well separated in ordination space from all other land cover types in both the subtropics and tropics (Figure 4). Old plantations in the tropics provide an exception. Although the canopy of old plantations was dominated by a single species (usually *Araucaria cunninghamii*) in both the tropics and the subtropics (Appendix 1), sites in the tropics were much less separated in ordination space from rainforest reference sites than sites in the subtropics. In the tropics, the assemblages of canopy species in both regrowth and young monoculture plantations were very different from rainforest reference sites. Cabinet timber sites varied widely in their assemblages of canopy trees in the tropics.

Although very different from rainforest reference sites, unmanaged regrowth in the subtropics was more similar in its canopy tree assemblage to rainforest than the unmanaged regrowth was in the tropics. Unmanaged regrowth sites were dominated by high frequencies of a few introduced trees and tall shrubs in the subtropics (particularly *Cinnamomum camphora*, *Ligustrum sinense* and *L. lucidum*) and by fewer individuals of the same species (and others such as *Psidium guajava*) in the tropics. However, the subtropics regrowth sites also included more native canopy tree species, particularly in the ground layer, than the younger tropical sites.

Overall species richness, proportions within growth forms, and assemblage patterns do not account for the influence of individual species within a community. Hence, we considered individually four native and four introduced exemplar species in terms of their frequency of occurrence in different land cover types (Appendices 1 and 2). Each of the native species considered in this paper (Appendix 1) are tall rainforest trees widely used in a variety of reforestation types in both the tropics and subtropics of Australia, while the four introduced species (Appendix 2) exemplify four different growth forms and two main dispersal mechanisms.

a. Subtropics canopy-growing trees



b. Tropics canopy-growing trees

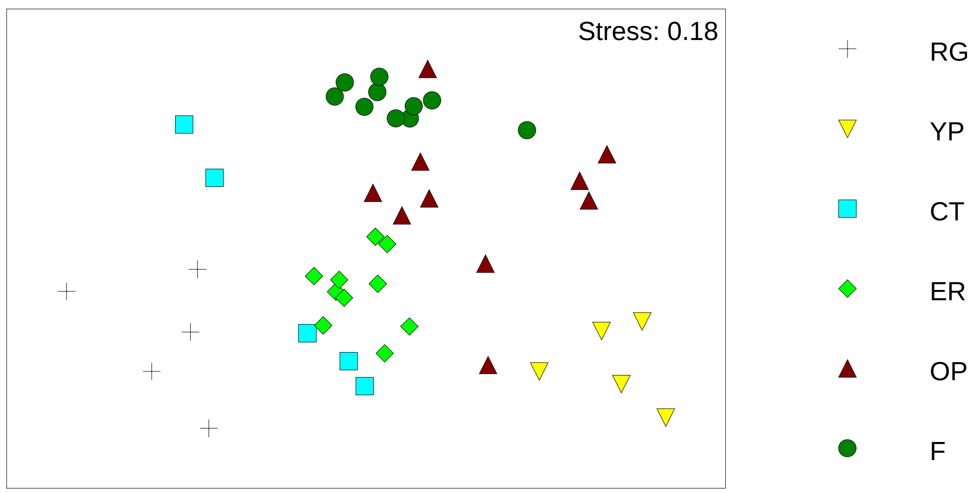


Figure 4 Ordination (SSH MDS, Bray Curtis metric, Stress = 0.2), showing trends based on frequency (0-15) of canopy tree species composition in all strata, in different styles of reforestation and rainforest reference sites (F) in the subtropics (a) and tropics (b). Reforestation styles are as follows: Regrowth - RG, Young plantation – YP, Cabinet timber – CT, Ecological restoration – ER and Old plantation – OP.

Discussion

Species richness and stratum

Differences in plant species richness between the different types of reforestation are not surprising since the various plantings differed in their silvicultural objectives; the older plantation monocultures were established and managed solely to provide timber, the restoration plantings were established largely to facilitate biodiversity recovery while objectives of the cabinet timber plantings included both timber production and biodiversity benefits.

While the plantings are still young, (even the oldest monoculture plantations are less than 70 years old) in comparison with natural rainforest reference sites, there are currently large differences in species richness between the different land cover types. Differences in plant species richness between the different forms of reforestation may have ecological consequences (e.g., in terms of their habitat for fauna: Kanowski *et al.* Chapter 12). These differences may be more associated with particular species or with forest structure. Thus, plantings differed in the composition of the species planted, e.g., ecological restoration plantings typically use many more fleshy-fruited species than timber plantations, which will influence their attractiveness to seed dispersing fauna.

The plantings are also very different from one another structurally (see Kanowski *et al*. 2003). These structural differences will influence the extent to which different types of reforestation facilitate the development of rainforest processes, such as ecological succession. For example, differences in canopy cover between timber plantations and restoration plantings, and the resultant differences in light levels, humidity and temperature may create an environment conducive to the recruitment of rainforest species.

Origin and growth form

Weed species are of particular interest in the establishment and maintenance of timber plantations since their control is both a major management expense and a conservation concern. Certain introduced species of particular growth form are widely regarded as environmental weeds that are capable of fundamentally altering the structure and function of ecosystems (e.g. Werren 2003, see also Groves and Burdon 1986, Bridgewater 1990, Michael 1994). For example, the relatively few species of woody weeds introduced to rainforest, particularly vine, tree and large shrubs, may have substantial capacity to transform this vegetation type.

There is a much greater proportion of tree species relative to species of grass, shrubs and herbs in the native assemblage than in the introduced assemblage in this study, and this is true also for the wet tropics and south-east Queensland bioregions in general (ANPWS 1991, Werren 2003). Invasive woody plants, particularly trees, are a threat to the biodiversity of the tropics in general (Binggeli *et al*. 1998). In the subtropics and tropics of eastern Australia, these species come from a taxonomically diverse group (Bebawi *et al*. 2002), but of the potentially serious invasive tree species listed by Werren (2003), only *Cinnamomum camphora* was detected in our sites. This species is widely regarded as being highly invasive in subtropical rainforests, but has received relatively little attention in the tropics, despite its establishment in the Atherton Tablelands.

Shrubs include taxa that are among the most invasive plants in subtropical rainforests (ANPWS 1991, Appendix 2). These include *Lantana camara*, *Ligustrum lucidum, L. sinense* and *Psidium guajava*, which are also highly invasive in tropical systems. *Lantana camara* is particularly associated with relatively high light levels within forests, while the remaining species are capable of colonizing intact rainforest. These shade-tolerant species have the potential to cause management concern even in reforestation that has facilitated rainforest processes (e.g., those with high levels of canopy cover).

Of the 19 introduced species that are considered particularly invasive of subtropical rainforest, in Australia by ANPWS (1991), 70 percent are vines. While none of these species were recorded in quadrats in this study, they are likely to increase considerably in abundance in the short term as the prognosis under the climate change scenarios currently considered (Hughes 2003) is for a greater spread of these transformer weeds.

Woody weeds, including vines, are considered of greatest significance in affecting biodiversity recovery in restoration of rainforest (ANPWS 1991). Other growth forms, in particular several grasses including *Panicum maximum*, are widely recognised as a threat to nature conservation values (Werren 2003). Grasses are primarily weeds of rainforest margins and of disturbance corridors, but also proliferate along riparian zones and other areas of natural disturbance. *Panicum maximum* is a relatively shade tolerant species and is particularly associated with edges and open canopies. It has the capacity to greatly increase fuel loads, thus rendering what are generally fire-sensitive communities more fire-prone (Werren 2001, 2003). This has particular importance in sites marginal for the growth of rainforest or potential rainforest sites for which open-forest processes have been facilitated.

The two study regions differ in composition and timing of establishment of introduced taxa, which in association with the management regime, will influence the trajectory of rainforest restoration. By comparing regions, this study has provided a prognosis for areas of different history. For example, distributions of the four environmental weeds that we targeted as exemplars (Appendix 2) suggest that these species may be able to thrive throughout the landscape within the two regions considered. It is therefore likely that the potential limits of the currently recognised environmental weeds will considerably expand. For example, the frequent occurrence of *Cinnamomum camphora* in pasture in the subtropics and its relatively recent occurrence in parts of the Atherton Tablelands suggest a dominant medium-term future for this species in both regions. We therefore suggest that the design and management of restoration programs will have a major influence on plant biodiversity outcomes by the way they promote or suppress, environmental weeds. These issues should be considered even while environmental weeds are not yet a major economic concern (as in the tropics in comparison with the subtropics).

Assemblage of canopy trees

We argue that the consideration of canopy tree species in all strata reflects the development of plant biodiversity in different rainforest types. This is because it includes recruitment of tree species which will in turn determine forest structure (see Tucker and Murphy 1997, McKenna 2001, Kanowski *et al*. 2003) and may influence the recruitment of other taxa (see Catterall *et al*. 2004). Patterns based on all canopy tree species also provide a context for biodiversity recovery in those reforestation styles which target only overstorey species (monoculture and cabinet timber plantations).

While 179 species of canopy-growing trees were included in CRRP cabinet timber plantations, these plantings mostly relied on a narrow genus pool, based largely on *Eucalyptus, Flindersia, Araucaria, Agathis* and *Elaeocarpus,* and the numbers of species in each planted area was relatively small (on average 11 species per site; see Lamb *et al*. Chapter 9). The relative contribution these young plantings currently make to plant biodiversity at any particular site is necessarily modest, and presently represents only a small increase over monoculture plantations in comparison to that found in intact forest. However, a possible long-term worth of all reforestation land cover types to biodiversity recovery may lie in the extent to which they can facilitate conditions and processes associated with a rainforest environment.

This study has demonstrated the considerable differences between rainforest reference sites and all reforestation land cover types examined in this study. Nevertheless, some types have a greater similarity of outcome to rainforest than others over the time frame examined. In particular, types which encourage rainforest processes or facilitate the colonisation of rainforest components tend to be most positive for biodiversity recovery. In this study, old plantations in the tropics were located adjacent to remnants of rainforest and most resembled rainforest reference sites (see also Keenan *et al*. 1997). Some of these sites received little stand management through thinning or pruning programs which tend to increase light levels, and weed control which removes understorey regeneration. Of the young reforested sites in the tropics and sub tropics, ecological restoration plantings most resembled the reference rainforest. Compared to other reforestation types, ecological restoration plantings were established using a diverse range of species, including many fleshy-fruited species attractive to seed dispersing fauna. Management of these sites included efforts to provide early canopy closure to minimise the need for longer-term weed management.

Characteristic timber plantation methods such as weed control in the establishment phase and allowing increased light in the lower canopy through pruning and thinning, may discourage successional rainforest processes, and thus may be less successful at promoting biodiversity in rainforest reforestation. Also, a reliance on a small number of predominantly wind-dispersed tree species, of limited value to seed-dispersing animals, limits the value of current timber plantation designs in biodiversity restoration (Tucker *et al*. 2004, Catterall *et al*. 2004, Kanowski *et al*. Chapter 12).

The role of plantations in enhancing plant biodiversity

The recovery of plant diversity on a local scale is enhanced by facilitating early canopy closure to exclude weeds (see also Florentine and Westbrooke 2004). The initial tree spacing of the cabinet timber plantings was typically around 3 - 4 m (equating to between 600 - 1100 stems/ha), which is less dense than ecological restoration plantings where trees are typically spaced 1.5 - 2 m apart (2500 – 4400 stems/ha). The choice of planting density involves trade-offs (see Catterall *et al*. Chapter 13). Wider spacing reduces the costs of establishment (including cost of supplying and planting the seedlings), but on the other hand, it increases the time taken for canopy closure, resulting in a greater maintenance effort to reduce competition from weeds. At the tree spacing of 3 - 4 m, weed control might be needed for up to three or four years before canopy closure occurs. This period is reduced when planting densities are greater (i.e. spacings are less). Without adequate weed control plantations can fail. For example, CRRP records indicate that, by 1998 when planting under that program was coming to an end, at least 15 % of plantations had ceased to have economic timber yield potential (Harrison *et al*. 2003). Several reasons were identified for this, but a lack of early weed control was the most important. Once canopy closure occurs most light-demanding weeds are excluded, although some can continue to thrive under more wide spaced plantations, or under open-crowned species such as eucalypts.

Successional development of reforestation then depends on seed dispersing fauna being able to reach the plantations (e.g. Wunderle 1997). Plantations isolated from a source of seeds such as a natural forest remnant are likely to acquire new plant colonists from outside more slowly than plantations close to natural forest remnants. For example, in north Queensland, Keenan *et al*. (1997) found sites within 200 m of intact forest could contain quite high numbers of species able to colonise the plantation and grow into the canopy, but that recruitment declined with distance from the forest edge. In the same region, McKenna (2001) found that the dispersal of native plants to rainforest plantings declined rapidly with distance from intact forest, with few rainforest plants dispersed to plantings isolated from native forest by more than 500 metres.

The composition of the plantation is also likely to influence the attractiveness of the plantation to seed dispersers in a number of ways. Firstly, some plantation tree species are more attractive to seed dispersers than others. For example, our data show a positive correlation between the number of fleshy-fruited, bird-dispersed plants used in plantations and the richness of frugivorous birds (the main dispersers in Australian rainforests) inhabiting or visiting those plantations (see Kanowski *et al.* Chapter 12). In particular, more seed-dispersing birds occur in cabinet timber plantations, which include some fleshy-fruited trees (e.g., *Elaeocarpus spp.*, *Gmelina spp.*), than wind-dispersed hoop pine plantations. Secondly, the composition of a plantation will influence its structural complexity. A structurally simple monoculture plantation may be less attractive to seed dispersers than a more structurally complex multi-species plantation. The young cabinet timber plantations surveyed in this study contained trees, but no understorey, and were not particularly structurally complex. On the other hand, the greater diversity of crown architectures and fruit resources in these plantations may be more attractive to many seed dispersing fauna than simple monocultures. Recruitment of rainforest plants and subsequent successional development is likely to be faster in the ecological restoration plantings, due to the closer tree spacing and the larger variety of species planted, especially the much greater use of fleshy-fruited species (Kanowski *et al.* Chapter 12).

In the early stages of plantation development non-planted species compete with the planted trees, and in timber plantations optimised for financial return, recruits are usually removed before they can hinder growth (Keenan *et al*. Chapter 10). After canopy closure the main competition is between the planted trees themselves; and silviculturalists seek to control such competition by periodically removing the least vigorous trees or those with poor form, a process known as thinning. Pre-commercial (or uncommercial) thinning, where there is no market for the small logs removed, is often necessary. The large expense of pre-commercial thinning was one of the reasons for the high diversity of species found in the older *Flindersia brayleyana* plantations in north Queensland; in this case no thinning was undertaken because no market could be found. In the absence of thinning, plantation tree growth slows and the volume of timber produced, and hence timber value per stem declines, but successional development continues, and biodiversity increases.

It is possible that, given time and under favourable conditions, monoculture plantations, ecological restoration plantings, cabinet timber plantations and unmanaged regrowth may begin to resemble each other, especially in a landscape where remnant patches of intact forest remain nearby. However, current silvicultural practices and clearfell harvest systems characteristic of timber plantations may limit long-term biodiversity outcomes (see Catterall *et al*. Chapter 13).

This raises an interesting dilemma for managers. How should these future cabinet timber plantations be managed? Should they be pruned to enhance commercial value and thinned to increase tree growth whenever markets for thinnings can be found? (Suggested thinning schedules are given in Keenan *et al*. Chapter 10). Or should thinning be excluded and successional development be encouraged to foster enhanced biodiversity? There is obviously no single answer to the dilemma because it will depend on the objectives of the forest grower, or landowner, and on the landscape context. Tree plantations take many years to grow and landowner objectives can change. A landowner with a cabinet timber plantation close to natural forest may decide that the biodiversity value of the plantation now exceeds any timber value and they will manage for enhanced biodiversity protection. A landowner with a plantation more distant from a source of a colonist might decide that the timber values exceed the biodiversity values and manage the forest, using pruning and thinning, to increase productivity. In this case current estimates of biodiversity might be modest and will be affected by plantation management and harvesting. Alternatively, such a landholder might decide to use timber trees which are particularly valuable to wildlife, or actively enrich the planting with native species (Tucker *et al.* 2004). Other management options might used, e.g. selective logging, or incorporating both the planted trees and any new colonists with commercial value (Lamb 1998).

Conclusions

The amount of plant biodiversity present in various types of reforestation depends on the numbers and characteristics of species initially planted, the management history and the age of the plantations or reforested site. The location of the reforested area within a landscape and the history of landscape-scale disturbance will also influence the extent to which successional development occurs. Rainforest timber plantings can lead to positive outcomes for regional biodiversity by facilitating processes that promote the colonization of rainforest taxa (all elements), provided that management regimes (e.g. plant spacing, careful species selection and early weed control) favour processes associated with the development of a rainforest environment. The rate at which this biodiversity develops will not be as rapid as in ecological restoration plantings, and its outcome will be truncated by harvesting. Tradeoffs between profitable timber production (which can be enhanced by thinning, pruning and removing understorey competition) and biodiversity (which may or may not be enhanced by the aforementioned management activities) need consideration.

Irrespective of the type of reforestation, the future is likely to see an increase in weed species in the tropics. It will therefore become increasingly important to minimise the requirement for on-going management of plantings. Achieving early canopy closure is the most effective means of insuring against weed incursion. It is likely to be cost effective to design reforestation programs with rainforest species around the facilitation of rainforest processes (e.g. rapid canopy closure). It is suggested that management and design to minimize the need for ongoing intervention will be important economic considerations in future reforestation efforts.

Acknowledgements

The study was conducted in the 'Quantifying Biodiversity Values of Reforestation' project within the *Restoration Ecology and Farm Forestry* program of the Rainforest Cooperative Research Centre (Rainforest CRC). Thanks to Nigel Tucker and Rob Kooyman for assistance with the botanical surveys. Thanks also to the many landholders and plantation managers who provided access to sites.

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Appendix 1

Native species

Flindersia brayleyana is a tall canopy tree restricted in natural distribution to north Queensland rainforest between Townsville and the Windsor Plateau. It is frequently planted in cabinet timber plantings in the tropics and subtropics, but is also used in ecological restoration and old plantations in both the tropics and subtropics (Figure 5). This species was not frequently encountered in forest reference sites in the tropics and does not occur naturally in the subtropics. Several other congeneric species are also used in ecological and cabinet timber plantings in both the subtropics and tropics.

Elaeocarpus grandis is a rapidly growing canopy rainforest tree occurring from northern NSW to northern Queensland (Boland *et al*. 1992). Although uncommon in forest reference areas (where it was not detected on any of our forest transects), this species is widely planted in both cabinet timber and ecological restoration sites. It was also encountered as a recruit in old plantations in the tropics and regrowth in the subtropics (Figure 5).

Castanospermum australe is a tall rainforest tree with a wide distribution in eastern Australia from the Bellinger River in NSW to Cape York, where it most typically occurs in gallery-type rainforests. This species was frequently encountered in rainforest reference sites in both the subtropics and tropics, and was also encountered in old plantations in the tropics (Figure 5). It was not found in old plantations of the subtropics, but was detected in unmanaged regrowth in the subtropics. It is planted in both ecological and cabinet timber sites in the tropics and subtropics.

Argyrodendron trifoliatum is a tall late successional tree in rainforests from northern NSW to northern Queensland, where it may dominate stands (Francis 1981). This species was very abundant in forest reference areas (particularly in the subtropics). It was also detected in old plantations adjacent to forest reference sites in the tropics, but not in the subtropics (Figure 5). It has been used in ecological plantings and in cabinet timber plantings in the subtropics. However, it was rarely encountered in other land cover types. Several other congeneric species also occur in both the tropics and subtropics. *Argyrodendron peralatum* tends to be favoured over *A. trifoliatum* in reforestation plantings in the tropics.

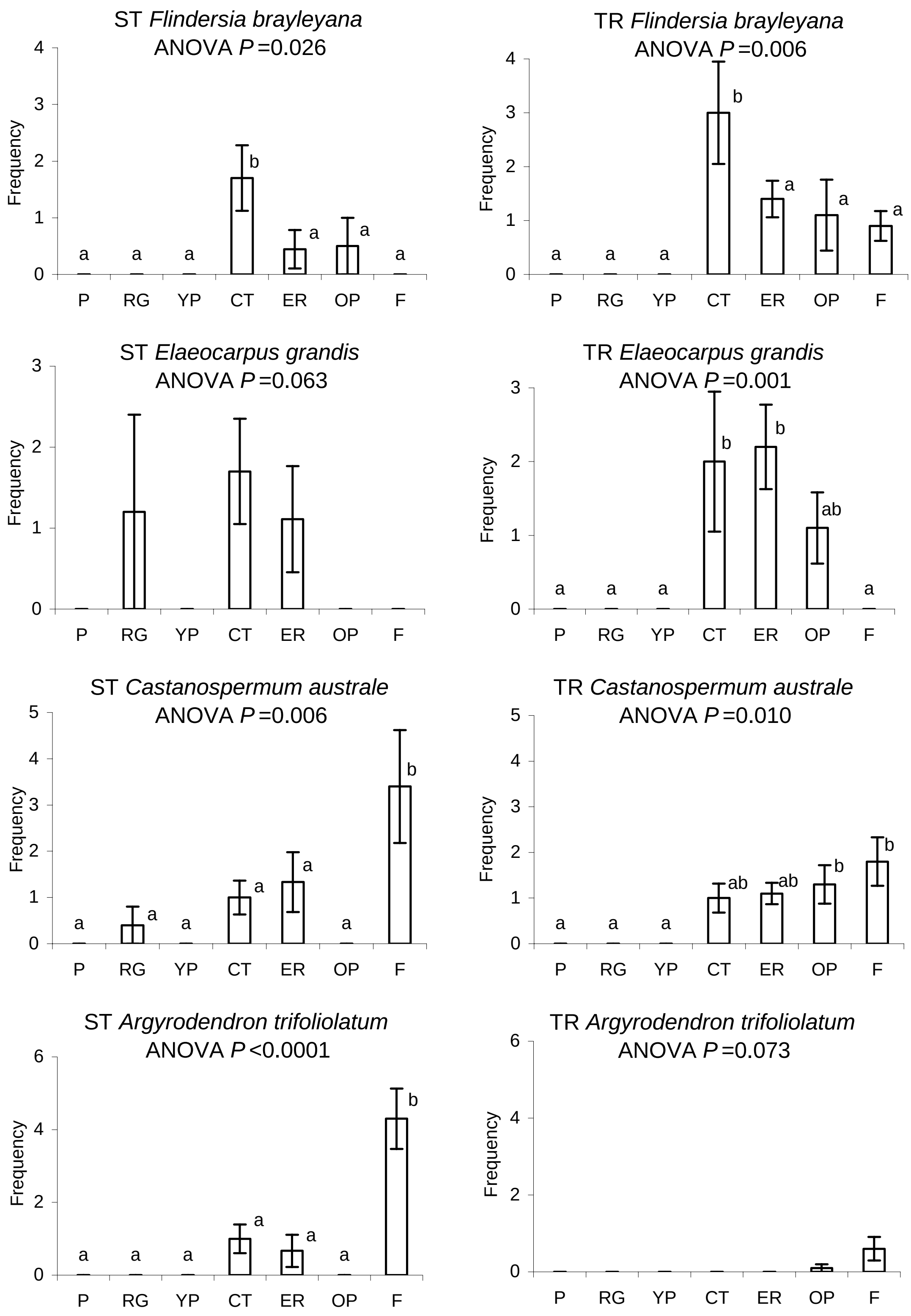


Figure 5 Mean frequency (see text for details) of four native tree species (*Flindersia brayleyana*, *Elaeocarpus grandis*, *Castanospermum australe* and *Argyrodendron trifoliatum*) in seven land cover types (Regrowth- RG, Young plantation – YP, Cabinet timber – CT, Ecological restoration – ER, Old plantation – OP; and rainforest - F and Pasture – P, reference sites) in subtropical and tropical Australia. Means with same letter are not significantly different (ANOVA, LSD).

Appendix 2

Introduced species

Cinnamomum camphora is one of few dominant canopy tree species that have become widely established as environmental weeds in the subtropics (others include *Ligustrum lucidum* and *Celtis sinensis*). This species is partly shade tolerant, is spread rapidly by birds and can persist in open pasture by resprouting following browsing. This species occurred at very high frequency in regrowth (where it was abundant in all strata) of the subtropics, and was also widespread in pasture in the same area (Figure 6). This species occurred in all but rainforest reference sites. By contrast, this species was of more limited extent in the tropics, but was encountered occasionally in unmanaged regrowth and ecological restoration. Some areas of the Atherton Tablelands include dense stands of this species, demonstrating its capacity to thrive in the region.

Panicum maximum is a tall (1.5-2 m), partially shade-tolerant clumping perennial grass native to southern Africa introduced as forage in the cattle industry. This species was not found in forest reference or old plantation sites in the tropics, but was frequently encountered in all other land cover types, particularly the relatively openly-spaced young plantations (Figure 6). It is less well established in the subtropics where it was commonly encountered only in cabinet timber sites. *Panicum maximum* was one of the few introduced species more frequently encountered in tropical than subtropical areas.

Ligustrum sinense is a tall, bird dispersed, shade tolerant shrub originating in southern China, and is one of few introduced environmental weed species to occur in forest reference sites (Figure 6); although at low frequency (others include *Psidium guajava* in the tropics). It was frequently encountered at dense regrowth in the subtropics and ecological plantings in the tropics, and also occurred at low frequency in relatively open sites (unmanaged regrowth, young plantations and cabinet timber plantings) in the tropics. However, this species was not detected in old plantations of the tropics or monoculture plantations of any age in the subtropics.

Lantana camara var. *camara* is a bird-dispersed tall sprawling shrub or vine from South America that can persist (but not thrive) in shade. This species is widespread in both the tropics and subtropics and was encountered in all land cover types except pasture (Figure 6). However, it was rare in forest reference sites in both the tropics and subtropics. It is frequently encountered in rainforest occurring in drier, more seasonal or less fertile sites in the same regions, and was frequently encountered in regrowth in the tropics but less so in the older regrowth of the subtropics. It was also frequently encountered in old plantations in the subtropics, but not in the tropics. It was frequently encountered in young plantations, cabinet timber and ecological restoration in both regions.

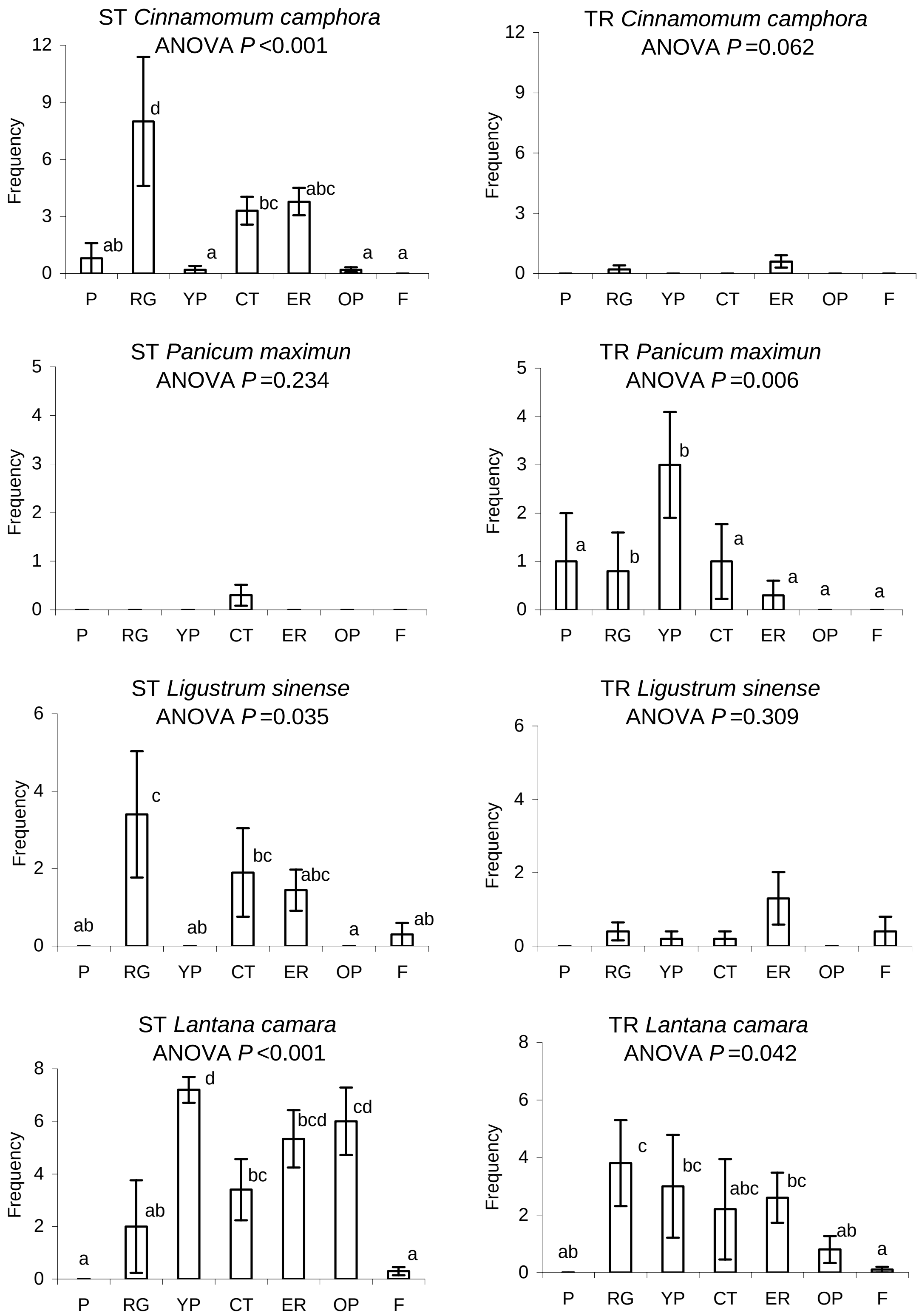


Figure 6 Mean frequency (see text for details) of four introduced plant species (Cinnamomum camphora, Panicum maxima, Ligustrum sinense and Lantana camara) in seven land cover types (Regrowth- RG, Young plantation – YP, Cabinet timber – CT, Ecological restoration – ER, Old plantation – OP; and rainforest - F and Pasture – P reference sites) in subtropical (ST) and tropical Australia (TR). Means with same letter are not significantly different (ANOVA, LSD).

12. Biodiversity values of timber plantations and restoration plantings for rainforest fauna in tropical and subtropical Australia

John Kanowski, Carla P. Catterall, Heather Proctor, Terry Reis, Nigel I.J. Tucker and Grant Wardell-Johnson

Abstract

It has been suggested that timber plantations could play an important role in the conservation of biodiversity in cleared rainforest landscapes, not only because of their potential to cost-effectively reforest large areas of land, but also because they may provide habitat for rainforest plants and animals. However, this last claim is largely untested. In this study, we surveyed the occurrence of a range of animal taxa in monoculture and mixed species timber plantations and restoration plantings in tropical and subtropical Australia. We used the richness of 'rainforest-dependent' taxa (i.e., birds, lizards and mites associated with rainforest habitats) in reforested sites as our measure of their 'biodiversity value'. We also examined whether the biodiversity value of reforested sites was correlated with habitat attributes, including plant species richness and vegetation structure and, further, whether biodiversity value was affected by the proximity of reforested sites to intact rainforest.

In general, our results showed that:

- *young timber plantations (both monoculture and mixed species) supported few rainforest taxa;*
- *Birds associated with rainforests were poorly represented in young timber plantations, but were moderately common in restoration plantings;*
- *Few rainforest lizards were recorded in young reforested sites, except in restoration plantings in the tropics;*
- *Rainforest mites were generally detected more frequently in restoration plantings than cabinet timber plantations, while the richness of rainforest mites in monoculture plantations varied between regions;*
- *The richness of rainforest birds in young reforested sites was positively correlated with plant species diversity and structural complexity, with similar correlations observed for rainforest lizards in the tropics;*
- *Rainforest mite richness was poorly correlated with measured habitat variables; and that*
- *Monoculture plantations close to intact forest tended to support more rainforest birds, lizards and mites than isolated plantations.*

These results suggest that plantations are likely to have limited value for rainforest taxa under conditions which often characterise broadscale reforestation: i.e., when plantations are established on cleared land, at some distance from intact forest and when plantations are managed intensively for timber production. Management of plantations for their faunal biodiversity values is likely to require the development of explicit design, management and harvest protocols, such as the incorporation of habitat features into plantations and/ or the reservation or restoration of native forest on part of the plantation estate.

Introduction

Rainforests cover less than 0.3% of Australia, but support around half its terrestrial biota (Adam 1994). In south-east Queensland and northern New South Wales (NSW), approximately half the area of rainforest present at the time of European settlement has been cleared for agriculture, plantation forestry and urban development (Floyd 1990; McDonald *et al.* 1998). In north Queensland, approximately one-quarter has been cleared (Winter *et al.* 1987; Erskine 2002). Forest types on arable land (e.g., floodplains and basalt plateaux) have been especially targeted for conversion to agriculture.

Following decades of community concern, the remaining areas of rainforest in Australia are now well represented in the reserve system (Adam 1994). However, the conservation of rainforests is likely to require more than the formal protection of remnants. Clearing and fragmentation have already wrought changes to the faunal composition of remnant forests (Date *et al*. 1991, Laurance 1994, Warburton 1997, Moran *et al.* 2004). Due to the complex interactions of plants and animals in rainforest dynamics, changes in the abundance of key animal species (e.g., seed dispersers, and seed and seedling herbivores) in remnant forests are likely to lead to the loss of biodiversity in rainforest remnants, even in protected areas, over the long term (Jones and Crome 1990, Lott and Duggin 1993; Turner 1996, Laurance and Bierregaard 1997, Gilmore 1999, Wright *et al.* 2002, Kanowski *et al.* 2004).

Revegetation is an important component of a strategy for rainforest conservation in Australia (Date and Recher 1991, Kooyman 1999, McDonald 1999, Catterall *et al.* Chapter 13). As yet, the extent of revegetation in cleared rainforest landscapes is small. In north Queensland, where government assistance for reforestation of former rainforest landscapes in Australia has been focussed, approximately 1,000 ha of diverse plantings established to restore natural rainforest communities (referred to subsequently as restoration plantings) and 2,000 ha of mixed species cabinet timber plantations have been established (Erskine 2002). The restoration plantings have largely been established to rehabilitate degraded remnants, enlarge the size of small remnants, or create habitat corridors between remnants (Joseph 1999, Tucker 2000). However, it may be necessary to revegetate a sizable proportion of the landscape to conserve rainforest biota over the long term (Catterall 2000, Catterall *et al.* Chapter 13). Although the scale of revegetation required is unknown, it is likely to be much larger than plantings currently established. For example, if all ‘endangered’ and ‘of concern’ rainforest types were to be restored to at least 30% of their presumed pre-European extent (the threshold below which forest types cannot now be cleared in Queensland), an additional 36,000 ha of cleared rainforest land would need revegetation in south-east Queensland alone (data compiled from Sattler and Williams 1999).

One reason why large areas of cleared land have not been returned to rainforest, even in areas where agricultural production has become marginally profitable, is the high cost of restoration. The rainforest restoration models typically practiced in eastern Australia involve the planting of a diverse range of trees and shrubs at high densities (Goosem and Tucker 1995, Kooyman 1996). These ‘ecological restoration’ plantings presently cost around \$20,000 to \$25,000 per ha, with little promise of a return from timber or other forest products (Erskine 2002; Catterall *et al.* Chapter 13). Without a large increase in government or private funding, or a substantial reduction in the cost of restoration (e.g., through the development of techniques such as direct seeding), the extent of restoration plantings is likely to remain small because of the costs involved in restoring rainforests.

Timber plantations have a greater potential to reforest much larger areas of cleared land. Not only are plantations much cheaper than restoration plantings (c. \$5,000 to \$10,000 per ha for mixed species plantations (Erskine 2002), less for monocultures), but they can also provide a return on investment when the timber is harvested.

For species with a proven production record (e.g. hoop pine - *Araucaria cunninghamii*), the expected financial return has been sufficient to encourage public investment in large-scale plantations and joint venture (government/ landholder) plantations on private land (Vize and Creighton 2001). Furthermore, plantations may recruit an understorey of rainforest plants and provide habitat for some rainforest animals (Parrotta *et al.* 1997 and references therein). For these reasons, it has been argued that timber plantations could play a major role in the restoration and conservation of biodiversity in cleared rainforest landscapes (Lugo 1997, Lamb 1998). Unfortunately, there are few data to test this claim.

Most studies of the potential value of timber plantations for rainforest biota have focussed on the recruitment of trees and shrubs to plantations (e.g., Keenan *et al.* 1997, Lamb *et al.* 1997, Parrotta *et al.* 1997). However, little is known about animal biodiversity in rainforest timber plantations (Bentley *et al.* 2000). Furthermore, most studies have been conducted in plantations established by conversion of intact forest, and/ or located adjacent to intact forest. Little is known about the potential biodiversity values of plantations established on cleared land at some distance from intact forest, conditions which would characterise the broad-scale reforestation of former rainforest landscapes.

In this paper, we present data from a research project investigating the biodiversity values of reforestation in former rainforest landscapes in eastern Australia. We survey the use of timber plantations (both monoculture and mixed species) and restoration plantings by rainforest-dependent birds, lizards and mites, and examine whether the occurrence of these taxa in plantings is correlated with aspects of plant species richness, vegetation structure and landscape context. Finally, we discuss the likely outcomes for faunal biodiversity in timber plantations under current management practices, and how these outcomes might be improved.

Methods

Study design

Our project surveyed a range of reforestation styles that are common in former rainforest landscapes of eastern Australia including monoculture timber plantations, mixed species cabinet timber plantations and ecological restoration plantings. Full details of the study design and methodology are provided elsewhere (Wardell-Johnson *et al.* 2002, Kanowski *et al.* 2003, Catterall *et al.* Chapter 13). Monoculture plantations were largely hoop pine, although in the tropics, we also surveyed some old monocultures of kauri pine (*Agathis robusta*), Queensland maple (*Flindersia brayleyana*) and red cedar (*Toona ciliata*). Monoculture plantations were established at relatively low densities (c. 1,200 stems per ha). Weeds were controlled by herbicides, slashing or grazing and trees were subject to thinning and pruning. Cabinet timber plantations typically comprised 6 – 20 species known from native forests for their potential to produce high-value appearance grade timber. Most were native rainforest species, although eucalypts (especially *Eucalyptus grandis* and *E. pellita*) and some exotics (e.g., *Cedrela odorata*) were often included. The plantations were established at similar densities and managed in a similar manner to monoculture plantations.

Restoration plantings mostly comprised a diverse mix of trees and shrubs (20–100 species, usually local species and provenances), planted at high densities (up to 6,000 stems per ha). In restoration plantings, weeds were controlled by hand or by herbicides, but trees were generally not thinned or pruned. All reforested sites were located on land which formerly supported rainforest (mostly complex notophyll vine forest in the terminology of Webb 1968). Old monoculture plantations were established by clearing and burning rainforest. Most young monoculture plantations were second rotation, except for two plantations established on already cleared land. All cabinet timber plantations and restoration plantings surveyed in the project had been established on cleared land or abandoned pasture.

We located reference sites in both pasture and intact rainforest. Pasture sites had been cleared of rainforest for 80–120 years, sown to exotic pasture grasses and subsequently grazed by dairy and beef cattle. Rainforest reference sites were selected to provide relatively undisturbed examples of complex notophyll vine forest and related forest types (Araucarian notophyll vine forest, complex mesophyll vine forest), representing the range of variation in the environments of reforested sites.

Research was conducted in tropical Australia (the Atherton Tablelands, north Queeensland) and in the subtropics (northern NSW and south-east Queensland). We obtained five to 10 replicate sites of each reforestation type and reference site type within each region to allow for variation in site history, management and landscape context. In selecting sites, we controlled for altitude and geology and major determinants of rainforest structure and composition (Webb 1968, Tracey 1982). The tropical sites were located at mid-elevations (500–850 m a.s.l.), mostly on basaltic soils, with rainfall between 1300 and 3000 mm per annum. The subtropical sites were located in the lowlands and foothills (10–400 m a.s.l.), on basaltic and metasedimentary soils, with rainfall between 1100 and 2000 mm per annum. The different site types were distributed across the rainfall gradient in each region, except in the subtropics, where monoculture plantations were mostly located in the drier parts of the study area. Replicate sites in each treatment were generally 1–10 km apart, except for monoculture plantations, where some sites were only a few hundred metres apart. However, closely adjacent sites in monoculture plantations differed in species planted or time of establishment. Most monoculture plantations were located amongst or adjacent to intact forest, whereas cabinet timber plantations and restoration plantings varied in their proximity to intact forest.

Almost all restoration plantings and cabinet timber plantations in our study areas were relatively young (one or two decades old, at most). Hence, a comparison of the biodiversity value of different types of reforestation was possible only for ‘young’ (5–22 years) plantings. Sites were constrained to be at least five years old, by which time denser plantings had usually attained canopy closure. To control for area effects on biota, we targeted sites which were greater than 4 ha, although a few sites as small as 2 ha were included to obtain sufficient replicates in some treatments. We also include data on the biodiversity values of ‘old’ (38–70 years) monoculture plantations. The resulting design is presented in Table 1.

Table 1 Attributes of rainforest plantings, pasture and intact rainforest sites surveyed in subtropical and tropical Australia.

Site type	Number of sites in: subtropics	tropics	Species planted	Age in years at survey: median (range)
Pasture reference sites	5	5	-	-
Monoculture plantations (young)	5	5	1	10 (5 – 15)
Cabinet timber plots	10	5	6 - 20	7 (5 – 10)
Restoration plantings	9	10	20 - 100	9 (6 – 22)
Monoculture plantations (old)	10	10	1	60 (38 – 70)
Rainforest reference sites	10	10	-	-

Sampling methodology

At each site, we conducted surveys of a range of taxa and ecological attributes (a full list of attributes surveyed is given in Catterall *et al.* Chapter 13). In this paper, we concentrate on results for birds, lizards and mites, and aspects of faunal habitat including floristic composition and vegetation structure. Surveys were conducted over a period of three years (between 2000 and 2002) on a standardised 100 m x 30 m (0.3 ha) plot at each site. Plots were located away from edges where possible.

Birds

Birds were assessed by recording all species seen or heard during six (subtropics) or eight (tropics) 30 minute surveys of the entire 0.3 ha plot. Only birds judged within the plot were used in analyses. Surveys were conducted at any time during daylight hours, except when hot or wet weather reduced activity levels. We were careful to rotate survey times across the different forest types. Surveys in the subtropics were conducted by a single observer, while tropical bird surveys were conducted by two observers, each of whom conducted two rounds of surveys of all sites. Two rounds of surveys were conducted every 3-4 months over the course of a year. No attempt was made to control for differences in detectability between sites (generally, visual detectability declined from pasture, through monoculture and cabinet timber plantations, restoration plantings and old plantations, to intact forest). However, most records were made from calls, which are less likely to be affected by differences in forest structure than sightings. Furthermore, the trend in visual detectability ran counter to trends in rainforest bird species richness (richness was highest in the more structurally complex plots), suggesting our results are conservative for rainforest birds.

Lizards

Lizards were surveyed by three 30 minute active searches of the entire 0.3 ha plot. If necessary, lizards were captured for identification using published keys (Cogger 2000). Surveys were carried out by a single observer (TR) on different days and over at least two different seasons.

Mites

Mites were extracted from two litres of leaf litter and surface soil collected at each plot, using a Tullgren funnel with a heat lamp operating for three days. The litter and soil was collected from a large number of ‘grabs’ from microsites (e.g., the forest floor, beside fallen logs, beside trees) located haphazardly across each plot. Mites were generally identified to family level (Walter and Proctor 2001). However, because of the poor state of taxonomy for the mite taxa Trombidioidea and Uropodoidea in Australia, these taxa were identified to superfamily rather than family. Likewise, most phoretic deutonymphal mites from the suborder Astigmata were simply identified as ‘hypopodes’ because of the difficulty of assigning them to families. Nevertheless, this level of taxonomic resolution provided about 70 taxa in each region.

Vascular Plants

Vascular plants were surveyed on five circular 78.5 m^2 quadrats, located systematically in each plot. Individuals rooted in the plot or, if epiphytes, growing on plants rooted in the plot were identified to species and recorded, if present, in each of three strata: canopy (top 1/3 of the canopy height), midstorey (2 m to 2/3 height of canopy) and ground (< 2 m high). The dispersal mode of plants was determined by reference to published sources (e.g., Tucker and Murphy 1997, Hyland *et al.* 2003) and unpublished data (D. Butler pers. comm., C. Moran pers. comm).

Species were categorised as bird-dispersed (mostly species with fleshy drupes, berries or arilate seeds), wind-dispersed (winged or plumed seeds) or dispersed by other modes. More comprehensive analyses of the plant data are presented elsewhere in this volume (Wardell-Johnson *et al.* Chapter 11).

Structural Attributes

Structural attributes were surveyed on five circular quadrats of 5-10 m radius, depending on the attributes measures, located systematically in each plot (for details, see Kanowski *et al.* 2003). Values for most of the structural attributes were strongly intercorrelated, hence for some analyses we reduced the dataset to an index of structural complexity. The index was calculated as the mean value of selected attributes at a site (see below), where each attribute was first standardised as a proportion of its average value in intact rainforest sites. The standardisation was conducted separately for tropical and subtropical sites. The structural attributes contributing to the index comprised canopy cover, basal area, canopy height, the abundance of woody stems (i) < 2.5 cm d.b.h., and (ii) > 2.5 cm d.b.h., the density of large trees (> 50 cm d.b.h.), the vertical diversity of tree heights, the abundance of special life forms (vines, epiphytes, hemi-epiphytes, strangler figs), leaf litter dry weight and an index of the volume of coarse woody debris.

Analytical approach

In this paper, we define biodiversity value as the richness of rainforest-dependent taxa recorded at a site, relative to a number of rainforest reference sites, using a standardised sampling protocol (see also Catterall *et al.* Chapter 13). This definition is based on the assumption that, from an ecological or conservation perspective, the elements of biodiversity that are of value in a former rainforest landscape are taxa potentially threatened by the clearing and fragmentation of rainforest, rather than taxa which may benefit from rainforest destruction (e.g. ‘grassland’ species). The definition is simple and readily applied to survey data, although it requires knowledge of the habitat preferences of target taxa. More sophisticated analyses of the biodiversity values of rainforest plantings (e.g., analyses which consider differences in the composition of entire assemblages) is presented in this volume (Catterall *et al.* Chapter 13).

For the purposes of this paper, we considered the ‘biodiversity value’ of rainforest plantings in terms of three faunal groups: birds, lizards and mites. For birds, habitat preferences were determined from published data (principally Kikkawa 1968, 1991, and Crome *et al*. 1994). We defined ‘rainforest’ birds as species largely associated with, or apparently dependent on, rainforest and associated wet sclerophyll forests (based on species occurrence in relatively extensive tracts of intact forest). ‘Other forest’ birds were species found regularly across a variety of forested habitats from rainforest to eucalypt woodlands, some being largely confined to eucalypt assemblages; while ‘grassland/ wetland’ birds were those species found mainly in grassland, pasture, swamps, or unforested streams, and sometimes in lightly timbered areas. A list of rainforest birds recorded in the study is provided in Table 2.

Table 2 Rainforest-dependent birds. recorded on surveys plots in rainforest plantings and intact rainforest sites.

Family	Species	Common Name
Megapodiidae	*Alectura lathami*	Australian brush turkey
	Megapodius reinwardt	orange-footed scrubfowl
Accipitridae	*Accipiter novaehollandiae*	grey goshawk
Columbidae	*Columba leucomela*	white-headed pigeon
	Macropygia amboinensis	brown cuckoo-dove
	Chalcophaps indica	emerald dove
	Ptilinopus magnificus	wompoo fruit-dove
	Ptilinopus superbus	superb fruit-dove
	Ptilinopus regina	rose-crowned fruit-dove
	Lopholaimus antarcticus	topknot pigeon
Psittacidae	*Cyclopsitta diophthalma*	double-eyed fig-parrot
Pittidae	*Pitta versicolor*	noisy pitta
Climacteridae	*Cormobates leucophaeus*	white-throated treecreeper
Pardalotidae	*Oreoscopus gutturalis*	fernwren
	Sericornis citreogularis	yellow-throated scrubwren
	Sericornis keri	Atherton scrubwren
	Sericornis magnirostris	large-billed scrubwren
	Gerygone mouki	brown gerygone
	Acanthiza katherina	mountain thornbill
Meliphagidae	*Xanthotis macleayana*	Macleay's honeyeater
	Lichenostomus frenatus	bridled honeyeater
Petroicidae	*Tregellasia capito*	pale-yellow robin
	Heteromyias albispecularis	grey-headed robin
Orthonychidae	*Orthonyx temminckii*	logrunner
	Orthonyx spaldingii	chowchilla
Cinclosomatidae	*Psophodes olivaceus*	eastern whipbird
Pachycephalidae	*Colluricincla megarhyncha*	little shrike-thrush
	Colluricincla boweri	Bower’s shrike-thrush
Dicruridae	*Machaerirhynchus flaviventer*	yellow-breasted boatbill
	Monarcha melanopsis	black-faced monarch
	Monarcha trivirgatus	spectacled monarch
	Arses kaupi	pied monarch
Campephagidae	*Coracina lineata*	barred cuckoo-shrike
Oriolidae	*Sphecotheres viridis**	figbird
Artamidae	*Cracticus quoyi*	black butcherbird
Paradisaeidae	*Ptiloris paradiseus*	paradise riflebird
	Ptiloris victoriae	Victoria’s riflebird
Ptilonorhynchidae	*Ailuroedus melanotis*	spotted catbird
	Ailuroedus crassirostris	green catbird
	Scenopoeetes dentirostris	tooth-billed bowerbird
	Sericulus chrysocephalus	regent bowerbird
Muscicapidae	*Zoothera heinei*	russet-tailed thrush
Sturnidae	*Aplonis metallica*	metallic starling

** considered a rainforest-dependent species in the tropics only*
Note: this is not a comprehensive list of rainforest-dependent birds occurring in subtropical and tropical Australia

Similarly, we defined ‘rainforest’ lizards as species largely confined to, or apparently dependent on, rainforest, according to published accounts (Covacevitch and McDonald 1991, Cogger 2000). A list of rainforest lizards recorded in the study is provided in Table 3.

Table 3 Rainforest-dependent lizards .recorded on surveys plots in rainforest plantings and intact rainforest sites.

Family	Species	Common Name
Agamidae	*Hypsilurus boydii*	Boyd’s forest dragon
Scincidae	*Calyptotis lepidorostrum*	a fossorial skink
	Egernia major	land mullet
	Eulamprus murrayi	a forest skink
	Eulamprus tigrinus	a forest skink
	Gnypetoscincus queenslandiae	prickly forest skink
	Lampropholis coggeri	a sun skink
	Lampropholis couperi	a sun skink
	Lampropholis robertsi	a sun skink
	Ophioscincus ophioscincus	a snake skink
	Ophioscincus truncatus	a snake skink
	Saproscincus basiliscus	a shade skink
	Saproscincus challengeri	a shade skink
	Saproscincus spectabilis	a shade skink
	Saproscincus tetradactylus	a shade skink

Note: this is not a comprehensive list of rainforest-dependent lizards occurring in subtropical and tropical Australia.

For mites, where habitat associations were not known *a priori*, we calculated the proportion of rainforest and pasture sites in which each taxa occurred. We defined ‘rainforest’ mites as (i) taxa detected in both study regions in rainforest, but not in pasture; and (ii) taxa detected far more frequently in rainforest than pasture in a region. For the latter, a 60% difference in frequency of occurrence between rainforest and pasture was considered meaningful: e.g., ‘rainforest’ mites included taxa detected in at least six of the ten rainforest sites and no pasture sites in one region, or if detected in one of the five pasture sites in a region, then in at least eight of the ten rainforest sites, and so on. The converse rule was used to identify ‘pasture’ mites. Remaining taxa were included in the ‘other’ category. A list of taxa identified as ‘rainforest’ mites in the study is given in Table 4.

Differences in the mean richness of rainforest taxa between different types of plantings and reference sites were analysed with ANOVA with post-hoc LSD tests. Results are reported separately for the tropics and subtropics, because of regional differences in biota as well as, for birds, differences in survey effort and observers.

To examine potential determinants of biodiversity value, we examined correlations between the richness of rainforest biota (birds, lizards and mites) and selected habitat attributes including plant richness and various structural attributes. For these analyses, we only included data from young replanted sites, as the old plantations differed considerably from the young plantings in site history (no intervening pasture or plantation phase) and landscape context (almost all the old plantations were located adjacent to intact forest), which might confound any correlation with habitat attributes.

We also conducted a preliminary analysis of the influence of proximity to rainforest on the richness of rainforest biota in young revegetated sites. In this analysis, sites were classified as ‘close’ if within 400 m of extensive or remnant (> 5 ha) rainforest (most were adjacent to rainforest), or ‘distant’ if more than 400 m from extensive or remnant rainforest (most were more than 1 km from rainforest).

These thresholds are arbitrary, but previous work suggests that small rainforest remnants tend to support only a subset of the biota of intact forest (e.g., Warburton 1997). This last comparison is made tentatively, as the number of sites in most categories was small, precluding statistical analysis.

Table 4 Mite taxa (mostly identified to family level) categorised as indicators of pasture and rainforest in subtropical and tropical Australia.

Mite taxon	'Pasture' mites		'Rainforest' mites	
	Subtropics	Tropics	Subtropics	Tropics
Acaridae		*		
Caligonellidae	*	*		
Cunaxidae	*			
Digamasellidae	*			
Erythraeidae	*			
Ixodidae	*	*		
Parasitidae	*	*		
Rhodacaridae	*	*		
Tarsonemidae		*		
Tetranychidae	*	*		
Tydeidae	*	*		
Alicorhagiidae			*	*
Bimichaeliidae				*
'hypopodes'[#]				*
Labidostommatidae			*	*
Penthalodidae			*	*
Rhagidiidae			*	*
Smarididae			*	*
Trachytidae			*	
Trombidiodea			*	*
Uropodoidea				*

[#] *phoretic Astigmata*

See text for explanation of categories.

Note: This is not a comprehensive list of rainforest-dependent mite taxa for each region.

Results

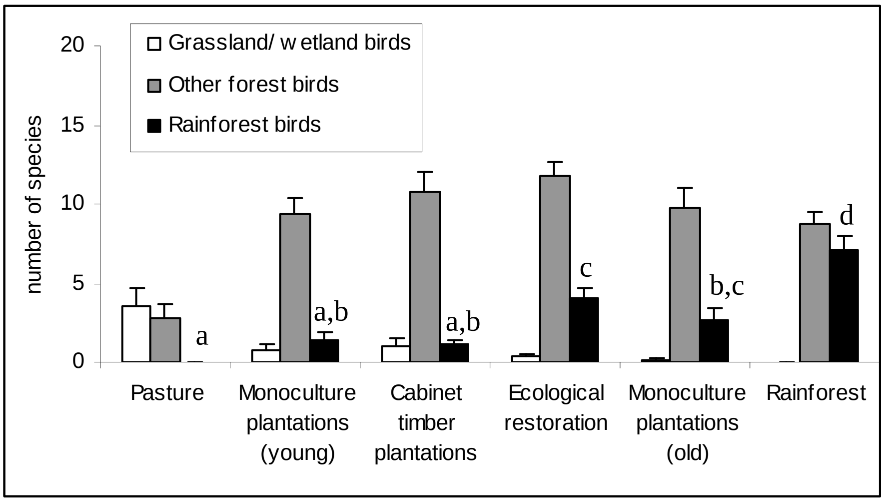
Birds, lizard and mite richness in timber plantations and rainforest plantings

Birds

Bird assemblages in young reforested sites were dominated by habitat generalists (Figure 1). Rainforest-dependent birds were relatively uncommon in young monoculture and cabinet timber plantations. In contrast, the richness of rainforest birds recorded in restoration plantings was about half that of intact rainforest. These patterns were similar in both study regions.

The richness of rainforest birds in old monoculture plantations varied between regions. In the subtropics, old plantations supported less than half the number of rainforest birds recorded in intact rainforest sites, on average. In the tropics, old plantations supported about 75%, on average, of the birds recorded in intact rainforest sites.

(a)



(b)

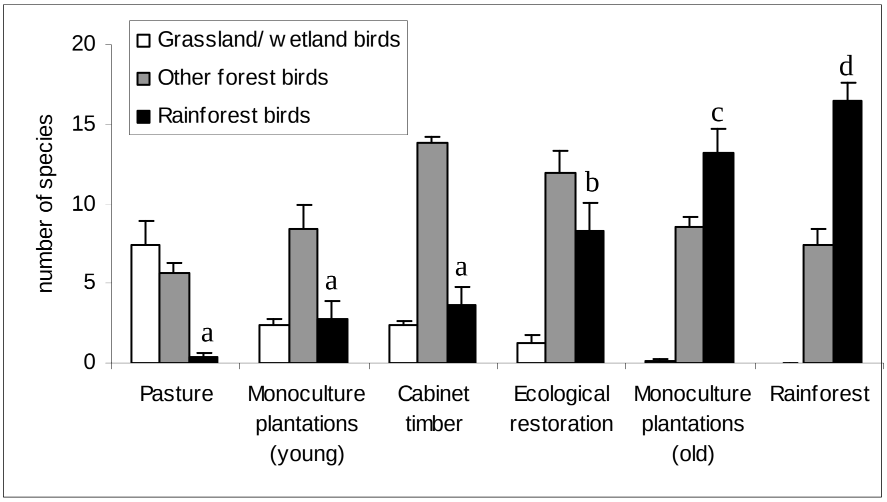
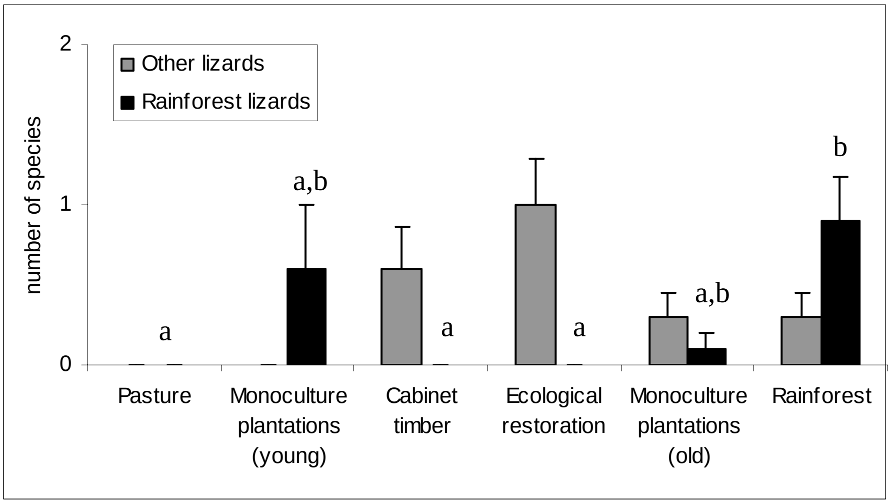


Figure 1 Bird species richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. 'Rainforest' birds = species largely confined to, or apparently dependent on, rainforest; 'other forest' birds = species found regularly across a variety of forested habitats, some being largely confined to eucalypt assemblages; 'grassland/ wetland' birds = species found mainly in grassland, pasture, swamps, or unforested streams, and sometimes in lightly timbered areas. Treatments with the same letters are not significantly different in rainforest bird richness.

Lizards

Only a few rainforest lizards were recorded in this study, especially in the subtropics (Figure 2). Assemblages in young reforested sites tended to be dominated by lizards associated with open habitats, rather than rainforest. In the tropics, rainforest lizards were recorded in restoration plantings and old monoculture plantations, but not in young timber plantations. Some rainforest lizards were recorded in young monoculture plantations in the subtropics, often associated with relictual coarse woody debris.

(a)



(b)

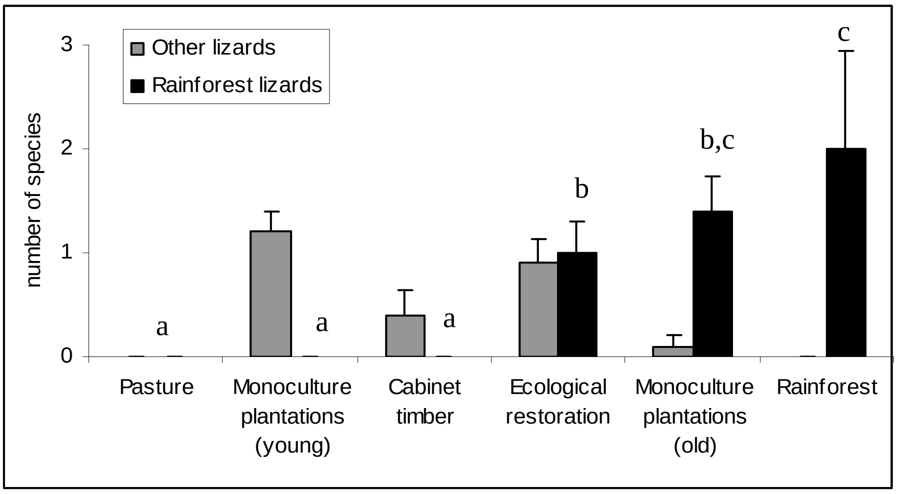


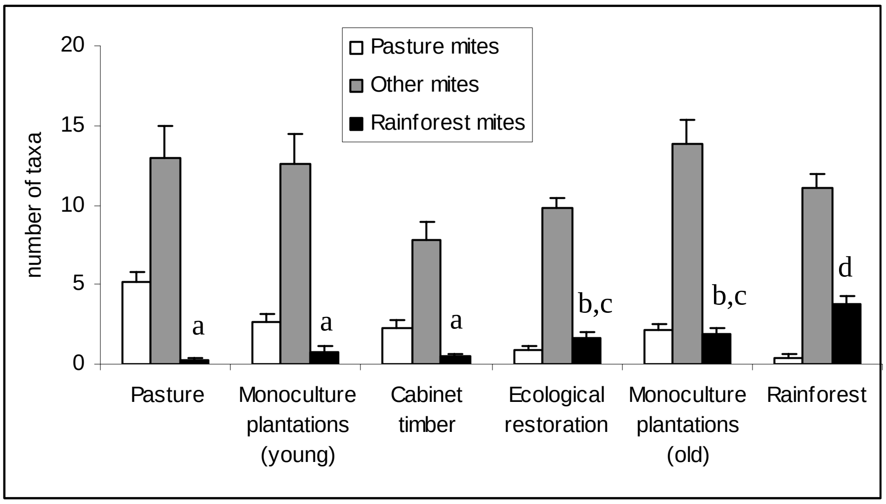
Figure 2 Lizard species richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. 'Rainforest' lizards = species largely confined to, or apparently dependent on, rainforest; 'other lizards' = species found regularly across a variety of habitats. Treatments with the same letters are not significantly different in rainforest lizard richness.

Mites

Mite assemblages (mostly identified at the family level) in reforested and reference sites were dominated by taxa associated with a wide range of habitats. Nevertheless, we identified a number of mite taxa which were strongly associated with intact rainforest (Figure 3**).** The richness of these 'rainforest' mites was generally higher in revegetated sites than pasture, but less than that recorded in rainforest. In young revegetated sites, rainforest mites tended to be least common in cabinet timber plantations and most common in restoration plantings. The relative richness of rainforest mites in young monoculture plantations varied between regions, with proportionally more rainforest taxa in plantations in the tropics than the subtropics.

The occurrence of rainforest mites in old monoculture plantations also varied between regions. In the subtropics, old plantations supported about half the rainforest mites of intact rainforest, whereas in the tropics, old plantations supported a similar number of rainforest mites as intact rainforest.

(a) Subtropics



(b) Tropics

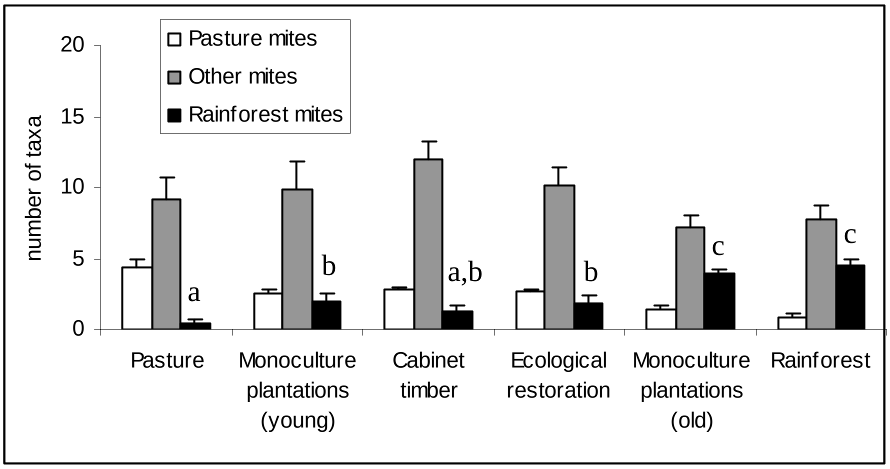


Figure 3 Mite taxon richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. Mite families were categorised by habitat associations according to their frequency of occurrence in pasture and forest sites (see text). Treatments with the same letters are not significantly different in rainforest mite richness.

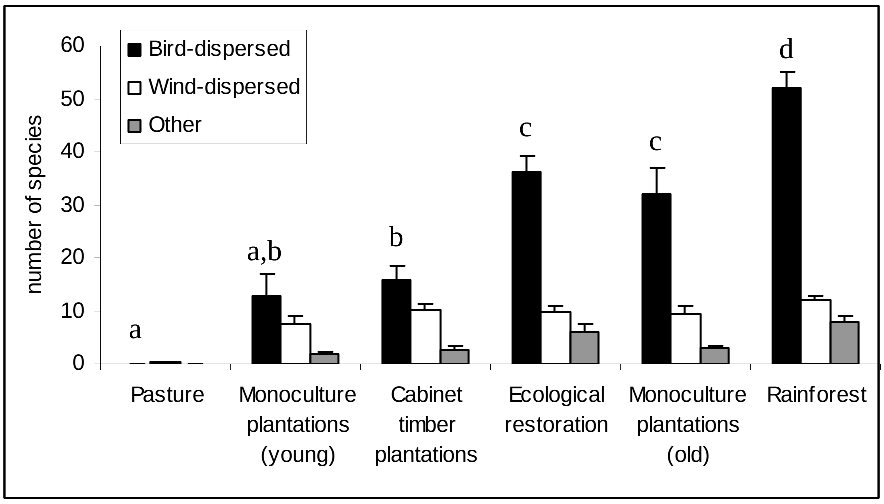
Habitat attributes of timber plantations and rainforest plantings

Plant species richness

For the purposes of this paper, we consider only plants in the canopy and midstorey (mostly shrubs, trees and vines), as most of the reproductively mature individuals which might provide resources for fauna (e.g., nectar, fruit) are in these strata. Within young revegetated sites, plant species richness in the canopy and midstorey increased from monoculture plantations, through cabinet timber plots to restoration plantings (Figure 4).

Most canopy and midstorey plants in restoration plantings were fleshy-fruited and dispersed by birds, similar to the pattern in intact rainforest. In contrast, bird-dispersed plants were relatively uncommon in the canopy and midstorey of young timber plantations, especially in the tropics. However, most old monoculture plantations supported a relatively rich flora of bird-dispersed plants.

a) Subtropics



b) Tropics

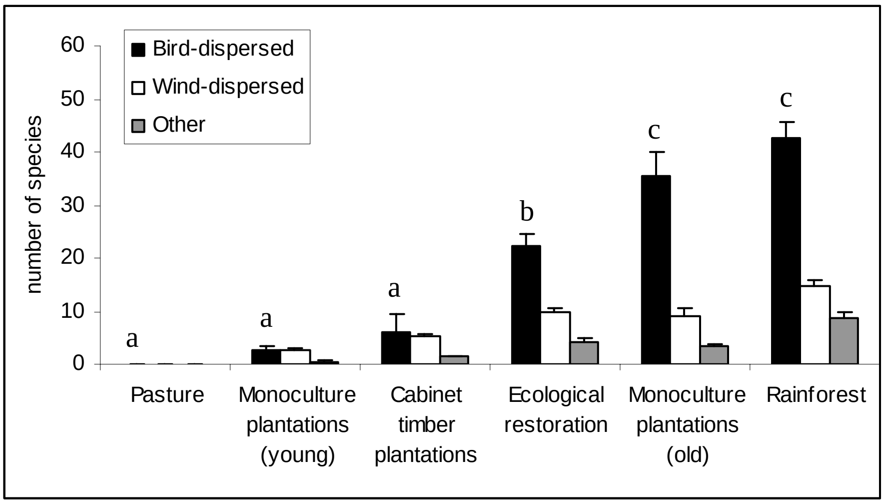


Figure 4 Plant species richness (mean, s.e.) in the canopy and midstorey of rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. Plants were categorised by the dispersal mode of the seed (bird dispersed = fleshy fruited drupe, berry or arilate seed; wind dispersed = winged or plumed seed). Treatments with the same letters are not significantly different in the richness of bird-dispersed plants.

Forest structure

Young monoculture and cabinet timber plantations typically had a simple structure, with an open canopy and grassy ground cover (Figure 5). Restoration plantings had a more complex structure, with a relatively closed canopy and understorey of shrubs, seedlings, herbs and leaf litter. Nevertheless, young revegetated sites generally lacked a suite of structural attributes which are characteristic of intact rainforest, including robust vines, epiphytes, hemi-epiphytes, strangler figs, large trees and large woody debris. Many of these structural attributes were well-developed in old plantations in the tropics, but not in the subtropics.

(i) a)

(b)

(ii) a)

(b)

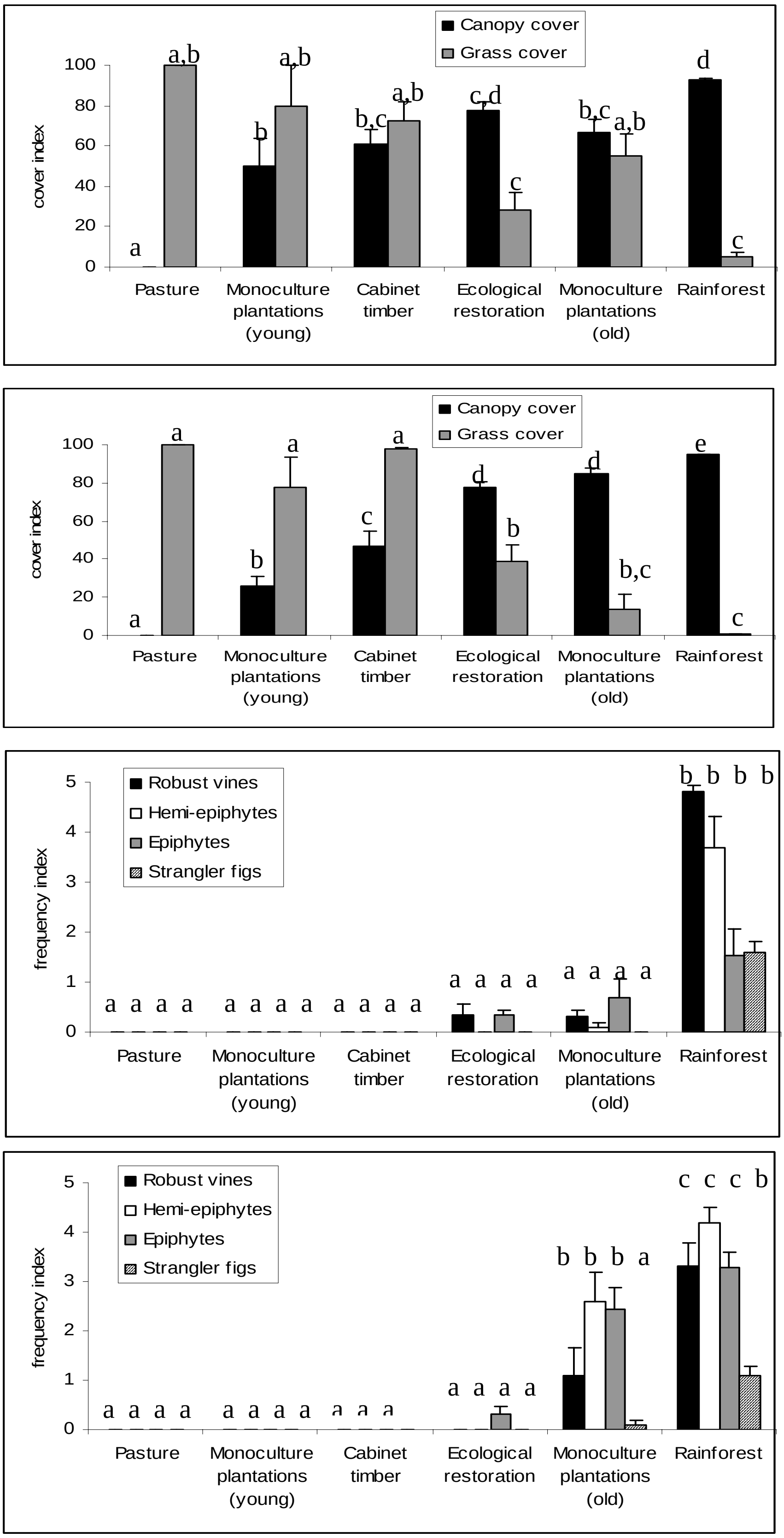


Figure 5 Selected aspects of the physical structure of the vegetation (mean, s.e.) of rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. (i) Canopy cover and grass cover: a) subtropics; b) tropics. Canopy cover = projective cover of vegetation > 2 m above ground; grass cover = frequency of occurrence in twenty-five 0.5 m radius plots per site. (ii) Abundance of special life forms (Webb et al. 1976): a) subtropics; b) tropics.

Correlations between the richness of rainforest biota and habitat attributes in young rainforest plantings

The richness of rainforest birds in young revegetated sites was positively correlated with a number of habitat attributes, including plant species richness and various aspects of structural complexity (Table 5). The richness of rainforest lizards in these sites was also associated with plant species richness and some structural variables, but only in the tropics. Few rainforest lizards were recorded in the subtropics however, so the analysis had little power in that case. The richness of rainforest mites in young revegetated sites was not significantly correlated with any of the measured variables, except for a positive relationship with canopy cover in the subtropics.

Table 5 Rank correlation (r_s, P) between the richness of rainforest-dependent birds, lizards and mites, and selected habitat attributes, in young timber plantations and restoration plantings in subtropical (n = 24) and tropical (n = 20) Australia.

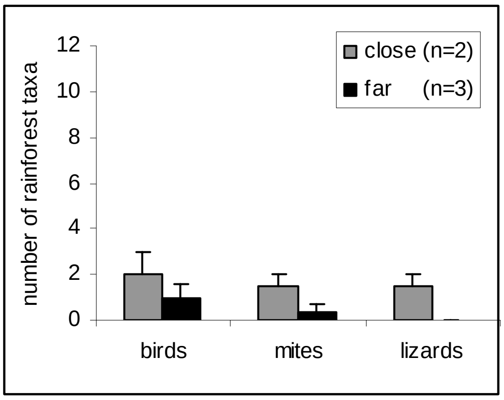
Habitat attribute	**Rainforest bird richness**		**Rainforest lizard richness**		**Rainforest mite richness**	
	Subtropics	Tropics	Subtropics	Tropics	Subtropics	Tropics
Plant richness in canopy and midstorey	**r = 0.59, P = 0.002**	**r = 0.62, P = 0.004**	r = -0.28, P = 0.18	**r = 0.46, P = 0.043**	r = 0.15, P = 0.48	r = 0.18, P = 0.45
Canopy cover	r = 0.33, P = 0.11	**r = 0.59, P = 0.007**	r = 0.21, P = 0.33	**r = 0.70, P = 0.001**	**r = 0.46, P = 0.023**	r = 0.04, P = 0.88
Abundance of woody stems < 2.5 cm d.b.h.	**r = 0.66, P < 0.001**	**r = 0.65, P = 0.002**	r = 0.19, P = 0.38	r = 0.39, P = 0.089	r = 0.12, P = 0.57	r = 0.18, P = 0.45
Abundance of woody stems > 2.5 cm d.b.h.	**r = 0.59, P = 0.003**	**r = 0.46, P = 0.044**	r = -0.28, P = 0.18	r = 0.43, P = 0.059	r = 0.35, P = 0.094	r = -0.01, P = 0.96
Index of structural complexity	**r = 0.75, P < 0.001**	**r = 0.59, P = 0.007**	r = -0.03, P = 0.90	**r = 0.57, P = 0.009**	r = 0.30, P = 0.15	r = 0.01, P = 0.95

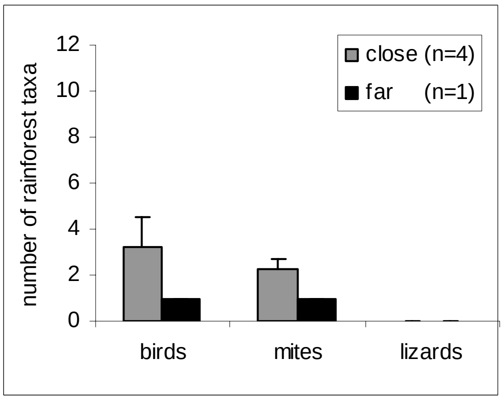
Note: given the number of correlations examined, at least one could be expected to be significant at α = 0.05 by chance alone.

Effect of proximity to intact forest on the occurrence of rainforest biota in young rainforest plantings

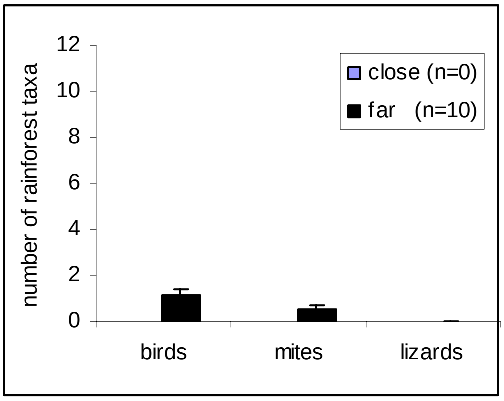
In both study regions, the richness of rainforest birds, lizards and mites in young monoculture plantations appeared to vary with proximity to intact rainforest (Figure 6). Plantations adjacent to intact rainforest tended to have more rainforest taxa than sites distant from remnant or extensive forest. In contrast, the richness of rainforest taxa in cabinet timber plantations and restoration plantings did not appear to be strongly influenced by proximity to rainforest. However, sample sizes in the two proximity categories were low in most cases, precluding rigorous analysis of trends.

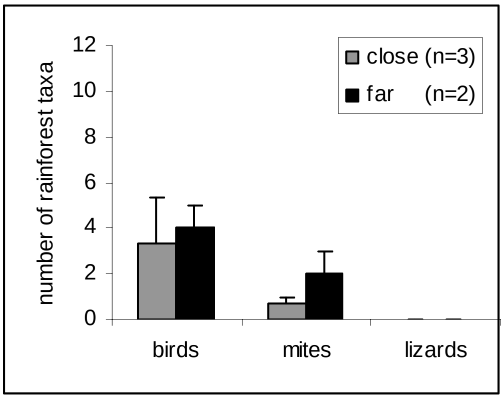
(i) monoculture plantations



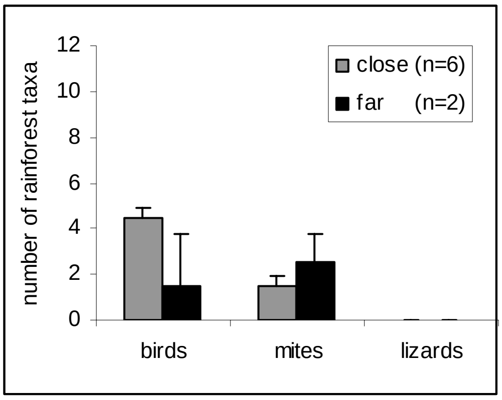


(ii) cabinet timber plantations





(iii) ecological restoration plantings



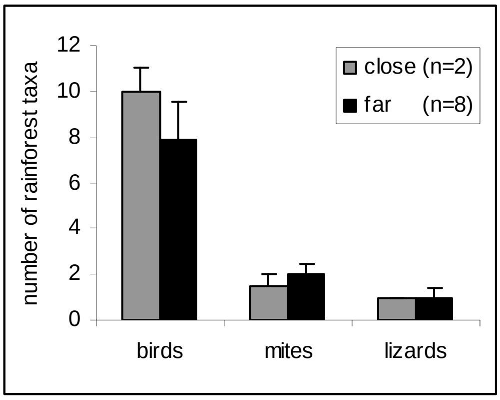


Figure 6 Richness of rainforest birds, lizards and mite taxa (mean, s.e.) in young rainforest plantings in the subtropics and tropics in relation to proximity to intact rainforest. Close = within 400 m of extensive or remnant (> 5 ha) rainforest; distant = more than 400 m.

Discussion

Biodiversity values of rainforest timber plantations

There have been few systematic surveys of faunal biodiversity in rainforest plantations (see Lamb 1998) and, until now, none which have contrasted the value of different types of plantations for rainforest biota. On the basis of the surveys conducted in this project, it is clear that timber plantations have much less value for rainforest biota, per unit area, than ecological restoration plantings, at least in the decade or two following establishment. These results are not surprising, given our limited knowledge of the habitat requirements of rainforest fauna (e.g., Kikkawa 1968, 1991 for birds), and the relatively poor development of suitable habitat in young timber plantations.

Nevertheless, it is possible that timber plantations could still make an important contribution to biodiversity conservation in former rainforest landscapes, as argued by a number of authors (Lamb *et al.* 1997, Lugo 1997, Lamb 1998), provided they recruit and maintain rainforest species over the longer-term. While some old plantations do support a rich diversity of rainforest plants and animals (e.g., those in north Queensland surveyed in this study and Keenan *et al.* 1997), the results from these plantations cannot be extrapolated to the broad-scale reforestation of cleared land, for several reasons. First, it is very unlikely that plantations established on cleared land will recruit as diverse a floristic understorey as plantations established by direct conversion of intact forest, where there is considerable regeneration from rootstocks and the soil seed bank (Fisher 1980). In contrast, the rootstocks and seedbank of rainforest trees are usually destroyed by a lengthy pasture phase (Hopkins and Graham 1984). Second, plantations established on cleared agricultural land must rely on the dispersal of seeds from forests elsewhere in the landscape to recruit rainforest plants. However, the dispersal of rainforest plants to revegetated sites is a function of their proximity to intact forest (e.g., Keenan *et al.* 1997, Lamb *et al.* 1997, McKenna 2001). Our data suggest this may also be the case for rainforest animals. For example, at even relatively small distances from intact forest, young timber plantations appear to recruit few rainforest birds, lizards and mites. Similarly, while most old plantations surveyed in this study were established adjacent to intact forest, we surveyed one old hoop pine plantation in the subtropics that was on private land, about 2 km from the nearest patch of rainforest. No rainforest birds, no rainforest lizards and only one taxon of rainforest mite were recorded in this plantation.

Third, the intensive management of plantations for timber production is likely to reduce the availability of habitat features required by many rainforest biota. For example, in north Queensland, many old plantations had not been thinned, or thinned only once, since establishment. These plantations are floristically rich and structurally complex (Keenan *et al.* 1997, Kanowski *et al.* 2003) and support a relatively rich rainforest fauna. In contrast, old plantations in the subtropics had been more intensively managed, with most sites subjected to several thinning cycles (Fisher 1980). The subtropical plantations are less floristically diverse and less structurally complex than the tropical plantations and support proportionally fewer rainforest birds, lizards and mites. However, this comparison is confounded by other differences between regions (e.g., the subtropical plantations experienced a drier climate than the tropical plantations, which may affect recruitment).

Biodiversity values of mixed species plantations

It is generally presumed that mixed-species plantations will support more biodiversity than monoculture plantations (Lamb 1998, Hartley 2002). While this notion is intuitively appealing, there are few data to test it. Our study found no evidence that mixed species plantations supported more rainforest birds, lizards or mites than monoculture plantations. There are several caveats to these results. First, the plantations were surveyed while still young. As plantations mature and the availability of resources such as fruit and nectar increases, mixed species plantations might be expected to support more rainforest animals.

However, many cabinet timber trees planted in Australia have wind-dispersed seeds (e.g., *Flindersia, Toona, Araucaria, Agathis, Eucalyptus*). The value of these plantations to rainforest frugivorous birds, at least, is unlikely to increase with maturity. Second, most mixed-species plantations surveyed in this study were located amongst cleared land, whereas monoculture plantations tended to be located adjacent to intact forest. That is, proximity to rainforest confounds our comparison of the biodiversity values of monoculture and mixed-species plantations.

The design and management of rainforest timber plantations for biodiversity conservation

The notion that rainforest timber plantations might make a significant contribution to biodiversity conservation is comparatively recent (e.g., Keenan *et al.* 1997; Lugo 1997; Lamb 1998). More traditionally, plantations have been viewed as an efficient means of producing timber. At present, plantation managers seem to hold to the traditional view. In subtropical and subtropical Australia, old plantations with high biodiversity values are currently being clearfelled. This is the most destructive of the possible options for harvesting these plantations identified by Keenan *et al.* (1997), other possibilities being selective thinning or adoption of a polycyclic silvicultural system. Although the harvested sites are being replanted, second rotation plantations are unlikely to support the same level of biodiversity as the old plantations. Not only will the soil seed bank and rootstock of native plants be depleted in second rotation plantations, but production methods have intensified in recent decades. Plantations are now managed using mechanical site preparation, the widespread application of herbicides and fertilisers, a reliance on a few superior provenances of trees and a reduction in rotation times (Fisher 1980, Constantini *et al.* 1997, Blumfield and Xu 2003). These measures are likely to reduce floristic diversity and structural complexity of plantations, and hence their value for rainforest biota.

Nevertheless, plantation managers may wish to consider the biodiversity values of rainforest timber plantations in the future, for various reasons. For example, environmental considerations are increasingly impinging upon the management of plantations, as a result of governmental regulation (e.g., the *Plantations and Reafforestation Act (1999)* NSW) and through certification schemes (e.g., DPI Forestry 2003). State government agencies and many private investors in timber plantations are also increasingly concerned to project a positive environmental image of their management practices, often for commercial reasons (e.g. Stanton 2000, DPI Forestry 2003).

Proposals for improving the faunal biodiversity value of plantations have been made by a number of authors (e.g. Catterall 2000, Boorsboom *et al.* 2002, Hartley 2002, Lindenmayer and Franklin 2002, Tucker *et al.* 2004). Common elements to these proposals can be grouped into two categories:

(i) changes to plantation design and management to increase the quantity and/ or quality of habitat features within plantations; and
(ii) the reservation of part of the plantation estate for biodiversity, either by the retention or restoration of native forest.

These potential actions are partly compensatory, in that management of plantations to promote habitat quality may reduce the proportion of the plantation estate that would need to be reserved for biodiversity, and vice versa (Lindenmayer and Franklin 2002).

Proposed changes to the design of rainforest timber plantations to improve their value as wildlife habitat have been listed under the rubric of ‘restoration forestry’ by Tucker *et al.* (2004). These include the greater use of the timber trees valuable to wildlife, notably fleshy-fruited plants, and in particular large-seeded species which are likely to be poorly dispersed to plantations. In both tropical and subtropical Australia, there are many candidate timber species that meet these criteria (Tucker *et al.* 2004), but knowledge of their silviculture is extremely limited (although this work has begun, e.g. Lamb and Keenan 2001). Tucker *et al.* (2004) also advocate the inclusion of some ‘keystone’ non-timber species in plantations, such as figs (*Ficus spp.*). Establishing plantations adjacent to native or replanted forest would also increase the likelihood that plantations are utilised by rainforest wildlife. However, this would also increase the risk that biota, including pests, weeds and exotic genotypes, could disperse from plantations into native forest, and these risks would need to be balanced against the potential benefits from such a strategy.

Proposed changes to the management of plantations to improve their value as wildlife habitat include measures to encourage the development and maintenance of a floristically diverse and structurally complex rainforest under the plantation canopy. These measures may include limiting the intensity and frequency of thinning operations, and selective or staggered harvesting regimes (Keenan *et al.* 1997, Lamb 1998, Hartley 2002).

However, until large-scale, long-term research is conducted on production-biodiversity trade-offs in rainforest timber plantations, the development of protocols such as those listed above will, in most cases, remain in the realm of reasoned speculation (Catterall *et al*. 2004).

Recommendations

- Management of rainforest plantations for their biodiversity values will require explicit design, management and harvest protocols to promote the development of habitat for rainforest taxa, and/ or the reservation or restoration of part of the plantation estate as native forest.
- At present, we can make few specific recommendations on measures required to support particular taxa in rainforest plantations. For example, of the taxa surveyed in this study, we could only confidently suggest measures for enhancing rainforest bird species richness (e.g., “promote the development of a diverse and structurally complex understorey of rainforest plants in plantations”). These measures might also enhance rainforest lizard richness, but we have no evidence they would enhance rainforest mite richness. The development of specific measures for mites and other taxa will require better knowledge of their habitat requirements.
- The development of suitable protocols for managing rainforest timber plantations for their biodiversity values will require investment in large-scale, long-term research on production-biodiversity trade-offs.

Acknowledgements

The study was conducted in the ‘Quantifying Biodiversity Values of Reforestation’ project within the *Restoration Ecology and Farm Forestry* program of the Rainforest Cooperative Research Centre (Rainforest CRC). Thanks to Stephen McKenna and Rob Kooyman for assistance with the botanical surveys, Elinor Scambler for helping conduct bird surveys in the tropics, landholders and plantation managers for access to sites and Cath Moran and Don Butler for their observations of plant dispersal modes.

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13. Trade-offs between timber production and biodiversity in rainforest plantations: Emerging issues and an ecological perspective

Carla P. Catterall, John Kanowski, David Lamb, Daryl Killin, Peter D. Erskine, and Grant Wardell-Johnson

Abstract

During the past two centuries there have been three major paradigm shifts in the management of Australian rainforests and the use of their timbers: from felling native forests towards growing plantations; from viewing forests and plantations as mainly providers of timber to viewing them as sources of multiple benefits (e.g. timber, biodiversity, carbon sequestration, catchment protection, recreation, regional economic development); and from timber plantations being developed mainly by government on public land towards those established by private citizens, companies, or joint venture arrangements, on previously-cleared freehold land. Rainforest timber plantations are increasingly established for varied reasons, and with multiple objectives. Landholders are increasingly interested in the biodiversity values of their plantations. However, there are few guidelines on the changes to plantation design and management that would augment biodiversity outcomes, or on the extent to which this might require a sacrifice of production.

This paper presents a conceptual framework for considering the interactions and trade-offs between biodiversity values and timber production within plantations of rainforest trees in the Australian tropics and subtropics, and discusses aspects of design and management that are likely to affect the outcomes. Three forms of trade-off are discussed: those related to plantation design and management, those connected with timber harvest cycles, and those involving landscape issues and site configurations (allocation of different areas for different primary goals).

Existing knowledge suggests that plantation design, harvesting, and management regimes which maximise timber production will make a limited contribution to sustaining rainforest biodiversity. Different designs and management regimes may be able to produce better synergies between timber production and biodiversity, but to determine this will require: (1) implementation of a greater range of plantation designs, including those which purposefully aim for differing combinations of biodiversity and production, established in different landscape contexts; (2) quantitative assessments of both biodiversity and timber production made simultaneously at a range of these sites, at an appropriate stage of their development; and (3) a built-in research component, which includes biodiversity expertise, at the initial stages of large-scale tree-planting schemes. Measurements on existing sites, such as those planted during the Community Rainforest Reforestation Program (CRRP) scheme in the Wet Tropics, are providing some useful data, but a wider range of plantation designs and management regimes also needs to be established and monitored. Further development and application of site-based methods for quantitatively monitoring biodiversity values within mixed purpose plantation projects are also needed; these include assessment methods for plantations within environmental certification (e.g. eco-accreditation) schemes.

Introduction

Historical developments in northern Australian rainforest tree plantations

Historically, the main purpose of planting rainforest trees in tropical and subtropical Australia has been timber production (Dargavel 1995). Many rainforest trees produce timber which is highly valued, especially for cabinet-making (Herbohn *et al*. 2001). There has been extensive research and development worldwide to establish techniques for assessing and managing timber yield and values in monocultures of both softwood and hardwood species. This has lead to prescriptions for planting and growing trees in a manner which improves the production of timber, including recommended techniques for propagation, tree spacing, thinning, pruning, and fertilising (Evans 1992). While research of this type is lacking for many Australian rainforest species, there have been some trials with rainforest cabinet timbers grown in both mono-specific and mixed-species plantations (e.g. Cameron and Jermyn 1991, Lamb and Keenan 2001, Keenan *et al*. Chapter 10).

Most Australian rainforest timber plantations have traditionally contained only one tree species (mainly hoop pine *Araucaria cunninghamii*; occasionally kauri pine *Agathis robusta* or Queensland maple *Flindersia brayleyana*). Additional species have received attention mainly if they are unwanted competitors (flora) or pests (vertebrate and invertebrate fauna) that potentially reduce the quality or quantity of timber, or because they play a role in increasing productivity (e.g., soil microbes or predators of pests).

More recently, there has been a growing interest in the non-timber benefits from establishing tree plantations on cleared land (e.g., Abel *et al*. 1997, Dames and Moore NRM/Fortech 1999, Bennett *et al*. 2000, Borsboom *et al*. 2002, Lindenmayer 2002, Hobbs *et al*. 2003). There is a wide variety of potential benefits associated with the establishment of tree plantations, including the maintenance or restoration of biodiversity, provision of ecosystem services such as climate regulation and water purification, regional economic development, and recreational opportunities (Table 1).

Table 1 Commonly perceived aspects of the value of plantations in rainforest regions. These are not independent of one another.

Type of value or benefit	Subcategories	Examples
Productive	Timber	Woodchip; veneer, plywood and sawn timber for furniture or building materials
	Other tree products	Fruits, seeds, rubber, drugs
Environmental	Ecosystem services	Climate regulation, water purification, land stabilisation
	Biodiversity	Variety of organisms, ecological processes, physical structure
Social	Community development	Regional economy, employment
	Individual wellbeing	Recreation, aesthetics, spirituality

However, until recently, many of these concepts have not been viewed from a utilitarian perspective. Therefore, there has been little research and development into the forms of plantation design and management that could improve their contributions to the value of plantations, or into techniques for assessing these contributions. Furthermore, most of the work cited above has involved *Pinus* or *Eucalyptus* plantations in temperate Australia.

In the early decades following European colonisation of northern Australia (c. 1850-1920), timber was readily obtained from old-growth tropical and subtropical rainforests that were formerly found in a few parts of eastern Queensland and New South Wales. However, the rainforests on arable land were soon cleared for agriculture (Adam 1994, Lamb *et al*. 2001, Catterall *et al*. 2004). By the 1980's there was rising public concern that these landscapes had been over-cleared, and that many of the remaining rainforests (mostly on mountain ranges) were being logged (e.g. Cassells *et al*. 1988). This concern was accompanied by a greater recognition of the environmental and social values of intact rainforest areas (Webb and Kikkawa 1990). These were viewed increasingly as places of beauty and grandeur that are especially rich in species of flora and fauna, and which play a role in local and global climate regulation. Rainforests may be defined by the presence of a closed canopy of broad-leaved trees of particular plant families or genera, with life-forms such as vines and epiphytes often present (see Bowman 2000, Adam 1994 for further discussion of rainforest definitions). In addition, the small area of rainforest found in Australia is noteworthy for its evolutionary distinctiveness, endemic fauna and flora, its links to Gondwanan rainforests which once covered the continent, and the high proportion of Australia's overall biodiversity that it supports (Adam 1994).

Between 1980 and 2000, various governmental initiatives either severely restricted or ended timber harvesting in native rainforests, which were by then seen mainly as a conservation resource (Catterall *et al*. 2004). Following these initiatives, most future rainforest timber supplies would have to be obtained from other sources. Candidates included imports of timber from other tropical countries, use of the existing hoop pine plantation areas, and the conversion of cleared agricultural land (e.g. pasture or cropland) to forest plantations. Since felling of timber from overseas rainforests raises environmental concerns, and the existing hoop pine plantation estate is relatively small in area, there has been increasing interest in establishing plantations on former agricultural land in rainforest regions (e.g. Lamb and Keenan 2001). Suggestions for plantation species have ranged from eucalypts (e.g. Annandale *et al*. 2002) to mixed-species cabinet timber plantations of mainly native rainforest trees (e.g. Lamb 1998). By definition, the latter represents some improvement in rainforest biodiversity, compared with either eucalypt or hoop pine monoculture (Lamb and Keenan 2001).

Also during this time, early experiments in the planting of rainforest trees to restore rainforest ecosystems began, with a view to helping sustain rainforest biodiversity (e.g. Tracey 1986, Kooyman 1991). To achieve these ends, a completely different plantation design and management system was devised, with a focus on achieving a dense canopy, establishing a high diversity of native plant species and a complex multi-layered vegetation structure, providing habitat for a diverse native fauna, and fostering the potential for successional processes resembling those of rainforest (Goosem and Tucker 1995, Kooyman 1996). Such plantings have been used to restore forest to streambanks, to provide links between remnant forest patches, and to increase the size of remnants, with no expectation that timber will be harvested from them. However, the high establishment costs for such plantings limits their use over large areas (Table 2, see also Erskine 2002).

Plantations for timber and/or biodiversity?

Clearly, it would be useful to know how to design plantations which have timber benefits together with environmental and social benefits, and to know the limits to the compatibility of these goals. It seems that many private rural landholders have planted trees during the past decade with an expectation for both timber and biodiversity benefits (Emtage *et al*. 2001). There is also a growing expectation that publicly-funded tree planting projects should contribute to achieving environmental goals.

Furthermore, the biodiversity values of plantations may soon be associated with some financial benefit for landholders. For example, this could occur through certification schemes (e.g. Nussbaum *et al*. 2001) which include an "eco-accreditation" element. Such schemes may improve access to particular markets (such as "ethical investment" programs), or may incorporate "biodiversity credits" which could be used to offset other forms of environmental damage caused by a business (e.g. Binning *et al*. 2002).

Table 2 The current spectrum of reforestation planting styles in rainforest landscapes of tropical and subtropical Australia. Note that there is considerable variation within each type of planting, and the two may intergrade in practice (after Catterall 2000, Lamb and Gilmour 2003, Catterall *et al*. 2004, Kanowski *et al*. Chapter 12).

	Main goal of planting	
	Timber production+	Ecological restoration
Tree species diversity	Low (typically 1-10)	High (tens - over 100)*
Species types	May include a substantial proportion of exotic species, eucalypts, and/or wind-dispersed rainforest species.	Few or no exotic species; few eucalypts; many fleshy-fruited rainforest species*.
Planting density	Lower (c. 1,000 stems/ ha or less)	Higher (c. 6,000 stems/ha)
Management	Grass and understorey suppressed with herbicide, slashing, and/or stock grazing. Fertilizers added. Stems and lower branches pruned, stems progressively thinned.	Initial herbicide followed by heavy mulching and selective weeding and/or herbicide; stock excluded. Little or no fertiliser. Native understorey allowed to develop.
Location	Often on level ground, fertile soils	Often in areas not desired for production – e.g. steep slopes, creek banks.
Cost (*circa* 2000)	$4-8,000	$20-25,000

+ *Incudes both monoculture and mixed-species plantations whose typical occurrence has differed (e.g. industrial plantations have been monocultures over large areas; mixed-species plantings have been established as smaller areas within multi-purpose agroforestry landholdings).*

* *Native rainforest in higher rainfall areas of subtropical and tropical Australia has 50-100 tree species/ha, few or no exotics, few or no eucalypts.*

Table 2 contrasts the design and maintenance characteristics of plantations aimed at rainforest timber production with those aimed at ecological restoration. Until recently, there has been an information vacuum concerning either the biodiversity values of the timber plantations or the timber values of the ecological restoration plantings. Most past plantation research and development has focussed on maximising timber yields, and much of the available technical advice on planting and managing timber trees has remained directed towards this.

Guidelines for improving biodiversity outcomes in rainforest timber plantations have been suggested (e.g. Keenan *et al*. 1997, Lamb 1998, Lamb and Keenan 2001, Tucker *et al*. 2004, Kanowski *et al*. Chapter 12), but until very recently these were based on reasoning informed by a knowledge of ecology and natural history and by general field experience, rather than being the outcomes of systematic research and development.

The extent to which such hybrid approaches produce synergistic or compromise outcomes for either biodiversity or wood production is largely untested. Without a better understanding of how to design plantations to meet multiple goals, there is a risk that investment in plantings will not achieve the outcomes now desired by many landholders and investors.

Quantitative assessments of plantation benefits and values, for different designs and management regimes, are needed to answer these questions. However, until very recently, the notion of quantifying biodiversity values was impractical; it is barely two decades since the term "biodiversity" was coined, and conservation values were previously viewed mainly in terms of rare vertebrate species on the verge of extinction. More recently, the notion of biodiversity as the variety of all life-forms, including genetic diversity, species diversity, and ecosystem diversity, has become widely accepted in both scientific and public arenas (Cogger 1994). The protection of biodiversity, together with the processes that sustain it, is also now widely incorporated in legislation (e.g. *Commonwealth Environmental Protection and Biodiversity Conservation Act*, and State Acts relating to land, vegetation and waterway management, nature conservation, and land use planning).

Biodiversity assessment methods are being developed and improved (see for example Margules and Austin 1991, Landsberg *et al*. 1999). The "Biodiversity Values in Reforestation" project of the Rainforest Cooperative Research Centre (CRC) has begun developing and applying techniques for assessing biodiversity attributes in replanted rainforest sites (Wardell-Johnson *et al*. 2001, Catterall *et al*. 2004, Kanowski *et al*. 2003, Kanowski *et al*. Chapter 12, Wardell-Johnson *et al*. Chapter 11).

The assessment has two components:

- First, a broad range of biodiversity attributes are measured in target plantations. These include forest structure (e.g. canopy height and cover, stem densities and diameters, woody debris), biota (e.g. birds, reptiles, invertebrates, plants), and ecological processes (e.g. seed predation patterns, litter decomposition).
- Second, the numerical values of attributes derived from these measurements (e.g. the proportion of bird species that are "rainforest-dependent") are compared with those obtained from a set of reference sites, within both pasture and intact rainforest, whose background environmental properties broadly match those of the replanted sites.

This paper presents, from an ecological perspective, a conceptual framework for considering the interaction between biodiversity values and timber production within plantations of rainforest trees. It also considers aspects of plantation design and management that are likely to effect these outcomes. This treatment draws upon current knowledge (where available), but the intent is also to stimulate consideration of gaps in current knowledge and to identify future research priorities.

Trade-offs involving biodiversity and production in relation to plantation style

One form of trade-off between biodiversity and timber production is determined by stand design and management. Features that are associated with higher biodiversity values include: denser tree spacing, more tree species (including fleshy-fruited species), greater variety of life-forms and age-classes, less pruning and understorey suppression, and greater total plantation area (patch size). The context of a plantation will also affect its biodiversity, as discussed later. These issues have been discussed by Catterall (2000), Kanowski *et al*. (2003), Nakamura *et al*. (2003), Tucker *et al*. (2004), Catterall *et al*. (2004), Proctor *et al*. (2004), Kanowski *et al*. Chapter 12 and Wardell-Johnson *et al*. Chapter 11.

Figure 1 illustrates these issues by plotting the hypothetical long-term (averaged over several rotation cycles) biodiversity values of a range of differently-managed sites against their wood production values. "Biodiversity value" is more accurately termed "rainforest biodiversity value", which is defined as the development of a rainforest-like set of biota and ecological processes, which can be quantitatively assessed by taking measurements from reference sites within intact rainforests growing under specified geographical and environmental conditions (after Catterall *et al*. 2004). An underlying simplifying assumption in Figure 1 is that the sites are similar in area.

There are two forms of relationship between production and biodiversity. First, an increase in tree cover from "pasture" to "forest" is accompanied by an increase in both biodiversity and timber values, i.e. at this level the relationship is positive (Figure 1). However, if only land that is "forested" is considered, the relationship becomes negative, and different plantation styles and management regimes will involve trading off production goals against biodiversity goals. At one end of the spectrum, rainforests that are lightly harvested will retain high rainforest biodiversity values, but will have low wood production. At the other end, an intensively-managed hoop pine plantation, established far from any other forest on a long-cleared site, could maximise the production of high-value timber, but would support limited rainforest biodiversity.

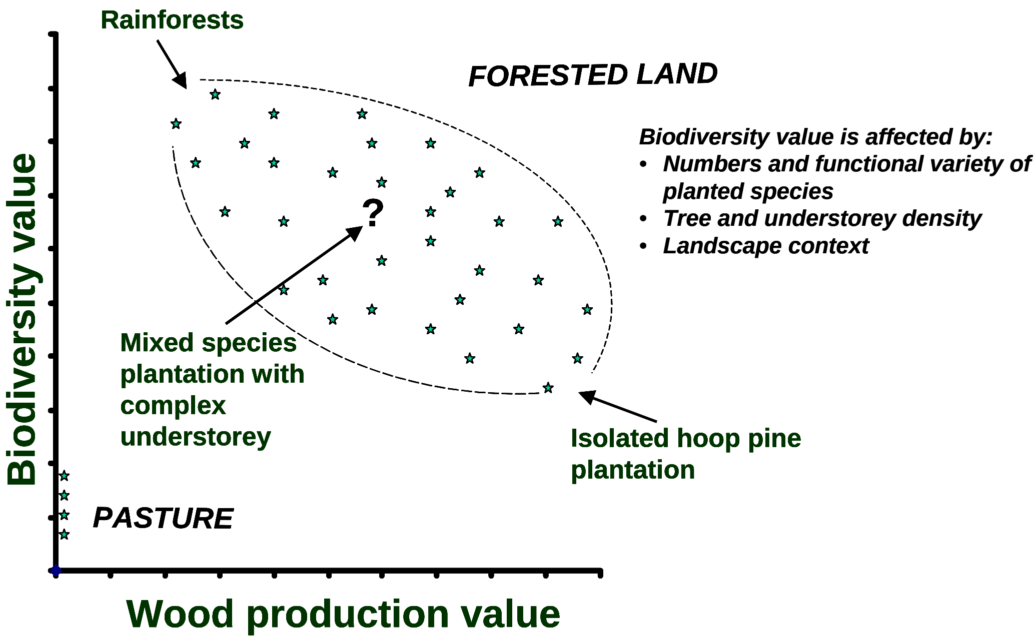

Figure 1 Hypothesized relationships between a site's long-term wood production value and its biodiversity value. Each point represents a site of fixed area and uniform type, which is characterised by a different form of tree cover and management regime (some examples are labelled). The values represent outcomes across a full harvest cycle for plantations. For simplicity, points are shown only for pasture (few trees) and relatively dense tree cover (forest), although sites with other forms of tree cover could occupy the space between pasture and forested land. "Rainforest" sites are assumed to be selectively harvested in a manner that has little impact on their biodiversity. Factors likely to strongly influence biodiversity value are listed.

Somewhere in between may lie various design and management compromises, for example, a moderately-isolated mixed-species plantation, in which the development of a complex native understorey is encouraged, may provide intermediate biodiversity value with moderate wood production. If it included non-timber trees of types that are particularly important to wildlife (such as native figs), the biodiversity would improve further, but its timber value would be reduced.

A plantation established adjacent to rainforest, without thinning or pruning, may acquire relatively high rainforest biodiversity value, but at some cost to wood production. The shape of the upper bound to the cloud of points in Figure 1 is important. The hypothetical convex edge, as drawn, allows for some plantation styles that give potential synergy between biodiversity and wood production (with a moderate increase in biodiversity value for very little decrease in production value). If the upper bound were straight, then increased biodiversity would always be traded for decreased production. If it were concave, then attempting to achieve a compromise between biodiversity and wood production through varying such design features as tree spacing or species composition would be a waste of time and resources. At present, we do not have the data to assess whether the relationships hypothesized in Figure 1 are empirically realistic. However, it should be technically possible to obtain such data, if plantations matching the range of design and management options could be found.

Trade-offs between biodiversity and production involving timber harvest cycles

A second form of trade-off between biodiversity and production lies in the harvest cycle. We know that, in some situations, old (40-70 year) plantations of rainforest timber species (hoop pine, kauri pine, Queensland maple), which were initially established as monocultures, can come to support a diverse rainforest biota which is similar in many respects to nearby mature rainforest (Keenan *et al*. 1997, Kanowski *et al*. Chapter 12). However, the overall biodiversity contribution that such plantations might make must be viewed over a complete rotational cycle. Figure 2 shows possible rates of development in both biodiversity and wood production, for a hypothetical timber plantation that is harvested at 30 years (caveats concerning the realism of the timescales are discussed later). "wood production" and "Biodiversity value" (again, comprising characteristics of rainforest) refer to the standing level of either at any given time.

In the examples shown in Figure 2, trees begin to senesce and decay after around 80 years, and the volume of standing timber hence declines. Since this provides important resources for fauna (such as food, nest hollows, and ground cover), biodiversity continues to increase after this time. Two scenarios for biodiversity development are shown: fast and slow. Under the fast scenario, more than half the rainforest characteristics present by 100 years have been acquired by around 30 years, compared with less than one-fifth under the slow scenario. The plantation's nature and context will affect both its maximum biodiversity value and the rate at which biodiversity develops. The biodiversity value of a mature rainforest is not shown at Figure 2, but is expected to exceed the plantation maximum (see for example, Kanowski *et al*. Chapter 12, Wardell-Johnson *et al*. Chapter 11).

Under a 30-year harvest rotation with slow biodiversity development (Figure 2), any given area of this plantation would never have much "biodiversity value", although its value could still exceed that of the same area of pasture or cropland. Under the rapid development scenario, the biodiversity value at harvest is better. However, while the realised wood value is determined by the harvest quantity, the overall biodiversity value is the average over the 30 years of development; still not particularly high. Figure 3 shows the joint pattern of development for biodiversity and wood; until around 40 years, the comparative rate of increase in wood value is much faster than the comparative rate of development of biodiversity value; at around 80 years both are relatively high; but subsequent increases in biodiversity value are achieved with only small gains in wood production.

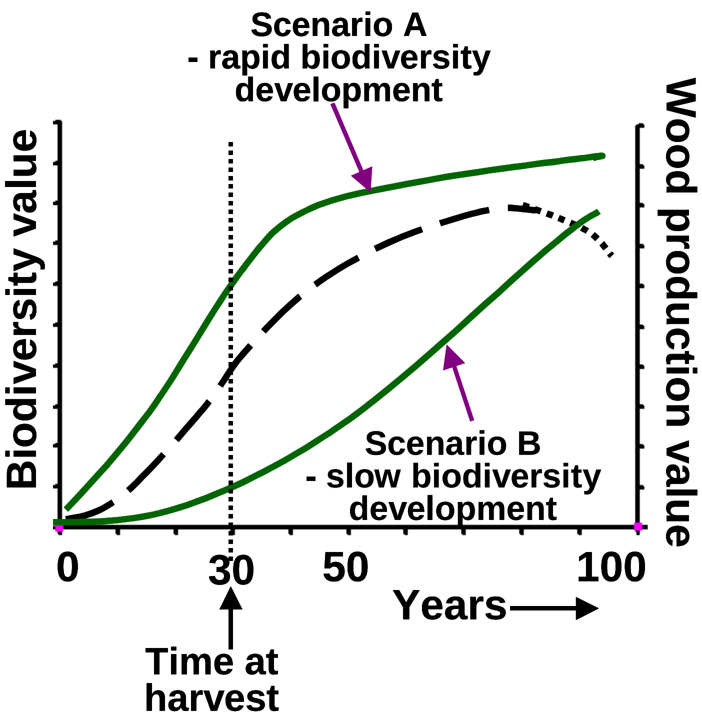

Figure 2 Possible patterns of temporal development of the value of a rainforest plantation in terms of rainforest biodiversity under two scenarios A (rapid) and B (slow) of development (solid lines); and wood production (dotted line). The timescales are hypothetical. Biodiversity value is conceptualised as the plantation's measured levels of attributes which characterise intact rainforest (and are lost or greatly reduced following clearing). Wood production is conceptualised as the value of the timber that could be obtained from clearfelling.

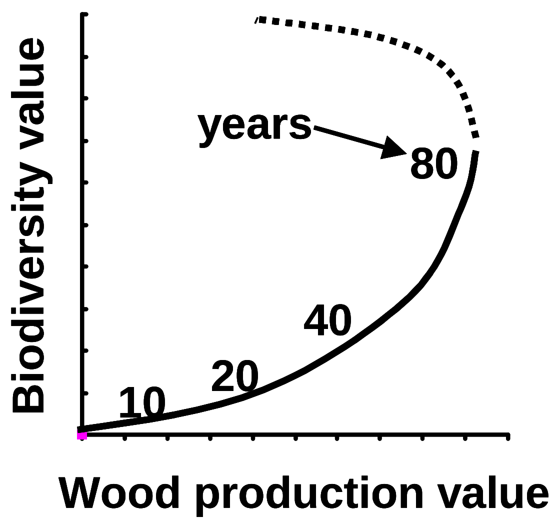

Figure 3 The relationship between the wood value and biodiversity value during growth of a rainforest plantation, according to the slower biodiversity development scenario of Figure 2. The numbers show the plantation's age.

The curves in Figure 2 are not intended to be fully realistic. In hoop pine plantations currently under management for peak wood production, the recommended rotation length is 45-50 years, at 400-1,000 stems/ha (Hogg and Nester 1991, Keenan *et al*. 1997, Lewty and Last 1998). The financial outcomes of decisions concerning the design and management of plantations are influenced by factors such as costs of establishment and management, discount rates and market prices. The value of standing timber in hoop pine plantations would continue to increase well past 100 years, while its net value over a rotation would diminish.

From a biodiversity perspective, rainforest trees typically do not begin to form large hollows until they are at least 200 years old. However, the relevant data on long-term tree performance is incomplete and widely scattered. If realistic curves were available for both production and biodiversity, optimisation techniques could suggest rotation cycles that would be appropriate for different levels of compromise between biodiversity and financial outcomes. Precise quantification could be very difficult, since many factors complicate both the value of timber and the achievement of biodiversity, and both are difficult to measure, especially if there are several tree species involved. Nevertheless, even approximate calculations may be a better decision guide than the often-incorrect assumptions currently being made by many landholders and managers.

In the example given (Figure 2), the biodiversity value would vary greatly during the course of a rotation. But if a plantation comprised stands of differing ages, this within-stand variation would be buffered at the scale of the whole plantation, even though the long-term average would not appear to differ between the two scenarios. However, the greater continuity in habitat availability could improve the overall biodiversity outcome, since older forest stages would always be present somewhere in the plantation and it would not be necessary for species to repeatedly recolonise the plantation from suitable habitat elsewhere (with possible associated time-lags in recruitment) as each cycle progressed. From a production viewpoint such asynchrony would also be desirable as it generates regular returns on investment (and is currently the practice in many plantation forests).

It could be argued that selectively harvesting individual stems would ensure that timber removal had less effect on biodiversity value than if all stems were clear-felled simultaneously but less frequently (e.g. Keenan *et al*. 1997, Lamb 1998, Hartley 2002). However, the resultant thinning of the stand might be detrimental to its ability to provide suitable habitat for rainforest-dependent fauna and fauna, depending on its effect on the plantation understorey (see previous section). Scattered patches of small-area clearing therefore may be more compatible with maximising biodiversity values than uniform stem removal, and would have an outcome similar to the asynchronous rotations discussed above, and perhaps more similar to the natural disturbance mosaic in rainforests, to which rainforest species are adapted. In fact, canopy gaps have been advocated as a means of increasing biodiversity at the plantation scale in temperate forest plantations (Spellerberg and Sawyer 1997, see also Lindenmayer and Franklin 2002). However, the lack of information on the basic biology, population dynamics, and recruitment processes of most rainforest flora and fauna species, coupled with the very large number of species involved, prevents reliable prediction of the outcome of such differences in management.

A more effective approach than such theoretical speculation would be to determine empirically the biodiversity, timber, and economic outcomes of differing forms of plantation design and management in long-term large-scale field trials.

Biodiversity, production and landscape issues

Importance of context, configuration and area to biodiversity

Both the absolute size (area) of a plantation, and its landscape context are important to its acquisition of rainforest biodiversity value, because they affect the ability of new species to colonise the site. Large natural areas nearby are likely to be a source of native colonists but small and more distant remnants may contribute little. In particular, many vertebrate species of rainforest are sensitive to patch area, to the amount of suitable habitat nearby (including the presence of direct habitat corridors), and to the amount of suitable habitat in the surrounding landscape. The recruitment of rainforest flora to plantations will also be affected by these factors, because birds and mammals are the main agents of seed dispersal for most plants of tropical and subtropical rainforest, as well as being important predators of seeds and seedlings (Willson *et al*. 1989, Kanowski *et al*. Chapter 12).

Patches less than five hectares in area, even if high-quality rainforest habitat, appear unlikely to ever support the full range of rainforest birds and mammals, no matter what their design and management, unless they are very close to larger areas of high-quality rainforest (Price *et al*. 1999, Catterall *et al*. 2004). Small patches of production forest are also likely to be less economically viable than larger patches.

Plantations can also be colonised by introduced species (including grazing stock). Both exotic and native colonists may also be influenced by the size and shape of the plantations, in ways that interact with the landscape context. For example, a narrow rectangular-shaped plantation surrounded by rainforest should acquire biodiversity values more rapidly than the same area if square, whereas the reverse is likely if the plantation were surrounded by pasture, and the maximum value reached in the latter case would also be lower. It is even possible that biodiversity values per unit area in very large plantations may fall, due to the increasing proportion of the plantation that is distance from any native forest in the surrounding landscape.

In general, a plantation would be expected to acquire greater levels of rainforest biodiversity if its context included: greater proximity to native forest, fewer weedy species in the landscape, more native forest in the landscape, and less exposure to adverse processes from adjacent areas (e.g. dry winds, insecticide drift or runoff, heavy grazing).

Plantations can also provide off-site biodiversity benefits which stem from the landscape context in which they are placed. These add further complexity to the accounting of their biodiversity outcomes. For example, a structurally simple monospecies timber plantation which borders a small remnant of intact forest may provide a buffer against exposure to wind and sun, so that the remnant experiences a more rainforest-like microclimate, and can support more of the rainforest flora and fauna that are sensitive to dryness than would be the case for an unbuffered remnant (see also Tucker *et al*. 2004). Timber plantings could also provide benefits to remnant rainforest patches by providing stepping stones or corridors of habitat between them (the quality of habitat that animals require for movement is likely to be less than that required for residency). However, negative impacts on rainforest biodiversity from such buffers or links are also possible at a broader spatial scale, for example if the plantation acted as a source of invasive exotic species, or if the plantation trees belonged to a non-local genetic race of a plant species present within the remnants.

Area also complicates the measurement of biodiversity value. Species-area curves are nonlinear; the rate, per unit area, at which new species are recorded at a site declines as the surveyed area increases (Connor and McCoy 1979). This affects estimates of the contribution of a plantation's area to its biodiversity. For example, if a 20 ha timber plantation contains 50% of the rainforest-dependent species that occur in 20 ha of rainforest, this does not mean that 40 ha of the same form of plantation would support 100% of the rainforest species, or that 10 ha of replanted rainforest would be equivalent to a 20 ha timber plantation. Even 1,000 ha of this plantation is unlikely to contain all the rainforest species that can be found in 20 ha of rainforest, because habitat elements essential to some species will always be missing.

While it is relatively straightforward, with current methods, to compare sites of the same area which differ in their type of planting, and to compare different areas whose type of planting is the same, it is more difficult to compare quantitatively the biodiversity values of two plantations that differ in both area and type of planting. Resolving these issues requires better information on species-area accumulation curves for different types and ages of plantation.

Trade-offs between biodiversity and production involving the configuration of site areas

A third form of trade-off between biodiversity and production lies in the configuration of the planted area. Most of the previous discussions have assumed that the design (e.g. tree spacing, species selection, early management) of a plantation is uniform over its entire area, and have considered the consequences of altering the design and harvesting over this area. An alternative would be to incorporate spatial heterogeneity into plantation designs, for example by designing and managing some sections of the nominal plantation area for timber production (with little expected biodiversity benefit), while other sections are allocated to restoration planting (designed for biodiversity outcomes, but with no expected timber harvesting). This option has also been discussed by Lamb (1998, 2001) and Kanowski *et al*. (Chapter 12), and more generally by Lindenmayer and Franklin (2002). The trade-off between biodiversity and timber production in this case will largely depend on what proportion of the land area is allocated for each purpose. However it could also be influenced by design and management practices within a section (including hybrid management, for example, if the "timber" section was designed to forego some timber production in exchange for incorporating some design aspects to improve biodiversity, such as fig trees or understorey development; or if the "biodiversity" section mainly comprised timber tree species with a relatively open spacing).

Without further empirical testing, it is not possible to say whether such area-based trade-offs could produce better production-biodiversity compromises than simply altering design and management within the plantation structure. The preferred type of trade-off is also likely to be affected by the context and nature of a plantation site. For example, where a previously-cleared site includes a waterway, then allocating land for ecological restoration along the waterway would be desirable because it also meets environmental goals other than biodiversity (such as those relating to water quality and streambank stabilisation). If a plantation site is far from intact rainforest, allocating a significant area to ecological restoration may be more important than if it is adjacent to a large rainforest remnant. Different forms of trade-off might suit different scales of enterprise, for example a small landholder might choose to compromise mainly on plantation design whereas a large-scale business might prefer to allocate sections of land for different purposes.

Area-based trade-offs could also be the most pragmatic from the viewpoint of balancing different primary objectives. Spatially separating the area of production forest from ecological plantings could assist in project management and accounting procedures, especially in large-scale projects that involve both private and public sector funding.

Conclusions and recommendations

During the past two centuries there have been three major paradigm shifts in the management of Australian rainforests and the use of their timbers (described in Adam 1994, Lamb and Keenan 2001). The shift has been from felling native forests towards growing plantations; from viewing forests and plantations as mainly providers of timber to viewing them as sources of multiple benefits (timber, biodiversity, carbon sequestration, catchment protection, others), and from timber plantations being developed mainly by government on public land towards those established by private citizens, companies, or joint venture arrangements, on previously-cleared freehold land.

This paper has examined and discussed, from an ecological perspective, the ability of plantations to act as a source of both timber and biodiversity benefits. The Commonwealth of Australia has committed to expanding its area of commercial forestry plantations to supply current and projected demand in pulp, sawn timber and timber products. But such plantations have limited biodiversity value.

Rainforest biodiversity in subtropical and tropical eastern Australia is a significant conservation issue at state, national and international levels, and rainforest restoration is part of the conservation strategy (Tucker *et al*. 2004, Catterall *et al*. 2004). But replanting rainforest for strictly biodiversity purposes is expensive, and unlikely to be carried out over large areas. Mixed-purpose plantations offer the prospect of some financial return, which might make reforestation more attractive to landowners, and thereby increase the opportunity to reforest larger areas of cleared land. However, motivations of small-scale private landholders are complex (Emtage *et al*. 2001), and affected by perceived threats to harvest security that may occur if a plantation's biodiversity values became high.

Current knowledge has enabled us to identify different aspects of plantation design and management which may either constrain or enhance a plantation's ability to provide both biodiversity and timber. In the future, various forms of environmentally-targeted incentives, such as environmental certification, carbon credits, salinity credits and biodiversity credits, may offer a changing economic context for privately-owned timber plantations (e.g. Binning *et al*. 2002). In this new context, changes to management or harvesting practices (such as the development of spatially heterogeneous plantations, or an extended rotation length) may become more economically attractive.

The rainforest landscapes of tropical and subtropical Australia offer an opportunity to compare the performance (for biodiversity, timber, and other attributes) of a range of different plantation designs and approaches to management, including timber monocultures, a variety of mixed-species timber plantations, and species-rich, complex restoration plantings (Table 2). Most of these are still young in successional terms (less than 20 years old) and there remains much to be learned about the rates and patterns of their biodiversity development (c.f. Figure 2). At these sites, strategically-timed ongoing monitoring can provide results to help improve the design of future plantation systems, and contribute to the development and application of environmental certification schemes.

In the Queensland wet tropics, the CRRP sites provide an opportunity to track the performance of tropical mixed-species timber plantations. On upland basalt soils, the best-developed and managed of these plantations, after 5-10 years, had a low to moderate ability to support rainforest biota (Kanowski *et al*. 2003, Catterall *et al*. 2004, Kanowski *et al*. Chapter 12). However, many of the CRRP plantings are dominated by eucalypts, rather than rainforest trees (Wardell-Johnson *et al*. Chapter 11), and most are very small in area (<5 ha, Catterall *et al*. 2004). Furthermore, their characteristics do not meet the requirements of rigorous experimental design (replication of sites with controlled variation in factors of interest). Thus they allow only limited exploration of the trade-offs involved in rainforest biodiversity and timber production.

It will be difficult to further develop a sound basis for designing plantations which provide novel combinations of timber, biodiversity, and other benefits, unless: (1) a greater range of plantation designs are established and tested, including carefully planned projects that aim to provide differing combinations of biodiversity and production, set within different landscape contexts; (2) there are simultaneous quantitative assessments of both biodiversity and timber at a range of plantation styles, at an appropriate stage of their development; and (3) there is a built-in biodiversity research component at the initial stages of large-scale tree-planting schemes.

Funding is needed to encourage a research-based approach that takes controlled risks with different forms of plantation design, management and harvest schedules. This also requires ongoing dialogue between forest restoration scientists and commercial forestry practitioners, and a wider recognition that these designs can be an investment in knowledge generation, for use in future decades rather than a few years hence.

Acknowledgements

Members of the Rainforest CRC 's Rehabilitation and Restoration Program, and its Program Support Group, in particular, Nigel Tucker, Scott Piper, Geoff Borschmann, Heather Proctor, Terry Reis, Steve Harrison, and John Herbohn have contributed discussions and information which aided the development of the ideas presented here.

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V

Socio-Economic Assessment of Rainforest Timber Plantations

14. The importance of considering social issues in reforestation schemes

John Herbohn, Nick Emtage, Steve Harrison, Dave Smorfitt and Geoff Slaughter

Abstract

This paper reports the results of a survey of north Queensland landholder attitudes with respect to a number of issues relating to participation in forestry. The survey explored the reasons why landholders plant trees, perceived obstacles to greater farm forestry, and attitudes to tree planting programs such as the Community Rainforest Reforestation Program (CRRP) and Private Joint Venture Scheme (PJVS). The results of the survey are discussed in the context of possible policy prescriptions that can be made at local, state and federal government levels to facilitate greater tree planting in the region. Many of the problems faced by local landholders are shared by landholders in other parts of Australia and throughout the world. This survey can thus serve as a case study, providing information on a number of issues concerning small-scale forestry policies that are of general relevance to the development of farm forestry programs.

Introduction

It is generally agreed that growing trees on farms[1] is socially desirable and that farm forestry generates positive externalities (Emtage *et al*. 2001). There also appears to be strong interest from many landholders in farm forestry, although in some regions such as north Queensland, the current levels of planting are low, however, with a little assistance from government in the form of policy initiatives such as subsidies, extension and creating a suitable 'environment' it is conceivable that a rapid expansion of farm forestry could occur in these regions as well. These policy measures could be universally attractive to all landholders, so it is important to identify groups of landholders who may share similar views and will react in similar ways to policy measures. This will allow more effective and targeted policy measures to be developed and implemented. For instance, farmers who rely on their properties for the majority of their income are likely to face different problems or impediments to becoming involved in farm forestry compared with a hobby farmer with substantial off-farm income and an urban background.

This paper discusses the importance of considering landholder attitudes when designing reforestation schemes. Previous studies relating to landholder attitudes to farm forestry in northern New South Wales (NSW) and Queensland are reviewed. The results of a survey of north Queensland landholder attitudes to a number of issues relating to participation in forestry are then reported. The next section then discusses the results of a cluster analysis of the responses to the survey, which identified a number of distinct groups (or types) of landholders. The results of the survey are discussed in the context of possible policy prescriptions that can be made at local, state and federal government levels to facilitate greater tree planting in the region.

Previous studies of landholders attitudes to farm forestry in tropical and subtropical Australia

Emtage *et al*. (2001) have summarised a number of recent surveys of landholder attitudes conducted in the Obi Obi Valley in south east Queensland (Harrison *et al*. 1994, Harrison and Sharma 1995), north Queensland (Broome 1993, Eono and Harrison 1996) and in northern NSW (Emtage 1995).

[1] A distinction is drawn here between growing trees on farms and the conversion of farms to industrial-scale forestry.

Specht and Emtage (1998) undertook a more comprehensive study of landholder attitudes in northern NSW, and Eono and Harrison (2002) have also surveyed attitudes of local government to tree planting.

Analysis of responses to previous surveys has revealed that environmental benefits have been perceived by landholders as being the most important benefit of tree planting both in north Queensland and elsewhere in Australia. For example, landholders reported the most important reasons for tree planting in the Obi Obi Valley in south-east Queensland as: to protect and restore land; to attract wildlife and birds; to pursue a personal interest in trees; watershed protection; and to improve the appearance of the property. Economic motives such as to make money and to diversify the farm business were ranked much lower (Harrison *et al*. 1994, Harrison and Sharma 1995). Similarly, in a survey of landholders participating in the CRRP in three north Queensland shires conducted by Broome (1993), land and stream protection and the provision of shade and windbreaks were viewed as the most important benefits of tree planting. Specht and Emtage (1998) found similar results with the highest rated reasons for tree planting in northern NSW being soil and land protection, provision of wildlife habitat and farm beautification. The lowest-rated reasons were associated with planting for various types of commercial timber production. Specht and Emtage (1998) also reported that while landholders rated the importance of planting trees for environmental reasons higher than planting for commercial reasons, the number of trees established for commercial timber production in the northern NSW region far outweighed those established for environmental reasons.

Analysis of the findings of past studies reveals a remarkably consistent pattern of motivations or reasons for tree planting. These attitudes prevail in a number of regions in tropical and subtropical Australia, which suggests that they are likely to be held by landholders in most, if not all, coastal regions in north-eastern Australia. This in turn suggests that tree-planting schemes that incorporate environmental values would be more acceptable to landholders than those that are designed solely or mainly to produce timber. This conclusion is supported by the resistance of some landholders in north Queensland to the planting of exotic pines because of their negative perceptions about the effects that these planting have on the environment and farm aesthetics (G. Sexton pers. comm.).

Byron and Boutland (1987) discussed the problems of restrictions to farm forestry and the choice of incentives to encourage farm forestry. They argued that the combination of particular objectives and resources available to the various types of potential participants results in different responses to incentives and variations in the social and economic impacts from the same incentive for different types of participants. Small-scale growers (i.e. farmers) are said to "…pose the most complex problem for forestry planners" (Byron and Boutland 1987, p. 238). They identified a number of critical impediments to small-scale foresters, including:

- small farm sizes can limit potential plantation size, particularly when combining forestry with agriculture;
- farmers' decision-making is sometimes coloured by agriculture priorities;
- varying and sometimes low levels of forestry expertise;
- the long wait for returns to forestry investments;
- uncertainty about future timber markets and stumpage prices;
- uncertainty about taxation provisions for forestry investments; and
- the failure of state and private extension services to develop systems or models of forestry that are compatible with landholders' objectives for the management of their farms.

The concentration by those providing incentives to small growers on 'core' or industrial forestry practices is described as probably the most important limitation to the success of many incentive schemes. Byron and Boutland (1987) cited the foresters' lack of familiarity with landholders' land management objectives and failure to investigate farmers' objectives and farmers' visions of how forestry could complement their other activities as critical impediments to the development of incentive programs that are attractive to landholders (Byron and Boutland 1987).

Given the long payback period for timber production, it is predictable that landholders will place greater emphasis on the benefits of tree planting that they gain in the shorter term such (i.e. those falling into the environmental, shelter and personal satisfaction scales). Therefore, it is not surprising that landholders would be unwilling or reluctant to participate in forestry projects that do not place sufficient emphasis on these types of benefits in combination with economic benefits.

Specht and Emtage (1998) identified an additional restriction to constraint on farm forestry development, namely the perceived instability of land management laws and regulations. Landholders in the northern rivers region of NSW identified sovereign risk – in particular the potential for the prevention of harvesting of planted trees on private land – as a serious impediment to farm forestry development in that region (Emtage 1995, Specht and Emtage 1998). The rural community of the northern rivers region is divided about the way that native forests should be managed and the impacts of logging on the recreational and biodiversity conservation values of forests. Public forests in that region have been the setting for many conflicts between environmental activists, timber workers and the State Forests of New South Wales (SFNSW) (Gibbs 1992, Dargavel et al. 1995). The laws and regulations relating to native forestry and plantations across Australia have been in a state of constant change over the past 20 years. Protests by northern rivers environmentalists have led to major revision of forest management practices, such as the decision of SFNSW to ban logging in rainforests in 1982. This decision had a similar effect to the declaration of the Wet Tropics World Heritage area in Queensland. Specht and Emtage (1998) reported that many landholders are distrustful of the land management policies that have been initiated by governments and believe there are likely to be changes in regulations in the future which disadvantage growers.

In summary, it appears from previous studies that the majority of landholders in coastal areas of tropical and subtropical eastern Australia view trees as an important component of the landscape for conservation and aesthetic reasons, but are not convinced of their commercial viability. In many cases the landholders think that the legitimate place for trees in their holdings is on the areas unsuitable for cropping or grazing, because they are too steep or have poor soil. In this way landholders view farm forestry as complementary to their other activities. However, in north-east NSW and south-east Queensland the majority of landholders with a high degree of income-dependence on their land do not perceive commercial tree growing as a legitimate farming activity, or as an economically viable alternative to agriculture.

Landholder attitudes to farm forestry in north Queensland

Survey methods

A survey of landholders was undertaken in the wet tropics of north Queensland, within the three shires of Atherton, Eacham and Johnstone. Most of the Johnstone Shire is bordered on the eastern side by the Coral Sea and on the western side by the foothills of the Great Dividing Range. The Johnstone Shire has a high annual rainfall, with sugar cane and bananas being the main crops grown. The Atherton and Eacham Shires are located on the Atherton Tablelands, an elevated and cooler area of lower rainfall (though adequate for rainforest species), where dairying has been a pioneering activity (see Table 1).

The survey of landholders in these areas canvassed their attitudes towards a number of issues related to tree-planting and farm forestry, including: the reasons that they considered important for tree planting, perceived obstacles to tree planting, attitudes towards various types of incentive schemes and their ratings of regional benefits of forestry. Landholders were presented with a series of

Table 1 Selected climatic and demographic data for the Atherton, Eacham and Johnstone shires of far north Queensland Australia.

Characteristic		Johnstone	Atherton	Eacham
Total area (km^2)	(1 July '96)	1 639	629	1 131
Annual Rainfall range	(mm/month)	85 – 605	22 – 305	82 - 465
Summer	(mean mm/month) (mean	365	187	267
Winter	mm/month)	183	48	178
Temperature range	(degrees Celsius)	16 – 28	10 – 28	12 - 40
Summer	(mean min. – max.^{0}C)	21 – 39	17 – 29	18 – 27
Winter	(mean min – max. ^{0}C)	17 - 33	12 - 23	13 - 22
Total population	(30 June '96)	19 780	10 131	6 293
Total number of businesses locations	(Sept '97)	1 667	817	549
Number of agricultural, forestry and fishing businesses locations	(Sept '97) (% of total in brackets)	760 (45.6 %)	266 (32.6 %)	319 (58.1 %)
Total area of established agricultural land (ha)	(March '96)	70 085	55947	52 390
Total value of agricultural economic output	(Aust. $ 1000s) March '96	148 337	37 004	39 935

Table 2 Questionnaire returns by shire.

Sampling frame and response rates	Shire				
	Johnstone	Atherton	Eacham	Other	Total
Total landholders	4,235	1,503	1,640		7,378
Landholders (> 10 ha)	1,550	667	762		2,979
Questionnaires distributed	260	112	128		500
Questionnaires not delivered	2	1	3	1	7
Questionnaires returned	109	49	61	5	224
Useable responses	94	40	54	5	193
Response rate - total responses (%)[1]	42.3	44.2	48.8		45.4
Response rate - useable responses (%)[2]	36.4	36.0	43.2		39.2

Notes: The category 'surveys not delivered' included all surveys that were returned unopened and marked 'addressee unknown' (or similar) or with advice that the addressee was unavailable to assist due to absence or similar reason; 'surveys returned' included all surveys that were returned by the addressee.

[1] Based on questionnaires returned irrespective of whether responses were useable; excludes 'questionnaires not delivered' from the denominator of 'questionnaires distributed'

[2] Based on questionnaires returned that had useable responses i.e. those which included responses for at least of the three sections dealing with benefits of tree planting, impediments to commercial timber production or assistance measures; excludes 'questionnaires not delivered' from the denominator of 'questionnaires distributed'

statements relating to each of these four areas and asked to rate the importance of each of these on a Likert scale of 1 to 5, with 1 representing 'not important' and 5 representing 'very important'.

Respondents were also asked to indicate the single most important impediment to tree planting and the single most important reason for planting trees. They were also asked a number of questions relating to financial and physical characteristics of their farms and also about personal characteristics including age and income.

Each of the shires provided access to their ratepayer database. Within each database, ratepayers were categorised according to the type of property held. The survey was only concerned with ascertaining the attitudes of landholders who had sufficient land to plant timber trees at a commercial scale.

Hence, only landholders in classifications directly related to rural land holdings (as opposed to commercial, rural residential and urban categories) and with 10 ha or greater included in the sampling frame. A total of 500 landholders were selected on a random sampling basis, stratified by local government area (LGA), with sample size for each LGA proportional to the number of target landholders in that LGA.

Questionnaires and a covering letter were distributed by post to the selected landholders in the Atherton, Eacham and Johnstone shires. Follow-up letters were sent to those not responding within three weeks of the initial posting. Table 2 provides details of the target population and response rate by shire.

The overall response rate for the survey was approximately 45% (Table 2) with response rates being similar between shires. Given that questionnaires were distributed by post, and 10 pages long, the response rates achieved are satisfactory as a representative sample.

Data analysis

Analysis of variance (ANOVA) was used to test for significant differences in responses of landholders. Where significant differences ($p > 0.05$) occurred, post hoc multiple comparison tests (Bonferoni; least significant difference (l.s.d.) were used to identify which means were significantly different. ANOVA and post hoc tests were used to identify significant differences in responses to a single question between shires. They were also used to identify significant differences between mean ratings for each question within a group of questions relating to reasons that they considered important for tree planting; perceived obstacles to tree planting; attitudes towards various types of incentive schemes; and their ratings of regional benefits of forestry.

R factor analysis (Hair *et al.* 1998) was used to identify the latent dimensions in each set of questions. That is, it was used to identify which questions within each group were highly correlated, and these questions were then combined to form a ‘scale’. Principle components analysis was used to obtain factor solutions and orthogonal factor rotation was used to assist in the interpretation of the factors identified. ANOVA, post hoc tests and factor analysis were performed using statistical analysis software (SPSS Version 11).

Findings of the Survey

Characteristics of the respondents

Characteristics of respondents are summarised in Table 3. There are distinct differences between the ownership status and farm sizes between shires. In the Eacham Shire a significantly higher proportion ($p > 0.05$) of properties are operated on the basis of a sole traders compared to the other shires. The average farm size in the Johnstone Shire is 30 ha larger than that of both the Eacham and Atherton Shires, which probably reflects the higher numbers of hobby farms in the Tableland shires.

Sources of income from farm and non farm activities are summarised in Table 4. In the Johnstone Shire, nearly 60% of farm income is derived from sugar cane production and a further 20% from annual crops (mainly bananas) (Table 4). The main on-farm sources of income for the Atherton and Eacham shires are dairy and beef cattle. Annual crops (including maize) also provide about 14% of on-farm income in the Atherton Shire. The three shires differ significantly ($p>0.05$) in the amount of income sourced from non-farm sources. In the Johnstone Shire only 13% of income is from off-farm sources compared with 44% and 58% in the Atherton and Eacham Shires respectively. Due to climatic conditions and the location of markets and processing facilities at the time of the survey, the highly profitable activities of sugar cane and banana production are concentrated in the coastal Johnstone Shire. For this shire, the high proportion of income from on-farm activities, as well as the larger farm sizes, is not surprising. The range of agricultural activities available to landholders in the Atherton and Eacham Shires is restricted in their nature and size due to climatic and site conditions.

Table 3 Ownership status, average land size and major sources of income of owners of properties in the Atherton, Eacham and Johnstone Shires.

Ownership and farm characteristics Ownership status	Johnstone	Shire Atherton	Eacham	All shires[1]
Sole trade	11 (10.8)	7 (15.9)	19 (31.7)	38 (18.0)
Partnership	69 (68.2)	30 (68.2)	36 (60.0)	138 (65.4)
Company	17 (16.7)	6 (13.6)	3 (5.0)	26 (12.3)
Other	5 (4.9)	1 (2.3)	2 (3.3)	9 (4.3)
Farm size				
<20 ha	1 (1.0)	6 (13.6)	12 (20.7)	20 (9.6)
20-50 ha	26 (25.7)	13 (29.5)	11 (19.0)	53 (25.5)
50 - 100 ha	30 (29.7)	12 (27.3)	19 (32.8)	61 (29.3)
> 100 ha	43 (43.6)	13 (29.5)	16 (27.6)	73 (35.6)
Average (ha)	112	82	82	95

Notes: Per cent figures are given in parentheses where appropriate.
[1] Includes five responses that could not be classified by shire.

Table 4 Sources of income from farm and non-farm activities.

Source of income	Percentage of total income			Mean All shires
	Johnstone	Atherton	Eacham	
Dairying	0.0	14.6	21.9	9.4
Beef cattle	5.5	14.4	10.5	9.2
Sugarcane	57.9	4.0	0.0	29.3
Annual crops	19.8	14.3	5.2	13.9
Other farm income	4.1	8.3	4.7	5.0
Non- farm income	12.7	44.4	57.7	33.2

Notes: Total is a weighted average percentage of all respondents including five responses for which shire of origin could not be identified. The mean for all shires includes five responses that could not be classified by shire.

Landholders reasons for planting

When asked to rate the relative importance of a number of reasons for tree planting, landholders attached far greater importance to the environmental and land protection benefits of trees compared with the commercial benefits (Table 5). Factor analysis revealed that landholders considered there are three distinct groupings of reasons (scales) for tree planting (Table 6).

Table 5 Importance placed upon various reasons for planting trees by landholders in the Johnstone, Atherton and Eacham Shires.

Reason for planting	Rating by Shire **J**	**A**	**E**	Sign. dif. **l.s.d.**	**Bon.**	Mean Rating (all shires)	n	Times mentioned as main impediment.	% of times rated '5'
To protect and restore land	3.9	3.9	4.2	ns	ns	4.0	172	42	5
To protect the local water catchment	3.8	4.0	4.2	ns	ns	4.0	170	42	7
To attract wildlife and birds	3.5	3.7	3.8	ns	ns	3.6	169	31	8
Personal interest in trees	3.3	3.4	3.7	ns	ns	3.4	170	26	12
To improve the look of the property	3.2	3.5	3.6	ns	ns	3.3	170	26	12
To increase the value of the farm	3.1	3.2	3.2	ns	ns	3.2	166	19	18
To create windbreaks	2.8	3.4	3.4	A. E. > J	ns	3.1	168	25	23
Legacy for children or grandchildren	3.3	2.7	3.2	J > A	ns	3.1	166	26	24
To make money in the future	2.9	2.5	2.4	ns	ns	2.7	167	15	34
To diversify farm business	2.6	2.2	2.2	ns	ns	2.4	163	13	45
Superannuation or retirement fund	2.3	2.1	2.1	ns	ns	2.2	164	13	55
To provide fence posts	1.5	1.8	1.4	ns	ns	1.5	161	3	72

Notes: Rating scale was 1 = not important, 5 = very important. "J" = Johnstone, "A" = Atherton, "E" = Eacham. Significant differences between means for each shire were tested using least significant difference (lsd) and Bonferonni tests for differences between means (p > 0.05). Significant differences between mean ratings for responses for each question were tested using the Bonferoni test for differences between means. Overlapping lines indicate means that are not significantly different from each other. The mean rating for all shires includes five responses that could not be classified by shire.

Table 6 Factor matrix of the reasons for planting trees by landholders in far north Queensland.

Scale name	Scale Mean	Questions	Factor 1	Factor 2	Factor 3
Commercial (0.815)	2.36	To make money	0.886	0.072	-0.060
		Diversify farm business	0.854	0.114	0.060
		Superannuation	0.759	0.285	-0.203
		Increase farm value	0.560	0.481	0.079
		Fence posts	0.547	-0.153	0.121
Personal satisfaction (0.731)	3.30	Improve look of property	-0.002	0.849	0.103
		Personal interest in trees	0.027	0.668	0.404
		Attract wildlife and birds	-0.108	0.627	0.535
		Legacy for children/grandchildren	0.421	0.537	0.000
		Create windbreaks	0.159	0.506	0.206
Environmental (0.866)	3.96	Protect water catchment	0.009	0.233	0.895
		Protect and restore land	0.036	0.191	0.894

Notes: The correlation of each question to each of three factors is shown. The questions with the highest correlation to each factor are grouped and given a scale name which 'best' describes the questions within it. The reliability of each scale is assessed by the use of Cronbach's alpha (Hair et al. 1998) shown under the scale name. Scale means are a composite of ratings for of factors that make up the scale. All scale means are significantly different (p < 0.05).

The first scale was labelled 'commercial' because of the grouping of questions with a strong focus on planting of trees for overtly commercial purposes such as to produce income or increase the capital value of the farm. The second scale was labelled 'personal satisfaction' because it grouped questions with a strong focus on personal and non-financial benefits of tree planting such as an personal interest in trees, farm aesthetics, creation of a fauna habitat and producing creating a legacy for their children. Benefits within this scale accrue primarily to the individual landholder. The third scale was labelled 'environmental' because of the strong focus on overt environmental benefits of tree planting in respect to land and water catchment protection. While landholders benefit to some extent, most of these environmental benefits accrue mainly to the wider community. Many of the reasons for tree planting grouped under the 'personal satisfaction' scale also have an environmental component. However the extent to which benefits accrue to the individual landholder is the main distinction between the 'personal satisfaction' and 'environmental' scales. The reliability of scales is usually assessed by calculating Cronbach's alpha, with the generally agreed upon lower limit being 0.70 (Hair *et al.* 1998). Cronbach alphas for all scales identified in the current study were high, ranging from 0.73 to 0.87.

Landholders place much greater importance on environmental and personal satisfaction as reasons for planting trees compared to commercial reasons (Table 6). Protection of land and water were ranked as the equally most important reasons to plant trees followed by three personal satisfaction reasons (Table 5). Four of the five questions grouped under the commercial scale were rated as the four least important reasons to plant trees. The relative importance attached to the various reasons suggests that landholders are planting trees for either conservation or personal satisfaction reasons, with little importance attached to tree planting for commercial purposes. This is further reinforced with the scale means for 'conservation' (3.98) and 'personal interest' (3.30) being significantly ($p<0.05$) higher than the scale mean for 'commercial reasons' (2.36) (Table 6). There were few significant differences in the ratings of reasons for tree planting between the three shires.

One difference was the far greater importance that Eacham and Atherton Shire landholders attached to tree planting for windbreaks compared to Johnstone Shire landholders. This probably reflects different land use patterns and environmental conditions between the shires.

Impediments to tree planting

Landholders were asked to rate the importance of a series of possible impediments to planting of trees for commercial purposes (ie. planting for environmental and personal satisfaction) Responses are summarised in Table 7.

The five most highly ranked impediments were a mistrust of government following World Heritage listing, a long wait for returns, fears that regulations may prevent future harvest, a lack of capital and an unwillingness to remove land from existing profitable use. Impediments that landholders placed little emphasis on were lack of expert advice, risk of fire damage, land being unsuitable and failure of trees to establish well on their property.

Factor analysis of the ratings for impediments to commercial tree planting revealed six distinct groups of impediments (or scales) for tree planting, as reported in Table 8. The first scale was labelled ‘economic and structural impediments’ because it includes factors that are associated with either the uncertainty of future cash flows (future prices, long wait for returns, low timber prices, a lack of information about returns and uncertainty about profitability) or concerns that future government intervention will place restrictions on landholders in terms of plantation management and harvest. Impediments that fall within the economic and structural impediments scale tend to dominate the ratings by landholders with the top three impediments falling within this classification. Labels attached to the other five scales relate closely to the questions that loaded onto the respective scales.

Incentives for tree planting

A number of incentives to encourage planting trees for timber production were rated by landholders, as reported in Table 9. These were secure harvest rights, tax deductibility of seedlings, rate remission by local government, tree-planting grants to farmers, higher market prices for timber and subsidised seedlings.

Factor analysis of the rating of possible incentives identified three scales (Table 10). The first group of incentives was labelled ‘economic incentives’ because all are associated with some form of financial assistance to landholders in the form of direct payments, savings on outgoings or guarantees to harvest timber. The second group of incentives is associated with the provision of information and includes the provision of information about silviculture, species and sites. Higher market prices for timber were also considered to convey information in the sense that current prices provided a signal that the growing of trees is likely to be a profitable activity. The scale made up of these questions was labelled ‘information incentives’. A third group of incentives, labelled as ‘joint ventures’, are those associated with various types of joint venture arrangements. Incentives classified as ‘economic incentives’ by factor analysis dominate the rating of incentives provided by landholders. The joint venture incentives were found to be the least favoured by respondents.

Regional benefits of tree planting

Landholders in the three shires considered soil and water benefits to be the most important regional benefits of forestry (Table 11). Creation of employment and regional economic stability were rated the lowest. Factor analysis indicates that regional benefits associated with planting trees could be categorised into two main groups – conservation and economic (Table 12). Conservation benefits were found to be significantly ($p<0.05$) more important than economic benefits.

Table 7 Landholder perceptions of obstacles to tree planting commercially on private land in far north Queensland.

Impediment to greater tree planting	Rating by Shire			Sign. dif.		Mean Rating all (shires)		Times mentioned as main impediment.	% of times rated '1'
	J	A	E	l.s.d	Bon.		No.		
Mistrust of government especially after World Heritage Listing	3.8	4.2	3.7	n	ns	3.8	166	52	14
Long wait for returns	3.8	3.5	3.2	J > E	ns	3.5	171	39	16
Fear that regulations may be introduced that prevent future harvest	3.6	3.3	3.4	n	ns	3.5	165	39	19
Finance required, lack of capital	3.6	3.1	3.3	n	ns	3.4	169	35	17
Do not want to remove land from existing profitable use	3.9	3.4	2.6	J, A > E	J > E	3.4	174	37	21
Low profitability	3.6	3.4	2.9	J > E	ns	3.3	159	27	15
Flexibility for future land use reduced	3.8	3.3	2.6	J, A > E	J > E	3.3	165	30	16
Labour required for planting and maintenance	3.1	3.3	3.4	n	ns	3.2	165	30	21
Uncertainty about future timber prices	3.4	2.8	3.1	n	ns	3.2	162	30	24
Lack of information about likely financial returns	3.5	2.9	2.7	J > E	J > E	3.1	163	26	24
Low prices being received for timber currently harvested	3.1	2.9	3.0	n	ns	3.0	157	25	27
Risk of storm/cyclone damage	3.7	2.1	2.2	J > E, A	J > E, A	2.9	165	22	24
Lack of information about appropriate species and markets	2.9	2.5	2.5	n	ns	2.7	159	18	36
Lack necessary machinery	2.1	2.4	2.4	n	ns	2.3	162	13	48
Risk of pest or disease damage	2.3	2.3	2.0	n	ns	2.2	163	7	38
Lack of expert advice on how to grow trees	2.2	1.7	1.7	J > E	ns	1.9	157	8	57
Risk of fire damage	2.1	2.1	1.5	J, A > E	ns	1.9	164	7	55
Land is unsuitable	2.0	1.7	1.8	J > E	ns	1.9	160	8	61
Trees do not establish well here	1.5	1.4	1.2	n	ns	1.4	162	1	78

Notes: Ratings are on a scale of 1 (not an obstacle) to 5 (a very significant obstacle). Landholders were also asked to identify the most significant impediment that they faced. Differences between means for each shire were tested using ANOVA, with post hoc tests of least square difference (l.s.d.) and Bonferonni (Bon.) being used to identify the nature of the differences (p > 0.05). "J" = Johnstone, "A" = Atherton, "E" = Eacham. Significant differences between mean ratings for responses for each question were tested using the Bonferoni test for differences between means. Overlapping lines indicate means that are not significantly different from each other.

Table 8 Factor matrix of landholders ratings of obstacles to planting trees on private land in far north Queensland.

Scale name	Scale mean	Question	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Economic Problems (0.873)	3.33*	Uncertainty about future timber prices	0.80	0.14	0.22	-0.02	0.10	0.08
		Fear that regulations will prevent future harvest	0.77	0.01	-0.09	-0.05	0.17	0.02
		Mistrust government especially after WHL	0.73	-0.02	-0.11	0.12	0.12	0.04
		Lack of information about likely returns	0.70	0.15	0.47	0.04	0.14	0.01
		Low current timber prices	0.70	0.10	0.36	0.00	0.09	0.14
		Uncertainty about future timber prices	0.63	0.36	0.21	0.29	-0.02	0.05
		Long wait for returns	0.59	0.44	0.17	0.26	0.04	0.08
Satisfied/ flexibility (0.816)	3.32*	Flexibility for future land use reduced	0.15	0.88	-0.02	0.05	0.15	0.00
		Do not want to remove land from existing profitable use	0.08	0.82	0.01	0.11	0.12	0.06
Lack advice (0.636)	2.28	Lack of expert advice on how to grow trees	0.03	-0.01	0.79	0.07	0.07	0.31
		Lack of information on species and markets	0.27	0.00	0.74	0.15	0.17	-0.05
Lack labour, finance, equip. (0.664)	2.94	Labour required	-0.02	0.06	0.18	0.79	0.05	-0.11
		Finance required, lack of capital	0.24	0.32	-0.02	0.70	0.01	0.08
		Lack of necessary machinery	0.02	-0.12	0.00	0.64	0.33	0.31
Fire/pest risks (0.718)	2.06	Fire risk	0.08	0.17	0.05	0.19	0.81	0.09
		Pest risks	0.26	0.08	0.17	0.09	0.77	-0.09
Poor land (0.660)	1.60	Trees do not establish well unsuitable	0.03	-0.02	0.14	0.08	0.10	0.87
		Land unsuitable	0.15	0.11	0.06	0.02	-0.08	0.83

*Notes: The correlation of each question to each of six factors is shown. The questions with the highest correlation to each factor are grouped and given a scale name which 'best' describe the questions within it. The reliability of each scale is assessed by the use of Cronbach's alpha (Hair et al. 1998) shown under the scale name. Scale means are a composite of ratings for of factors which make up the scale. All scale means are significantly different ($p < 0.05$) except for those marked with a **

Table 9 Landholders ratings of various forms of potential incentives to plant trees on private lands in far north Queensland.

Potential incentive	n	Mean	% times rated '1'	% times rated '5'
Secure harvest rights	173	4.1	10	57
Tax deductibility of seedlings	172	3.9	9	48
Rate remission by local government	173	3.9	11	45
Tree planting grants paid to farmers	171	3.8	13	47
Higher market price for timber	172	3.8	12	45
Subsidised seedlings	172	3.8	11	40
Subsidised government tree planting schemes with no profit sharing	169	3.4	24	35
Ongoing advice to maximise quality and yield	172	3.3	17	26
More support for Landcare groups	168	3.1	21	23
Greater knowledge of suitable species and growth rates	172	3.0	21	22
Joint venture - annuity until harvest	170	3.0	32	28
Joint venture - annuity for 5 years	170	2.5	40	14
Joint venture - profit sharing	169	2.2	50	12

Notes: No significant differences were found between shires. Incentives were rated on a scale of 1 (very little incentive) to 5 (great incentive). Overlapping lines indicate means that are not significantly different from each other.

Table 10 Factor matrix of the ratings given to various potential incentives for planting trees on private lands in far north Queensland.

Scale name	Scale mean	Questions	Factor 1	Factor 2	Factor 3
Economic incentives (0.869)	3.70	Rate remission	0.795	0.293	0.100
		Planting grant	0.767	0.183	0.263
		Subsidised seedlings	0.731	0.378	0.089
		Tax deduction for seedlings	0.728	0.321	0.042
		Subsidised gov. tree planting schemes	0.706	-0.001	0.201
		Secure harvest rights	0.623	0.390	0.112
		More support for Landcare	0.573	0.131	0.175
Information incentives (0.818)	3.35	Ongoing advice to max. quality and yield	0.260	0.884	0.063
		Greater knowledge of species and growth	0.205	0.869	0.063
		Higher market price for timber	0.322	0.651	0.146
Joint incentives (0.857)	2.51	Joint venture - annuity for five yrs	0.198	0.088	0.925
		Joint venture - cost/profit sharing	0.187	-0.104	0.830
		Joint venture - annuity until harvest	0.149	0.329	0.801

Notes: The correlation of each question to each of three factors is shown. The questions with the highest correlation to each factor are grouped and given a scale name which 'best' describe the questions within it. The reliability of each scale is assessed by the use of Cronbach's alpha (Hair et al. 1998) shown under the scale name. Scale means are a composite of ratings for of factors which make up the scale. All scale means are significantly different ($p < 0.05$).

Table 11 Landholder ratings of regional benefits of forestry on private lands in far north Queensland.

Benefit	Mean	n	%of times rated '1'	% times rated '5'
Water protection	4.2	176	3	52
Soil protection	4.2	179	2	54
Soil fertility	3.9	176	5	38
Stability of flora systems	3.8	174	5	38
Stability of fauna systems	3.8	173	5	37
Carbon sequestration	3.7	174	11	40
Creation of employment	3.6	176	8	30
Economic stability	3.5	175	8	27

Note: No significant differences were found in the variable between shires. Incentives were rated on a scale of 1 (very little incentive) to 5 (great incentive). Overlapping lines indicate means that are not significantly different from each other.

Table 12 Factor matrix of landholder ratings of regional benefits of forestry on private lands in far north Queensland.

Scale name	Scale mean	Questions	Factor 1	Factor 2
Conservation benefit (0.915)	3.94	Flora stability	0.902	0.138
		Fauna stability	0.901	0.162
		Soil protection	0.900	0.026
		Soil fertility	0.783	0.316
		Water protection	0.775	0.029
		Carbon sequestration	0.708	0.271
Economic benefit (0.911)	3.52	Economic stability	0.144	0.943
		Creation of employment	0.121	0.942

Notes: The correlation of each question to each of two factors is shown. The questions with the highest correlation to each factor are grouped and given a scale name which 'best' describe the questions within it. The reliability of each scale is assessed by the use of Cronbach's alpha (Hair et al. 1998) shown under the scale name. Scale means are a composite of ratings for of factors which make up the scale. Scale means are significantly different (p < 0.05).

Discussion

The attitudes of landholders in north Queensland to impediments to tree planting for commercial timber production in the current study are similar to attitudes of landholders in the Obi Obi Valley in southern Queensland. Obi Obi landholders rated the long payback period, harvest rights, shortage of capital and labour, and low profitability as the four most important impediments (Harrison *et al*. 1994, Harrison and Sharma 1995). These four impediments are also rated amongst the top six impediments by landholders in the north Queensland study.

The most highly rated factor in the north Queensland study – a mistrust of Government especially after World Heritage listing – is a factor that has local relevance to north Queensland. Mistrust of the government was also highly rated as an impediment to plantation development in the northern rivers region of NSW (Emtage 1995, Specht and Emtage 1998). The World Heritage listing, although supported by the majority of Australians, resulted in bitter community divisions and the loss of the local timber industry. Many local residents consider the listing to have been a political decision designed to gain votes from metropolitan electorates in Melbourne and Sydney at the expense of the local community. Even more than 10 years after listing, considerable resentment still appears to persist amongst rural communities most adversely affected by the decision and who have not benefited from an increase in tourism. Associated with this resentment is scepticism about the motives of the federal government in resource utilisation and conservation decisions.

Many landholders have expressed concern that if they establish plantations (particularly if comprised of mixed rainforest species) that the government is likely to intervene and restrict their ability to harvest their plantations and force them to manage these areas for purely environmental purposes.

The general mistrust of government by many landholders combined with their specific concerns about harvest rights has implications for policy-makers. Unless clear measures are introduced to alleviate these concerns, it is unlikely that large-scale planting for commercial purposes/timber production will be undertaken. It is also not surprising that secure harvest rights, along with favourable taxation treatment, were the most highly rated of the various forms of incentives available to encourage the planting of trees for commercial timber production. A guarantee of harvest rights and taxation incentives have also been found to be the most highly rated incentives by landholders in the Obi Obi Valley (Harrison *et al*. 1994, Harrison and Sharma 1995) and in northern NSW (Emtage 1995, Specht and Emtage 1998).

Measures to address harvest right concerns could include the recording of areas planted on property title deeds and rate notices, assurance of compensation in the event that logging is not allowed or restricted, and state and federal legislation that specifically allows plantation harvest as an 'as of right' activity. It would also appear that a more favourable tax regime both at the Federal level (i.e. through modification of the *Income Tax Assessment Act 1936, 1997*) and at the local level, through favourable changes to rates charged by local government, may act as an incentive for greater levels of tree planting by some landholders.

Various forms of assistance have been provided by government departments in the past to facilitate farm forestry. Assistance measures range from subsidised seedlings, provision of technical advice and other extension services, planting schemes under which government department's plant trees either free or at a subsidised cost to the landholder, tree planting grants paid directly to landholders and various joint venture arrangements (Harrison *et al*. 1996, Herbohn *et al*. 1998). Payment of grants directly to landholders is clearly the preferred form of direct assistance measure. Joint venture arrangements on the other hand are clearly the assistance measure least favoured by landholders. Similar opinions were also found in the Obi Obi Valley (Harrison *et al*. 1994).

The lack of support is associated with a loss of control by landholders over the management of land planted under joint venture arrangements, as well as restrictions on species landholders can plant along with restrictions on the planting design. The harvest security provided by joint venture arrangements does not appear to be sufficient compensation for loss of control over the management of their land. This would indicate that the most successful assistance measures will be those that allow landholders to retain a substantial degree of control and flexibility in the management of their land.

Landholder types in far north Queensland

Groupings of landholders from survey data

Landholders within the rural community were grouped using hierarchical cluster analysis of their responses to the scales constructed for the topics ‘reasons for planting trees’ and ‘restrictions to planting trees’. The groups defined on this basis were then assessed for the purposes of:

1. determining if they differed in terms of their attitudes to different types of potential assistance for farm forestry;
2. assessing the socio-economic characteristics of the groups and differences between them; and
3. to assess if the groups differed in terms of their past or intended farm forestry behaviour.

Examination of the average ratings for different reasons for planting and restrictions to planting gives some indication of the types of people in each group. Analysis of the differences in socio-economic characteristics between the groups provides further assistance in understanding the types of people involved and why they think as they do (see Tables 13 and 14).

Table 13 Land size and land use by groups.

Group Number	Log size (log 10)	Cropping (% of holding)	Native forest (% of holding)	Degraded pasture (% of holding)
1	1.76	47	9	1
2	1.73	16	31	6
3	1.91	37	11	9
4	2.00	45	25	3
5	1.87	38	27	2

Table 14 Dependence on landholding for income, family labour requirements and years managed by groups defined through cluster analysis.

Group	Income from land (% of total gross income)	Total family labour/week (hours)	Time managed the land (years)
1	45	60	17
2	36	45	14
3	54	64	18
4	71	99	27
5	62	55	21

The groups were differentiated by the physical characteristics of their landholdings and land use practices. These differences included the size of their landholdings, the proportions of land they devoted to cropping and that covered by native vegetation, and the proportion of land considered to be ‘degraded pasture’ (Table 13).

In many cases the differences in socio-economic characteristics found between the groups reflected differences found between those which had and had not planted trees on their land (Emtage et al. 2000). This is partly because there were significant differences between the proportions of members in each group who had already planted more than thirty trees on their land.

In addition to differences in the physical attributes and land uses between the groups, they also differed in terms of their reliance on the landholding for income, the amount of labour that the family put into managing the landholding, and the time over which they had managed the landholding (Table 14).

Interpretation of the landholder groups by extension personnel

The analyses of responses to the survey were presented to a group of fifteen people dealing with landholders (mostly extension personnel employed through various government departments and programs) in the north Queensland region at a one day meeting where the extension personnel were asked to aid the authors' interpretation the survey responses. They were first asked to define and briefly describe common types of landholders in the north Queensland region they recognised from their previous training and experience before being shown the results of the cluster analysis. Table 15 illustrates the initial landholder groups/types described by the personnel.

Table 15 Initial classification of landholder types in the north Queensland region by farm forestry extension personnel.

Group name	Key characteristics
Progressive second generation farmers	Have inherited land (and debt); have similar enterprises as parents but greater education, more emphasis on conservation farming
High intensity farmers	Strongly commercially orientated, often involved in banana and or sugar production, seek to maximise area of land under crops
Traditionals	Follow old style farming practices, large property size
Retired professionals	People with high education and strong financial position who retire to the land as a lifestyle choice
Experienced/ comfortable farmers	Largely debt-free, older, running profitable landholdings with minimal direct labour inputs (ie. use contractors regularly)
Absentee landholders	Often become retired professionals with high incomes and education, little time. Often use land as tax break, frequently employ managers. Considerable variation in strategies used.
Marginal farmers	On poorer quality land running marginally profitable enterprises. Many desperately seeking information and /or methods that will allow them to run the landholding profitably.
Hobby farmers	Smaller landholdings providing only small proportions of landowners' incomes. Frequently well educated and in 'good' jobs but with considerable variation.
Conservationists	Land management dominated by strong conservation ethic.

The extension personnel were then shown the results of the cluster analysis and subsequent analyses used to examine the characteristics of each group and differences between groups. The meeting was split into three teams. These teams were asked to assess if the groups they had earlier described matched with the groups found through cluster analysis. The extension personnel were also asked to recommend communication strategies and incentive programs that might appeal to members of the various groups. The relationships between the groups first described by the extension personnel and those in the cluster analysis are shown in Table 16.

Table 16 Comparison of extension personnel's landholder types and those identified through cluster analysis.

Cluster analysis group	Extension team 1 names	Extension team 2 names	Extension team 3 names
1	Progressive second generation farmers	Marginal farmers Hobby farmers	**High intensity farmers** **Marginal farmers**
2	Retired professionals, Conservationists, Hobby farmers, absentee farmers	Retired professionals, Conservationists, Hobby farmers, absentee farmers	**Retired professionals, Conservationists, Hobby farmers, absentee farmers**
3	Experienced/ comfortable farmers	Progressive second generation farmers	**Progressive second generation farmers**
4	High intensity, traditional, marginal farmers	High intensity, traditional	**Traditional**
5	High intensity, traditional	Experienced/ comfortable farmers	**Experienced/ comfortable farmers**

Note: Bold names are those adopted by authors

It can be seen that there was a high degree of consistency between the names of the groups given by the three teams of extension personnel. Given these consistencies it was decided to adopt the names of the third group of extension personnel as the names for the groups identified through cluster analysis (column four in Table 16). These names were adopted because firstly, they made sense, and secondly, the authors considered that the adoption of the names developed by the extension officers would help them to understand the groups and give them a sense of "ownership" of the research.

Descriptions of the landholder groups

In the following section the characteristics of each of the groups is briefly described in terms of their defining socio-economic characteristics and their primary motivations for and restrictions to farm forestry development.

Group 1: High intensity farmers

Group 1 was the third smallest group (14% of sample) and reported the second greatest rate of previous planting. They gave high ratings for personal and conservation reasons for tree growing but expressed a relatively low interest in timber production. Most were concerned about the potential loss of flexibility for future land management decisions, they feared loss of the satisfaction they derived from carrying out their present activities and the financial impacts of planting. They rated a lack of advice lowly as a restriction to planting but did express interest in information about farm forestry on which to make decisions.

Members of this group are characterised by a small property size relative to their dependence on the land for income, a high proportion of land used for cropping, with high family input of labour, and moderate dependence on their land for their income (45%). They have the second shortest history of land management and the second highest levels of education, a strong commercial orientation, and relatively little areas native forest compared to other groups.

Group 2: Retired professionals, hobby farmers, conservationists, absentee farmers

Group 2 made up 20% of the sample. In the case of the CRRP, the main ‘client’ group of the scheme was the members of Group 2 (retired professionals, hobby farmers, conservationists, absentee farmers) (see Herbohn et al. (2003)). The members of Group 2 are primarily interested in growing trees for conservation reasons. They gave low importance ratings to all restrictions, including lack of advice. They are well educated with the bulk of their income derived off-farm. Most of this group has planted more than thirty trees on their land, but are restricted in future planting because of the small size of their landholdings.

In terms of tree planting, Group 2 could be termed the innovators within the community with a significantly higher level of planting than all other groups. They reported a strong relative interest in tree planting for personal reasons and comparatively low interest in planting for commercial reasons. They still, however, reported the greatest intention to plant in the future for mixed commercial, conservation and personal reasons. They are characterised by small property size with some native forest, high levels of education, and relatively short periods of ownership and low dependence on land for income.

Group 3: Progressive second generation farmers

Group 3 rated the importance of tree planting for all reasons higher than the other groups, and had the second greatest proportion of members that had undertaken previous tree planting. They also, however, foresee many problems with future plantings, rating all scales of restrictions to planting (except satisfaction with present activities) higher than all other groups. They are the second smallest group comprising only 7% of the sample.

Members of Group 3 have a large property size, a positive attitude to tree planting and report having areas on their properties that have potential for farm forestry development. Members of Group 3 have a greater reliance on their landholding for income and slightly lower education than the members of Group 2 with many having diplomas but not degrees. They want more advice and information and appear to be enthusiastic about tree planting but adverse to perceived associated risks.

Group 4: The traditionalists

Group 4 placed the lowest ratings of importance on all reasons for tree planting, had the lowest reported previous involvement in planting, and reported the least intention to become involved in farm forestry in the future. This group would appear to be the least likely to become involved in farm forestry in the future. Like Group 1, they rated their satisfaction with present activities and concern about the potential loss of flexibility for management decisions highly as restrictions to future planting. They were the smallest group at only 6% of the sample.

This groups is characterised by a long history of managing their property, have large property sizes, with some areas of native forest, very high family labour inputs, and a high degree of dependence on the landholding for income.

Group 5: Experienced/comfortable group

Group 5 is the largest of the groups comprising half the respondents in the sample. Members of this group had the second greatest average interest in commercial plantings (significantly lower than Group 3 where $p<0.05$), but reported few past and little intended planting activity. They have managed the land for over 20 years, and have a low family labour input relative to the proportion of income they earn from their property. They have an average of 38% of their land under crops and get an average of 60% of income from the landholding.

Members of this group appear to be not really against tree planting but ambivalent or unwilling to become involved in farm forestry, possibly because of their age, and perhaps the knowledge and finance/labour input required.

Developing policies to support farm forestry

One of the main purposes of defining and describing the various groups or types of landholders in the community in regards to farm forestry is to improve the effectiveness and efficiency of publicly funded farm forestry extension and support. The aims are to use these groups as a basis for improving:

- understanding the socio-economic factors affecting farm forestry development;
- understanding the range of objectives that members in the rural community have for farm management and the effects these objectives have on the type of farm forestry they wish to practice;
- the planning and administration of support schemes for farm forestry; and
- the development of effective communication strategies to target rural extension programs.

As part of the meeting used to present the results of the survey to extension personnel they were asked to recommend different types of assistance to support the various landholder groups to become active farm forestry practitioners. Table 17 presents the recommendations of the types of assistance relevant for the various groups made at this meeting together with a summary of the factors seen to be the main influences on their planting behaviour.

Table 17 Main influences on planting behaviour and recommended support schemes by extension personnel for different groups of landholders.

Group		Influences on planting behaviour	Recommended support
1	High intensity	Have some personal interest in trees but also a strong commercial focus and limited capital (land size) leads to risk aversion. Enjoy agricultural production.	Provide information about multiple purpose plantings Provide tax breaks/incentives and rate reductions
2	Retired professionals hobby farmers	Strong personal interest in tree growing and lower reliance on landholding for income leads to high participation in farm forestry.	Continued CRRP scheme (provide labour, information and organisation for planting activities), develop networks.
3	Progressive second generation	Strong interest in tree growing but greater reliance on landholding for income and lower ability to cope with demands of planting and management.	Provide advice about plantings Provide tax breaks/incentives and rate reductions
4	Traditional	Low personal interest in tree growing. High reliance on land for income. Enjoy agricultural production.	Develop options for short rotation plantations and annuity schemes
5	Experienced/ comfortable	Moderate personal interest in tree growing and reliance on land for income.	Develop options for short rotation plantations and annuity schemes

Concluding comments

Surveys of landholder attitudes can provide important information for the design and implementation of forestry schemes such as the CRRP. It is important to know what landholders consider to be the important benefits of forestry, as this helps in the design of schemes that can be tailored to their needs. In addition, it is important to identify the constraints to greater involvement of landholders in forestry. By doing so, this allows actions to be taken to address these impediments, and in some cases, lobby for policy changes and support measures to be put in place.

The grouping of landholders according to their responses to the survey illustrates the potential of cluster analysis techniques to develop understanding of the diversity in attitudes to farm forestry in the rural community. Grouping landholders assists the assessment of the state of development of farm forestry within the community, helps in the development of programs to assist different types of landholders to take-up farm forestry, and the development of means to communicate these programs. The definition of groups of landholders helps those planning and administering farm forestry assistance programs to understand the range and nature of variation in attitudes, practices and socio-economic circumstances of rural landholders at a regional scale. It allows for the assessment of assistance programs to see if the basic needs of different types of landholders are being catered for. The groups can also be used for the purpose of training extension officers about the types of landholders they may deal with in the field. There is still, however, a need for extension personnel to be available to take into consideration the situation of individual landholders.

Acknowledgments

The authors would like to acknowledge the financial support provided for this project by the Rainforest Cooperative Research Centre. The assistance of Dr Rod Keenan (previously Queensland Forestry Research Institute) and Gary Sexton (previously Community Rainforest Reforestation Program) in some aspects of the research reported above is gratefully acknowledged. The authors also express gratitude to the Shires of Atherton, Eacham and Johnstone for providing access to their respective ratepayer databases and to the landholders who agreed to take part in the survey.

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15. Economic issues and lessons arising from the Community Rainforest Reforestation Program

Steve Harrison, John Herbohn, David Smorfitt, Nick Emtage and Jungho Suh

Abstract

A large number of socio-economic research projects have been conducted in north Queensland which have drawn on observations from, or been otherwise inspired by, the Community Rainforest Reforestation Program (CRRP). The research may be considered under the headings of financial performance of farm-grown timber, externalities (or environmental values), impediments to tree planting on farms, analysis of the timber supply chain including timber marketing, and facilitation of forest industry development. This paper summarises a variety of insights generated by the research, on small-scale forestry based on native tree species and on policy measures which may be adopted to promote tree growing on farms in tropical north Queensland.

Introduction

The Community Rainforest Reforestation Program (CRRP), when initially proposed, appeared to be a major initiative towards forest industry development in tropical north Queensland. There was a high level of optimism about farm forestry at the inaugural CRRP annual meeting in Innisfail in 1993, although it is notable that few landholders attended the meeting. The financial arrangements of the CRRP were generous compared to past forestry support schemes in Australia. Initially, landholders were required to prepare the planting site and install fencing to exclude cattle; seedlings, planting and early maintenance were provided free of charge. Later a contribution or 'landholder levy' towards planting costs was required (see Vize *et al.* Chapter 2).

By 2000, the overall impact of the CRRP was small, and resulted in the planting of only about 1780 ha of farm forestry. However, during its life –from 1993 to 2000[1] – the CRRP was a fascinating (if expensive) experiment in small-scale, non-industrial private forestry. It may be that the generous terms of the program contributed towards its downfall. Some landholders probably did not value their plantations sufficiently highly to carry out adequate weed control or other stand management operations. Other landholders probably came into the scheme without any clear harvest intentions, but with a desire to have native rainforest trees growing on their land.

There are sharply contrasting views about whether the Plantation Joint Venture Scheme (PJVS) in which equity was shared with the State government, and later and to a lesser extent National Heritage Trust funding for tree planting, undermined the support and funding for the CRRP. There was competition to recruit landholders for both programs, although the programs were targeted at different groups.

From an economist's viewpoint, hard information on the CRRP was really only available about land preparation, planting, and early maintenance costs. However, the demonstration that many native hardwood species which can potentially produce very high quality timber could be established in farm plantations provided the stimulus for a variety of economic studies into small-scale mixed-species plantings. These studies have been concerned with both the financial performance of plantations from the landholder's perspective (the private payoff) and the benefits and costs to the

[1] Tree planting under the CRRP finished in 1998, but forestry extension was provided until 2000.

community (social payoff). This paper reviews the findings of various studies undertaken by members of the socio-economic research group of the Rainforest CRC and by their postgraduate students, as reported in books, journal articles, research reports and conference papers.

Some of the main socio-economic research projects carried out by the group, which draw on experiences of the CRRP, are listed in Table 1. These projects have an economic focus, but also have social implications. A number of related projects have also been conducted overseas – in the Philippines, India and Vietnam – and in other parts of Queensland and New South Wales, but are not elaborated here.

Table 1 Some economic research areas drawing on lessons from the CRRP.

Financial performance of farm-grown timber	Stand yield and forest enterprise modeling Forestry financial modeling in a whole-of-business context Economics of applying silvicultural management to native forest on farms
Environmental and other non-wood values of farm forestry	The optimal rotation when carbon sequestration is taken into account Multicriteria analysis of riparian revegetation The 'total economic value' of the CRRP Commoditisation of positive environmental externalities from farm forestry (including carbon sequestration) Biodiversity benefits of rainforest reforestation
Impediments to farm forestry	Forestry impediments as stated by landholders Impact of reforestation on land values
Timber supply chain and marketing	Timber quality and harvest intentions under the CRRP The cost and role of portable sawmilling relative to fixed-site milling Cabinet-makers timber sources, uses and preferences Consumer purchase attitudes to products made from rainforest cabinet timbers Marketing and export of farm-grown timber Markets for and potential utilization of timber in the Aurukun Shire
Timber industry facilitation	Support measures for forest industry development in north Queensland Sources of private finance for farm forestry

Financial performance of farm grown timber

A major objective of the research undertaken by the socio-economic research group was to develop financial models to predict yields from farm-grown plantations of mixed native tree species. It was recognized that financial performance of growing native timbers as a business enterprise will vary depending on a variety of factors, e.g. site productivity, species used and their growth rates and harvest ages, stumpage price, and the discount rate. There is a clear need for estimates of financial performance of farm forestry ventures. This type of information contributes to the confidence of landholders in planting trees, and is relevant to forestry extension and to the recognition of plantation value when valuing farm land.

Stand yield and forest enterprise modelling

A number of forest enterprise financial models have been developed by the research group, the most comprehensive of which is the Australian Cabinet Timbers Financial Model ACTFM (Herbohn *et al*. 1997, 2001a, Dayananda *et al*. 2002). Development of the ACTFM was impeded by lack of stand yield information for species planted under the CRRP. In the absence of stand growth curves, a Delphi survey was used to obtain estimates of harvest age and mean annual increment from a number of forestry experts. The model is programmed in Microsoft Excel, using a series of macros. Financial performance (expressed as net present value, internal rate of return and other criteria) is predicted for mixtures of up to six tree species. Default yield, price and cost data are provided, but the user may choose to enter their own values.

Application of this model (e.g. Harrison *et al*. 2001a) suggests that farm forestry using rainforest cabinet species is marginally attractive as an investment and relatively high risk. For example, a monoculture of *Acaucaria cunninghamii* (hoop pine) and a mixture of *Eucalyptus cloeziana* (Gympie messmate) and *Flindersia brayleyana* (Queensland maple) were both predicted to have a positive net present value at a discount rate of 4%, but a negative NPV for a 6% discount rate. Harvest age, mean annual increment, timber price and discount rate adopted appear to be key factors affecting investment performance estimates.

Forestry financial modeling in a whole-of-business context

The ACTFM has been extended to allow evaluation of forestry ventures within a whole-of-farm-business context, with allowance for crop and livestock activities and the impact on the annual cash position of the firm. The software package arising from this work is the Australia Farm Forestry Financial Model (AFFFM) (Harrison *et al*. 2003b, Herbohn *et al*. in press). In case studies with the AFFFM, farm forestry on the Darling Downs was found to be unattractive as an investment, but management of native forests in the New England region appeared to be profitable and fitted well within overall farm operations (Thompson *et al*. in press). The difference arises because of the high outlay and long payback period for plantation forestry relative to applying silvicultural management to native forests. The AFFFM has been applied to evaluate farm forestry investments throughout Queensland, including areas where the CRRP was implemented, under a JVAP project (Herbohn *et al*. In press).

Environmental and other non-wood values of farm forestry

The optimal rotation when carbon sequestration is taken into account

Pegg (1997) examined the impact of including carbon sequestration benefits in an optimal economic rotation for hoop pine. Allowing a return for carbon reduced the optimal rotation from 45 to about 40 years, because young and actively growing trees have a greater annual carbon uptake that trees approaching optimal harvest age for timber production. Limitations of the study were that no account was taken of changes in soil carbon, of the carbon costs of growing and harvesting the plantation, or carbon leakage after harvest. However, the study does suggest that taking account of environmental (non-wood) values could lead to changes in optimal forest management.

Multicriteria analysis of riparian revegetation

Multicriteria analysis has been used to compare riparian revegetation options for the Scheu catchment, a small catchment in the Innisfail district typical of some of the riparian plantings under the CRRP (Qureshi and Harrison 2001a,b). Estimates were made of the cost of tree planting and the loss of income from sugarcane production, and of the environmental benefits, for a number of tree buffer widths. The net present value of the revegetation options was then treated as part of the input along with other benefits of riparian revegetation which could not be quantified in dollar terms. The estimated costs and benefits for the four options are presented in Table 2.

Table 2 Estimated costs and benefits of the four riparian revegetation options along Scheu Creek[a].

Cost and benefit category	Option			
	A	B	C	D
Cost item				
Land opportunity cost ($/yr)	6,298	11,092	9,118	18,800
Site preparation and tree planting cost ($)	171,520	302,080	248,320	512,000
Maintenance cost ($)	3,430	6,041	4,966	10,240
Benefit item				
Reduction in rodenticide and weedicide costs ($/year)	409	409	409	409
Reduction in rat damage cost ($/year)	2490	2490	2490	2490
Reduction in flood damage costs ($/once-in-10 years)	10,000	10,000	10,000	10,000
Reduction in off-site damage costs ($/once-five years)	1,000	1,150	1,300	1,150
CO_2 sequestration benefit ($/year)	335	590	485	1,000

a. The four options examined were: A: 3m vegetated buffer on inside meanders, 6m buffer on outside meanders, 3m buffer along straight reaches; B: 5m buffer on inside meanders, 10m on outside meanders, 5m along straight reaches; C: 5m buffer buffer on inside and outside meanders and along straight reaches; and D: 10m buffer on inside and outside meanders and along straight reaches. Buffer strip varied between 7.2 and 20.5 ha.

Table 3 Weights assigned to each sub-objective by stakeholder groups in Scheu Creek catchment.

Objective and sub-objective	Stakeholder group				
	Farmers	Sugar mill staff	Fishermen	Local community	Environmental -ists
Ecological					
Groundwater quality	0.019	0.010	0.057	0.018	0.041
Surface water quality	0.023	0.011	0.160	0.019	0.067
Land stability	0.043	0.030	0.037	0.157	0.067
Watercourse stability	0.041	0.053	0.114	*0.242*	0.122
Land habitat	0.029	0.023	0.131	0.180	0.202
Stream habitat	0.035	0.015	*0.160*	0.108	*0.202*
Social					
Protection of human health	0.128	0.107	0.112	0.060	0.062
Protection of recreational fishing	0.023	0.017	0.022	0.013	0.010
Protection of recreational values	0.024	0.019	0.022	0.003	0.025
Economic					
Loss of land	*0.349*	0.127	0.026	0.010	0.013
Water treatment cost	0.133	0.217	0.026	0.094	0.054
Off-site damage cost	0.152	*0.371*	0.132	0.094	0.136

The importance of weightings placed by stakeholders on environmental, social and economic sub-objectives, derived by a technique known as the analytic hierarchy process, are reported in Table 3. Some clear differences arise between stakeholder groups. For example, the environmental sub-objective of protecting stream habitat was given a high weighting by fishermen and environmentalists. Farmers placed a high weighting on the economic sub-objective of reduction in loss of cropping land. The local community representative placed highest weight on the environmental sub-objectives of watercourse stability, while the sugar mill staff representative gave the highest weight to the economic sub-objectives of reduction in offsite damage costs.

Not surprisingly, this research indicated that cane farmers and sugar mill staff preferred narrow buffers while other stakeholders including fishers and environmentalists preferred wider riparian buffers.

More importantly, the analysis provided importance weights for a number of economic, social, and environmental criteria from the viewpoint of the various stakeholder groups. It is probably beyond the role of economics to suggest tradeoffs between the different stakeholder groups, but having information on the importance that various stakeholder groups attach to particular outcomes provides a better basis for policy makers to understand and deal with conflicts.

The total economic value of the CRRP

A large number of potential economic costs and benefits have been identified for the CRRP, as listed in Table 4.

Table 4 Categories of potential costs and benefits of re-establishing rainforest.

Program costs – private
Land preparation, planting, maintenance, harvesting, transport and marketing costs
Administration costs (accountancy, insurance)
Costs of increased feral animal damage to other enterprises
Opportunity cost of not using land for other purposes
Program benefits – private
Revenue from thinnings and harvest timber
Taxation concessions from investment in trees
Reduced soil loss and streambank erosion
Benefits to livestock (e.g. shelter) and crops (e.g. increased insect control by birds)
Landscape/farm beautification benefits
Sale of non-timber forest products (honey, plants)
Existence, amenity and privacy values of additional native flora
Existence and amenity value of additional native fauna
Program costs – social
Overhead costs of administering the CRRP
Salaries of government agency staff for time spent on program
Costs of growing seedlings or acquiring them from private nurseries
Plantation maintenance (weed control, fertilizing, pruning, thinning)
Training and subsistence costs of LEAP scheme workers
Forestry research costs directly associated with the program
External costs due to improved habitat for pest animals (e.g. cockatoos, feral pigs)
Reduced local government revenue should rate concession be given for planted areas
Program benefits – social (including environmental)
Employment for tree establishment, maintenance and harvesting
Training of a skilled workforce and satisfaction of participants in gainful employment
Additional wildlife habitat and corridors, and rainforest seed dissemination
‘Upstream’ benefits to input suppliers, and ‘downstream’ benefits to timber millers and processors
Increased knowledge base for tropical timber production and rainforest regeneration
Carbon sequestration; protection of water quality in streams; flood mitigation
Increased attractiveness of the area to tourists

In theory, it is possible to estimate the total economic value (TEV) from the program, including both private and community benefits, and including environmental and social as well as financial benefits. In practice, it is only possible to make estimates of a relatively narrow selection of the cost and benefit items.

High environmental values have been recognized for tropical forests, and it would appear that some of these values carry over to plantation forestry in the tropics (Harrison *et al*. 2000; Harrison 2000). A study was undertaken to estimate the economic value of plantations established under the CRRP, including timber value and other benefits (confined to benefits from carbon sequestration, water quality, economic flow-ons, research and training, and ‘conservation’) (Eono and Harrison 2002). As indicated in Table 5, the estimated timber plus economic flow-on benefits are of similar magnitude to estimated environmental and other non-wood benefits (each of about $3-4M). These estimates are highly sensitive to the discount rate adopted and timber price assumptions.

Table 5 Net Present Value (NPV) estimates for the CRRP ($M, year 2001 prices).

Parameter being changed	Change (%)	Total costs (C)	Timber revenue (T)	Flow-on benefit (F)	Environmental benefits				Total external-ities (B)	NPV (T+F+B-C)
					Carbon	Water	Conse r- vation	Training		
Baseline	7%	9.8	3.4	1.5	2.9	0.1	0.7	0.3	4.0	-0.9
Discount rate	5%	8.6	8.9	1.3	2.6	0.1	0.6	0.2	3.5	5.1
	9%	9.1	1.6	1.3	2.4	0.1	0.3	0.2	3.0	-3.1
Timber price	+3%	9.8	10.1	1.5	2.9	0.1	0.7	0.3	4.0	5.8
	-3%	9.8	1.0	1.5	2.9	0.1	0.7	0.3	4.0	-3.3
All costs	+10%	10.8	3.7	1.5	2.9	0.1	0.7	0.3	4.0	-1.5
	-10%	8.8	3.1	1.5	2.9	0.1	0.7	0.3	4.0	-0.3
Carbon price	$3/t	9.8	3.4	1.5	0.4	0.1	0.7	0.3	1.5	-3.4
	$50/t	9.8	3.4	1.5	6.4	0.1	0.7	0.3	7.5	2.6
Mean	10%	9.8	3.7	1.5	3.2	0.1	0.7	0.3	4.3	-0.2
Annual Increment	-10%	9.1	1.4	1.3	2.2	0.1	0.3	0.2	2.8	-3.5

Impediments to farm forestry

Forestry impediments as stated by landholders

A variety of surveys have been conducted by the research group into landholder attitudes to farm forestry. A postal survey was carried out in three shires in north Queensland, in which 500 questionnaires were distributed and 188 usable responses obtained (see Herbohn *et al.* Chapter 14). Table 6 summarises attitudes to a number of possible reasons for planting rainforest species on farms. It is clear that environmental benefits dominate.

On the other hand, the major perceived constraints to planting were found to be uncertain property rights (mistrust of government especially after World Heritage Listing, fear that regulations may be introduced that prevent future harvest) and financial reasons (long wait for returns, finance required, lack of capital, low profitability) (Harrison *et al*. 1996, Emtage *et al*. 2001).

In the CRRP, local governments were found to have rather different goals for farm forestry than landholders, placing higher priority on benefits of timber production and employment (Eono and Harrison 2002).

Table 6 Importance placed on various reasons for planting trees in three CRRP shires.

Reason for planting[a]	N	Mean rating by shire				Frequency of rating '5' (%)
		John-stone	Ather-ton	Eacham	Over all	
To protect and restore land	172	3.9	3.9	4.2	4.0	42
To protect the local water catchment	170	3.8	4.0	4.2	4.0	42
To attract wildlife and birds	169	3.5	3.7	3.8	3.6	31
Personal interest in trees	170	3.3	3.4	3.7	3.4	26
To improve the look of the property	170	3.2	3.5	3.6	3.3	26
To increase the value of the farm	166	3.1	3.2	3.2	3.2	19
To create windbreaks	168	2.8	3.4	3.4	3.1	25
Legacy for children or grandchildren	166	3.3	2.7	3.2	3.1	26
To make money in the future	167	2.9	2.5	2.4	2.7	15
To diversify the farm business	163	2.6	2.2	2.2	2.4	13
Superannuation or retirement fund	164	2.3	2.1	2.1	2.2	13
To provide fence posts	161	1.5	1.8	1.4	1.5	3

a. Reasons rated on a scale of 1 (not important) through to 5 (very important). Source: Harrison et al. (2001b).

Attitudes to incentives

Landholders in the survey of three north Queensland shires were also asked about their attitude to various tree planting incentives. Greater assurance of harvest rights and planting subsidies were ranked highly by landholders (Table 7).

Table 7 Landholders' ratings of various forms of potential incentives to plant trees on private lands in far north Queensland.[a]

Potential incentive	N	Mean rating	Frequency of rating '1' (%)	Frequency of rating '5' (%)
Secure harvest rights	173	4.1	10	57
Tax deductibility of seedlings	172	3.9	9	48
Rate remission by local government	173	3.9	11	45
Tree planting grants paid to farmers	171	3.8	13	47
Higher market price for timber	172	3.8	12	45
Subsidised seedlings	172	3.8	11	40
Subsidised gov't tree planting schemes with no profit sharing	169	3.4	24	35
Ongoing advice to maximise quality and yield	172	3.3	17	26
More support for Landcare groups	168	3.1	21	23
Greater knowledge of suitable species and growth rates	172	3.0	21	22
Joint venture – annuity until harvest	170	3.0	32	28
Joint venture – annuity for 5 years	170	2.5	40	14
Joint venture – profit sharing	169	2.2	50	12

a.: No significant differences were found between shires. Incentives were rated on a scale of 1 (very little incentive) to 5 (great incentive).
Source: Harrison et al. (2001b).

Impact of reforestation on land values

Increased land value is sometimes used as an argument when promoting farm forestry. However, research indicates that while establishment of plantations of mixed native species increases land values, the increase is less than the amount invested in establishing and maintaining the trees, i.e. the forestry is not fully capitalized into land values (Harrison *et al*. 2001c). This appears to be due in part to difficulty for land valuers and real estate agents in placing values on immature plantations. It is notable that 72% of the CRRP landholders surveyed perceived that tree plantings would increase the value of their properties, though most thought the increase would be less than 2% (Eono and Harrison 2002). It would appear that the timber value of the stand is not factored into valuations until the trees are about 15 or more years of age. Availability of improved financial models may help to overcome the valuation problem.

Timber supply chain and marketing

Timber quality and harvest intentions under the CRRP

One of the stated goals of the CRRP was the re-establishment of a timber industry following the loss of the native forest timber resource due to World Heritage listing of the Wet Tropics rainforests. Shea (1992) in his consultancy to evaluate the desirability of a program such as the CRRP envisaged planting areas of the order of 1000 ha per year over 30 years. It was originally planned that 80% of the area planted would be for timber production and balance conservation plantings. The relatively small area actually planted under the program (about 2000 ha), and evidence that somewhat less than 80% of plantings may actually be harvested obviously made this goal unachievable. For example, Harrison *et al*. (2003a) investigated stand management and harvest intentions of CRRP growers in the Atherton and Eacham Shires. About 14% of a sample of 72 CRRP participants said they carried out no management of their trees, 53% said they are managing for multiple uses, and 14% stated they are managing trees solely or dominantly for timber production. Also, 47% stated they intended to harvest all of their CRRP trees while 36% stated they did not intend to harvest any of their CRRP trees. In almost all cases, the preferred harvest regime was selective logging, to be followed by replanting. It is possible that views concerning harvesting could change as trees planted under the CRRP mature. Should prices of cabinet timbers increase in real terms, those who have carried out appropriate pruning and thinning may be induced to harvest, particularly when cash is needed for special purposes such as intergenerational property transfer.

The cost and role of portable sawmilling relative to fixed-site milling

An early view of the socio-economic researchers was that timber millers may be taking an unfair share of the forestry ‘resource rents’. Typically, there is unequal market power between growers and millers, with many growers supplying only one mill in their immediate area (the miller being in what is called a monopsonist position). However, observation suggests that many hardwood mills have closed as a result of reduced log supply due to the World Heritage listing, and resource security continues to be a problem for those remaining. Some mills are apparently operating at low throughput (high on their long-run average cost curve) and using outdated, and hence high-cost technology. An exception is Ravenshoe Timbers, but that company does not mill farm-grown timber and has export and domestic markets.

Use of low-cost portable sawmills seemed a means of overcoming the high-cost milling problem. Research led by Smorfitt examined the role of portable sawmills in the timber supply chain in north Queensland. Data were obtained from various suppliers of portable sawmills and from a survey of portable mill operators (Smorfitt *et al*. 1999, 2002a, 2003). This research indicates that portable mills can reduce milling costs per unit of roundlog when small volumes are handled.

However, the cost difference is less than expected, especially if allowance is made for more selective log purchases by portable mill operators and industry contribution costs made by fixed-site mills. It was noted that often portable mills are operated at a fixed site for long periods. Portable mills appear to be able to handle a wide range of log sizes, equivalent to that of fixed site mills, though they mill fewer tree species. Considerable skill is needed to obtain high quality sawn timber using a portable sawmill.

Cabinet-makers timber sources, uses and preferences

Surveys of cabinet-makers in Cairns, Townsville and Brisbane indicate that they regard rainforest cabinet timbers highly and that they are willing to pay price premium over that paid for various pine species (Herbohn 2001b, Smorfitt *et al*. 2002b). Timber availability, suitability, customer request, and colour and grain are the most important factors in the decision of cabinet-makers to select a particular species. Price only becomes important when it cannot be passed on to the purchaser. However, there is little demand from cabinet-makers for native rainforest cabinet timbers because of the difficulty in obtaining ready supplies when required. As indicated in Table 8, the demand for rainforest timbers is highest among small to medium sized cabinet-makers in north Queensland, large cabinet makers in north Queensland, and cabinet-makers of all sizes in Brisbane, use mainly composite wood products as an input.

The survey results reject the suggestion that cabinet-makers will purchase timber directly from landholders. Rather, they require timber that is ready to use (i.e. dry and cut to standard lengths) and readily available (e.g. from a central supply point). Cabinet-makers operate on a just-in-time inventory system and keep little timber inventory. Ready timber availability (easy to locate and in a form suitable for immediate use) is a critical factor in the choice of inputs, and they are prepared to pay a premium for this convenience of supply. Currently, the supplies of rainforest cabinet timbers are fragmented, and cabinet-makers are not willing to spend the time locating supplies, preferring instead to use more readily available substitutes, including imported tropical timbers. It was observed that higher prices were paid for an imported silky oak substitute than for the local product of similar quality because of the reliable supply.

Table 8 Use of rainforest cabinet timbers and composite wood products as inputs into products

Wood input	City	Fraction of total wood inputs used (%)		
		Small firms	Medium firms	Large firms
Rainforest timbers	Cairns	26	9	2
	Townsville	32	18	6
	Brisbane	7	4	3
Composite wood products	Cairns	50	64	84
	Townsville	33	49	64
	Brisbane	59	61	70
‘Cabinet timbers’	Cairns	46	28	12
	Townsville	61	38	13
	Brisbane	27	25	14

Note: Cabinet timbers are the aggregate of ‘rainforest timbers’, ‘imported tropical timbers’ and ‘other Australian hardwoods’. Source. Herbohn et al. (2001a).

Cabinet-makers were asked to rank the rainforest species in terms of suitability to meet their future timber needs. Table 9 presents opinions of the Cairns and Brisbane cabinet-makers. Although rankings for particular species differs slightly, five species are listed in the six most popular for both areas. The one exception is hoop pine, ranked third by Brisbane cabinet-makers and only fifteenth by those in Cairns, probably due to greater availability, price competitiveness, and promotion in the Brisbane market.

Table 9 Comparison of Cairns and Brisbane cabinet-makers' top 15 species recommendations against CRRP plantings.

Species	Cairns ranking	Brisbane ranking	Fraction of Cairns respondents (%)*	Fraction of Brisbane respondents (%)*	Fraction of total CRRP plantings (%)
Queensland maple (*Flindersia brayleyana*)	1	4	83.9	60.0	7.7
Northern silky oak (*Cardwellia sublimis*)	2	5	82.1	51.4	0.5
Red cedar (*Toona ciliata*)	3	2	78.6	70.0	0.2
Qld walnut (*Endiandra palmerstonii*)	4	6	75.0	51.4	**
Tasmanian oak (*Eucalyptus spp*)	5	1	67.9	77.1	***
Northern silver ash (*Flindersia schottiana*)	6	7	60.7	47.1	1.8
Maple silkwood (*Flindersia pimenteliana)*	7	(17)	57.1	20.0	1.4
Silver ash (*Flindersia bourjotiana)*	8	8	51.8	45.7	1.4
Kauri pine (*Agathis robusta*)	9	14	51.8	28.6	6.0
Black wattle (*Acacia melanoxlon*)	10	13	53.6	27.1	2.1
Black bean (*Castanospermum australe*)	11	12	48.2	28.6	2.6
Red silkwood (*Palaquium sp.*)	12	19	51.8	17.1	**
Satin silky oak (*Macadamia sp.*)	13	11	44.6	30.0	**
Red siris (*Paraserienthes toona*)	14	(20)	55.4	17.1	2.1
Hoop pine (*Araucaria cunninghamii*)	15	3	35.7	67.1	10.3
Rose mahogany (*Dysoxylum fraserianum*)	(20)	9	28.6	48.6	**
Red mahogany (*Eucalyptus pellita*)	(21)	10	25.0	38.6	12.7
White beech (*Gmelina leichhardtii*)	(23)	15	26.8	25.7	0.3

Source: Herbohn et al. (2001b).

*Notes: *Timber was rated highly or very highly recommended; **Species either not in the planting list or less than 1000 planted; ***Multiple eucalyptus species. Comparative rankings in parenthesis if out of the top 15 recommendations.*

These results indicate that a number of rainforest and eucalyptus species, in particular Queensland maple, red cedar, northern silky oak, black walnut, Tasmanian oak and hoop pine have sound market prospects. A comparison of the species recommended by cabinet-makers and those which have been planted under the CRRP in north Queensland reveals a notable disparity.

Of the five most highly ranked species by Cairns cabinet-makers (all of which are native rainforest species), only Queensland maple was planted to any extent (7.7% of CRRP planting up to 1997). These data give strong support for the need for growers to plan species choice and silvicultural management to meet market requirements. It would appear that the small volume of available timber is not the problem so much as fragmentation of supply. It would be quite possible for a high-value industry to develop with small yet regular supplies of timber, distributed in a coordinated fashion from a central point, e.g. 10,000 m^3 per annum or even 5,000 m^3.

To facilitate such an industry, it would probably be necessary for growers to market cooperatively or at least through a central supplier. A grower cooperative could coordinate log sales and perhaps provide other services such as provision of market information and product promotion. The North Queensland Timber Co-operative (NQTC) has been formed to undertake this role, but has yet to achieve significant success. Problems faced include the difficulty in recruiting a sufficiently large membership, providing the incentive for growers to sell through the cooperative rather than individually, and accumulating operating funds to provide services to members. Examples exist of successful grower cooperatives in southern states, but these are found where a much larger and more profitable forestry industry already exists.

Consumer purchase attitudes to products made from rainforest cabinet timbers

Three consumer surveys were conducted in Townsville and one in Cairns to examine purchase behaviour and attitudes towards products made from Australian rainforest cabinet timbers (ARFCTs).

Table 10 indicates the history of purchases of products made from ARFCTs, for the four groups and in aggregate. It should be noted that there is some potential for bias (in knowledge and purchasing preferences) in the Cairns WoodExpo survey toward ARFCT from the respondents interviewed at the shopping centers. Thus Table 10 does report the Cairns WoodExpo results separate from and together with the Townsville surveys. Overall, close to one third had purchased items in the past year although there was a difference between Townsville (21%) and Cairns (45%) which may be due to the purchases made at the WoodExpo. Overall over half had made purchases in the past five years, with the Townsville group (26%) having made a greater proportion of purchases than the Cairns group (18%) in the 1 to 5 year category. The purchase rate was highest for the Cairns WoodExpo group, followed by the telephone group. It should also be noted that caution should be used in attempting to generalize these findings to other areas.

Table 10 Analysis of last purchase of Australian Rainforest Cabinet Timbers (ARFCTs) product.

	Last purchase of ARFCTs (expressed as a % of respondents)					
Population Group	<1 year	1-5 years	6-10 years	>10 years	Never	n
K-mart shopping centre	18	37	10	10	25	60
Willows shopping centre	18	16	13	4	49	45
Telephone survey	26	22	10	12	30	50
Townsville Combined	21	26	11	9	34	155
Cairns WoodExpo	45	18	3	6	28	94
All Combined	30	23	8	8	31	249

Source: Smorfitt et al. (2001).

As indicated in Table 11, more than 85% of all respondents felt that ARCTs are ‘slightly superior’ or ‘vastly superior’. The lower proportion of Willows respondents (78%) who rated ARCTs as vastly superior may be accounted for by the greater proportion of respondents (44%) who fell into the less than 25 years age group, reduced availability of these products in recent years, and perhaps the slightly lower education levels in this survey group. No significant differences were found between the sexes in their rating of the relative timber value of ARCTs and composite wood products. In contrast, respondents appeared to have difficulty in rating ARCTs against eucalypt species, e.g. 40% of the combined Townsville groups felt they were unable to make a judgement.

Table 11 Rating of ARCTs against Composite wood products (%)

Population Group	Vastly inferior	Slightly inferior	Comparable	Slightly superior	Vastly superior	Don't know	Sample size
K-mart	0	0	0	5	91	5	64
Willows	0	2	4	7	78	9	45
Telephone survey	0	0	2	6	88	4	50
Townsville combined	0	1	2	6	85	6	159
Cairns WoodExpo	0	0	1	1	97	1	95
All combined	0	0	2	3	91	3	254

Source: Smorfitt et al. (2001).

Townsville respondents who were interested in buying ARCT products but had not done so in the past five years were asked to indicate their level of agreement with a number of statements concerning reasons for not making a purchase (Table 12). ‘Value for money’, ‘poor quality’, ‘preference for other products’ and ‘destruction of rainforest’ did not appear to be of major concern. Approximately 40% regarded these products as ‘too expensive’, while 50% were undecided about whether these timbers were still available.

Table 12 Level of agreement with reasons for not purchasing ARCT products, for respondents who indicated an interest in purchasing ARCTs but have not done so during the past five years, Townsville combined sample (n=49).

Statement	Level of agreement (% of respondents)				
	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
Too expensive	4	24	35	29	8
Low value for money	14	55	18	10	2
Substitutes better quality	16	63	16	4	0
Prefer other materials	8	59	22	8	2
Destruction of rainforest	0	35	20	24	20
Timbers not available	6	22	51	20	0

Source: Smorfitt et al. (2001).

Marketing and export of farm-grown timber

Creating a favourable economic climate for farm forestry is likely to be more effective than subsidies to tree growers. Emtage *et al*. (2001) found that while most landholders agreed with the proposition that governments should do more to support farm forestry, they were most interested in the government establishing a supportive economic and legal framework in which forestry development decisions can be confidently made. It appears that the level of adoption of farm forestry in Australia will depend to a large extent upon landholders being able to feel secure in investing in such a long-term activity, and having the resources to do so. In particular, the regulatory environment and markets for timber need to be stable and transparent.

Tropical timber products from regional centres such as north Queensland face severe domestic transport cost constraints (Cox and Quayle 2001). There is a need for high-value products to justify transport costs from north Queensland to markets in major population centres. It is necessary to produce value-added products such as plywood, veneer, laminated board, finger-jointed mouldings, specific rare timber logs or furniture products. In other words, small-scale forest producers have to consider the importance of growing, managing and processing timber into more valuable products to outweigh this impediment, most likely involving cooperative marketing arrangements.

Cox and Quayle (2001) pointed out that Australia might be able to exploit its advantage of proximity to available markets in Asian countries. It would of course be difficult for north Australian producers to compete with the labour or raw material costs of small-scale furniture producers in these countries. It is worth noting that signatories to the 1994 GATT Uruguay round have agreed to eliminate tariffs on furniture products completely in the next decade. This means major importers of furniture products such as Japan, the USA and members of the European Union have agree to open their markets to these products.

Australian hardwood timbers have some unique features as well as being managed for sustainable yields, which may help gain entry to these markets, especially if the timber be certified under an internationally acceptable standard.

Timber produced by small-scale operators faces considerable disadvantage in terms of access to export markets (Cox 2002), and high freight and handling costs at wharves, port charges and an adverse international shipping freight cycle (Cox and Quayle 2001). Australian government support for the domestic industry has not been as generous as that of some of our near competitors; for instance, investment tax allowances, tax holidays while businesses are established, export market development support and training are provided to Malaysian firms.

Lack of experience of Australian producers in export markets is an impediment to international competitiveness. Thus, the small-scale forestry sector could benefit from emulating the marketing approaches pursued by industrial timber processors. The hoop pine processors of Queensland (Araucaria Australia Ltd) provide an example of how to overcome this lack of experience: 'The araucaria industry processors created a business entity to act as a focus for their group and sought funding from government and industry to develop a united export marketing approach. Many of the processors were inexperienced in export marketing so a series of seminars were held and a trade tour of potential markets in China and Japan was conducted to give the industry members greater knowledge and exposure in these areas' (Cox and Quayle 2001, p. 111).

Timber industry facilitation

Support measures for forest industry development in north Queensland

Some recent research has focused on the requirements to facilitate redevelopment of a vibrant timber industry in north Queensland e.g. Harrison and Herbohn (2002), Killin and Brazenor (2003). Various measures may be adopted by governments to assist in overcoming impediments to small-scale forestry and thus make the enterprise more attractive to individual landowners.[2] Government intervention normally involves a combination or package of these measures. Governments are themselves major plantation owners and competitors with private growers, which in Queensland is probably a deterrent to private sector forestry investment. As a price leader, state government can have a considerable influence over stumpage prices. Also, governments are in a position to remove some of the major impediments to farm forestry, such as the sovereign risk that harvesting will not be allowed.

As well as such forms of assistance, there is a need for various forms of infrastructure support for farm forestry in north Queensland. Private Forestry North Queensland (a regional plantation committee or industry cluster) and the North Queensland Timber Co-operative have the potential to

[2] Possible options may include private sector incentives, promotion of forest practice through extension and training, taxation provisions, remissions of land tax, removal of legal impediments, support for timber exporting, joint venture agreements, introduction of carbon trading, funding of forestry research and quarantine and disease control.

provide some assistance in this regard, but require more resources to make an effective contribution. The CRRP and the DPI-Forestry plantation Joint Venture Scheme were major forestry facilitation measures, but both had short funding lives in north Queensland, as did forestry extension, raising questions about government commitment to farm forestry in the region. Revitalised extension services for growers, further support for development of the grower cooperative, facilitation of external finance, further government plantings on former farmland (including former sugarcane land) and a range of other support measures are possible.

Sources of private finance for farm forestry

Lack of capital and the long payback period are impediments to farm forestry, so access to venture capital could potentially finance a large increase in area planted (Sharp 2002, Sharp *et al*. 2004). It is apparent however that relatively high returns are required by capital providers to invest in forestry (about 12% internal rate of return), which suggests that this form of facilitation will only occur at specific and favoured sites, such as areas of rainfall at least over 1000mm and with reasonably fertile soils.

Future research directions

Socio-economic research in relation to non-industrial forestry is continuing in north Queensland, but the focus has changed somewhat from the farm setting to regional industry development and forestry impacts. Low prices for dairy products and sugar, and the demise of the tobacco and tea tree oil industries, created a need for alternative farm enterprises. Research opportunities exist in relation to the impact of forestry on regional economic activity, employment and social infrastructure in depressed rural areas on the Atherton Tableland. A further research area concerns support measures to promote forest industry development. Projects in these areas could draw considerably on the lessons learnt from research relating to the CRRP.

Another important research area is that of converting ecosystem services from forests into tradable products. Forest ecosystem services for which market mechanisms to reward growers appear promising include carbon sequestration, salinity mitigation, and protection of water quality (Pagiola *et al*. 2002). As well, there is a possibility of developing payments for landscape amenity and recreation value, as has occurred in Europe for at least a decade (e.g. Hummel 1991). An analysis of the estimation and monitoring requirements for trading carbon sequestration credits from forestry was undertaken by Lamb (2001). This indicated that transaction costs could be high, such that trading may not be viable for small plantation areas.

Concluding comments

In terms of economic and social aspects, farm or non-industrial forestry in north Queensland has been heavily researched, and the CRRP has been the focus of much of this research. A large amount of information has come out of this program, from a variety of research projects, with insights into forestry opportunities, impediments and facilitation measures. In a sense, financial modelling has been a forestry facilitation measure, in that greater information can be provided on the likely financial performance of farm forestry at various sites. The range of socio-economic projects reported here perhaps represents the most in-depth research into non-industrial forestry in the tropics conducted anywhere in the world.

There would appear to be an adequate supply of land suitable and available for forestry, and a wide variety of fast growing, high-quality rainforest and eucalypt species exist. Some individuals are highly enthusiastic about forestry, and have established impressive stands. Forestry as an enterprise has potential to complement landscape amenity and nature-based tourism in the region. However, various impediments exist to re-establishing a vibrant timber industry. A culture of farm forestry is lacking, forestry extension services are weak, and there is concern over harvest rights. North

Queensland is distant from major population centres and timber markets, and stumpage prices are relatively low. It remains to be seen whether further efforts by various individuals and groups to promote forestry in the region, in a time of depressed conditions for alternative landuses, will lead to forest industry expansion.

Acknowledgements

We wish to acknowledge research support from the Rainforest CRC, the Joint Venture Agroforestry Program, Australian Centre for International Agricultural Research, and the North Queensland Joint Afforestation Board for the research reported here. Also, the cooperation of various landholders, cabinet makers and others in providing survey information is gratefully acknowledged.

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VI

Concluding Remarks

16. Reforestation with rainforest trees: Challenges ahead

Peter D. Erskine, David Lamb and Mila Bristow

Introduction

Since the cessation of rainforest logging in tropical and subtropical Australia there have been a number of published works on different aspects of growing native rainforest timbers, yet much of the relevant research has remained undocumented.

The recent completion of the Community Rainforest Reforestation Program (CRRP) in north Queensland and other programs promoting farm forestry in the subtropics, as well as the restructuring of Queensland government departments of Primary Industries and Natural Resources, has meant that many of the people who conducted research in this field have recently changed jobs or research focus. This book was an attempt to capture the ecological and silvicultural knowledge we have gained over this period of time before it was lost.

In this concluding chapter we reflect on what might make future reforestation with rainforest trees successful and the critical research areas that still need to be addressed. To facilitate this task we pose a number of questions over which researchers and practitioners have pondered in recent years.

What do we now know about reforestation with rainforest species that we did not know before?

The changes in knowledge are summarised in Table 1 and this suggests we have made some advances.

For example, we now have a better understanding of the site preferences of a variety of tree species. Some seem very tolerant of a range of conditions and the good growth of *Elaeocarpus grandis, Flindersia brayleyana, Flindersia schottiana* and *Grevillea robusta* demonstrates that certain rainforest species can grow successfully in a range of soil and climatic conditions and in open pasture sites in both the tropics and subtropics.

On the other hand, other species (eg. *Melia azedarach* and *Castanospermum australe*) are dependant on specific site factors. Eucalypts were also used in the CRRP plantings and some species had both good growth and form in a range of sites. All the comparatively fast growing species could be considered as "best bet" choices for farm forestry plantings in specific areas (see Bristow *et al.* Chapter 6 for climatic/edaphic trends).

Fertilizer applications and silvicultural prescriptions for all the faster growing species can probably be devised from the general principles that have now been established. However, there has been a lack of progress on the potential pests, diseases, timber quality or provenance versus site interactions for most rainforest timber trees.

Table 1 A summary of the ecological and silvicultural knowledge concerning reforestation using rainforest tree species, at the time of cessation of logging and listing of the Wet Tropics on the World Heritage register in 1988, and at present.

Topic	1988	Now
Identity of potential timber plantation species	Commercially attractive species identified on basis of earlier logging operations; some limited knowledge of growth rates of some species when grown in plantations.	More detailed knowledge of growth rates of many species at a wider range of sites and field conditions.
Seed sources for these species	Species distribution patterns known. Less knowledge of fruiting phenology. No knowledge of provenance differences.	Still only limited knowledge of seeding phenology; no studies of provenance differences among species.
Nursery techniques to raise these species	Only limited experience of seed storage requirements and methods needed to raise seedlings of most species.	More knowledge of seed storage requirements and methods for raising seedlings.
Vegetative propagation methods for these species	Limited knowledge.	Some knowledge.
Nutrition of rainforest tree species grown in plantations	Limited knowledge.	Broader understanding of nutrients most likely to be limiting for a variety of species.
Growth rates	Some knowledge.	More knowledge (but only of early growth stages).
Wood quality of rainforest tree species grown in plantation	Limited knowledge.	Some knowledge about a few species
Species-site matching	Limited knowledge of a few species only.	Some knowledge of several key species.
Insects and diseases affecting rainforest tree species being grown in plantations	Limited knowledge.	Still only limited knowledge.
Designing mixed species plantations for timber production and biodiversity	No knowledge, some theories.	Some knowledge; design principles now being developed.
Stand management – pruning to optimise timber quality	Basic principles only.	Basic principles only.
Stand management – thinning to maximise growth.	Limited knowledge.	Principles established.
Developing reforestation methods for ecological restoration.	No knowledge, some undeveloped theories.	Some knowledge though techniques are still very expensive.

How large is the newly established rainforest plantation timber resource?

Wood *et al.* (2001) calculate that there is around 4200 ha of mixed species plantations (a surrogate measure of rainforest plantings) in the tropics and subtropics but there is little knowledge about the condition of this resource. Although tree performance measures exist for subtropical sites (Lott *et al*. Chapter 3, Glencross and Nichols Chapter 7), the only large dataset for rainforest timber plantings comes from the CRRP. There are records of how many seedlings (Table 2) and what species were planted but there has been little monitoring of species or stand survival. It has been suggested that seedling survival increased over the life of the CRRP as practitioners became more skilled (G. Sexton pers. comm.). One estimate is that the overall survival rate of seedlings in these stands was 85% (QDNR 1998). On the other hand, the smaller and more specialized dataset used in Bristow *et al.* (Chapter 6) found that the average survival of trees in growth plots at age eight years was 61% (Figure 1) and this rate did not change significantly between establishment years ($F(4,96) = 1.0026$, $p = 0.4102$). This dataset only included plantations that had received reasonable levels of maintenance so this undoubtedly overestimates the average tree survival in CRRP plantations by this age. These overall averages mask differences in the survival rates of individual species because data collection began when plantation stands were several years old and certain species may have already died out. Observations suggest there are large between-species differences.

Table 2 Number of seedlings planted per year by the CRRP (D. Skelton and G. Sexton pers. comm.).

Year	Number of seedlings
1992/93	121,421
1993/94	292,109
1994/95	358,561
1995/96	209,175
1996/97	130,544
1997/98	67,847
Total	1,179,657

These variations in seedling survival rates are matched by large differences in planting densities and individual growth rates. No systematic sampling has yet been carried out to assess species and size class data, meaning it is difficult to estimate the extent of the new resource.

Did the CRRP prompt new plantings of rainforest species?

One of the explicit aims of the CRRP was to facilitate the creation of a new timber resource based on plantations of high-value rainforest tree species (Shea 1992). To date it seems this objective has not been realised. Some 1780 ha of mixed species tree plantation were established but, subsequent to the financial support offered by the CRRP, relatively few landowners have since embarked on a vigorous, commercially oriented planting program. Some of the possible reasons for this were discussed in Herbohn *et al.* Chapter 14. The most recent figures for tropical and subtropical farm forestry mixed species plantations indicate that only 240 hectares per annum have been established between 1995 and 2000 (Wood *et al*. 2001). Large numbers of small ecological restoration plantings have been established for "conservation" purposes but the overall areas of these are small. With several notable exceptions, the conservation benefits of these have probably been modest.

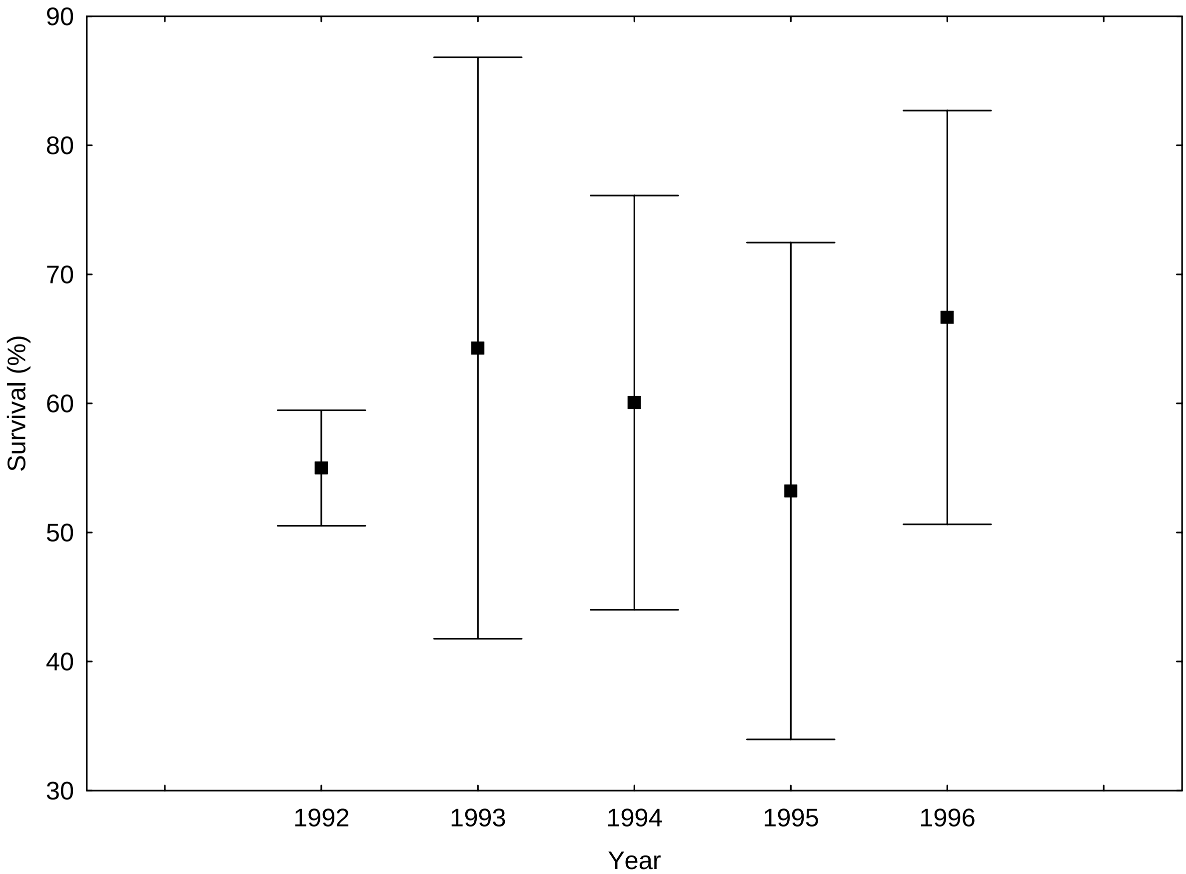

Figure 1 Mean survival (±1 SD) of trees planted in different years of the CRRP.

A striking comparison can be made with reforestation activities in other parts of Australia over this time. Since the launch of the Plantations 2020 Vision in 1997, more than half a million hectares of new plantations have been established in Australia at an average planting rate of around 70,000 hectares per annum (Wood *et al*. 2001). The majority of these plantings are hardwood eucalypt plantations grown for paper pulp (some for salinity mitigation) and established with private capital via managed investment scheme plantation projects. Many of these plantations have been established on private farmland by listed companies because of the relatively short term investment needed and a conducive governmental regulatory environment. The species used in the rapidly expanding private plantation estate have generally been limited to eucalypt species (particularly *Eucalyptus globulus*) which have rotation lengths less than ten years.

Plantations of rainforest species must differ from such operations. Rainforest species have minimum rotation lengths of between 15 and 60 years, depending upon the species, and are traditionally used as feature-grade, sawn timber which supplies high value cabinet wood markets. These longer rotation times may be compensated for if the timber values are higher but recent price trends are towards lower prices in the absence of sufficient new timber to sustain the market (see Harrison *et al*. Chapter 14). Although the expansion of short rotation tree plantations is continuing at a rapid rate, the prospects for longer rotation species appear problematic because even the longer term investors, such as superannuation fund managers, are unlikely to invest in products that do not produce returns in less than ten years and for which future markets are uncertain. Additionally, questions about resource security, lack of extension advice for growers, and the inconsistencies between policies at different levels of government, continue to obstruct the planting of rainforest timber species on private lands.

The integration of improved seedling stocks, financial models, farmer payments, pest and disease management and careful site selection by companies planting short-rotation hardwoods has provided a sound basis for successful plantation forestry industry in temperate Australia, and has successfully attracted investors. Knowledge of many critical factors in establishing rainforest timbers is lacking and must be improved if rainforest plantations are to emulate the recent success of short-rotation eucalypt plantations. The obvious risks with long rotation trees means that Government intervention, investors with long term vision, or novel forestry financing systems will be needed to provide the means to solve these research problems.

How to make the choice between rainforest mixtures and 'sure bet' monocultures of *Araucaria* or easier-to-grow eucalypts?

One of the striking features of the reforestation programs in the tropics and subtropics was that the vast majority (>80%) of farm forestry plantations were mixed species plantings (Wood *et al*. 2001). This preference seems to have continued and appears to be primarily because mixtures are thought to be capable of providing a wider variety of ecosystem services than monocultures, and perhaps because they appear more natural looking (O'Hara 2001). Additionally, the CRRP in north Queensland encouraged the planting of mixtures as a trade-off between their objectives of timber production, watershed protection and creating wildlife habitat. At the commencement of the CRRP the design of most of these mixtures was essentially *ad hoc* or based on relatively untested theories and methods. For this reason a significant part of the early research effort went into trying to devise some guidelines to improve these plantation designs (see Lamb *et al*. Chapter 9).

In the meantime, various practitioners, especially in the subtropics, developed their own refinements. One example was the so-called Mitchell Low Maintenance Method (Mitchell 1998) which has been used to plant mixtures of timber species in southeast Queensland. This was explicitly used to create permanent forests which could be selectively harvested. This method involved planting 'height promoter trees' (fast growing species such as *Elaeocarpus grandis*) close to slower-growing species at a stocking rate of 2000 stems per hectare. The general rationale was that the 'height promoter trees' would restrict lateral branching in the shaded slower-growing species, resulting in greater bole lengths that would be suitable for cabinet timber production. The method used extensive mulching and herbicides to completely eliminate all weed competition during the early establishment years. Although this method did produce some high growth rates for the fast-growing species at suitable sites (Mitchell 1998), the long term management of this type of planting is problematic because it is difficult to cost-effectively prune and harvest the height promoter trees without damaging slower-growing species. Further, on steeper sites planted using this method gulley erosion has been observed, probably because of the lack of any understorey vegetation. Considering that research into native tropical and subtropical timbers has generally been limited this method has, nevertheless, been successful in encouraging small-holders with a diversity of objectives to plant rainforest timber plantations.

The widespread and continued use of mixtures by landholders in the wetter regions of the topics and subtropics also suggests that most growers like some conservation benefits from plantations. But the weight they give to habitat creation or timber production varies. "Best bet" species including the widely planted *Araucaria* and eucalypts, should be used if growers require low risk production outcomes and need some confidence that there is likely to be a market for the timber. Other growers may be prepared to grow species which have higher levels of risk (*ie.* longer rotation times and an undeveloped market) but provide more conservation gains. Several options are outlined below for forest growers who have these different objectives.

Option A – grower largely interested in production

- Use *Araucaria, Elaeocarpus grandis, Flindersia brayleyana* or eucalypts such as *Eucalyptus pellita, E. resinifera, E. cloeziana* and hybrids.
- Plant only as monocultures.

Option B – grower interested in some production but also some rainforest habitat gains

- Use species such as *Araucaria, Acacia* spp*., Elaeocarpus grandis, Flindersia brayleyana, F. schottiana* or *Grevillea robusta.*
- Use monocultures or mixtures (pair-wise or intimate) with species of similar growth rates.
- Include some trees which will bear fruit such as *Ficus* to provide food sources for rainforest fauna.

Option C – grower largely interested in rainforest habitat gains

- Use as many species as possible and sourced from local provenance (maximum diversity method - Goosem and Tucker 1995)
- Alternatively, plant a cover crop of a fast growing pioneer species such as *Acacia* spp. (framework species method - Goosem and Tucker 1995) and underplant with fruit-bearing later successional species.
- Plant at close spacings to ensure rapid canopy closure.
- Reduce costs by attempting direct seeding of rainforest species.

Obviously, any of these options could be combined across a landholder's property depending upon their objectives and the landscape attributes (*ie.* combine Option C near riparian areas for maximising biodiversity gains and Option A on degraded sites for production gains). Additionally – as this list of options is based on our present knowledge of reforestation – future research work to establish and test a greater range of plantation designs could provide a wider variety of options to growers.

What is the role of reforestation in the landscapes of the humid tropics and subtropics of Australia?

Landscape reforestation can increase the income potential of landowners across a region by integrating the extraction of forest products with more traditional forms of agriculture. Another important role of reforestation in the wetter areas of the tropics and subtropics is to create habitat for rainforest flora and fauna. If designed and managed correctly, rainforest timber plantations can create corridors or stepping stones for rainforest fauna across a landscape (see Catterall *et al.* Chapter 13). However, when plantations are established at low stocking rates and with few fleshy fruited species, such as by the CRRP, there is little evidence that they perform this function well (see Kanowski *et al.* Chapter 12 and Wardell Johnson *et al.* Chapter 11). Currently, it appears that when the CRRP attempted trade-offs between biodiversity and production in plantations they may not have done very well at either. However, over time the habitat complexity of these plantations should increase (as these plantations appear rarely managed for production goals) and thus become more important to rainforest species particularly by increasing forest landscape connectivity. For future plantations, intentional design for plantation composition, layout and location is recommended to address specific goals.

The new regional natural resource management (NRM) bodies (Qld), or catchment management authorities (in NSW), are charged with developing regional plans that specify catchment-wide activities to address a range of issues including land and water management, biodiversity and agricultural practices. Such plans are crucial if we are to resolve jursidictional inconsistencies, for example some Local Government Areas in northern Queensland explicitly discourage riverine reforestation (because it purportedly slows the rate at which flood waters are able to escape) while others encourage it (to protect river banks from erosion).

These regional plans are landscape strategies to assist with the delivery of national funding to achieve natural resource management targets, and there was some hope that they would include incentives for farm forestry. The recently completed draft NRM plan for the Wet Tropics (FNQ NRM & Rainforest CRC 2004) has a variety of priority programs, one of which is the protection and enhancement of remaining natural vegetation. The investment strategy for this NRM plan has not been completed at the time of going to press, but it is likely that most of the investment for this priority program area will be to protect natural vegetation "as it can take many decades (and many more resources) to enhance and reinstate vegetation" (FNQ NRM & Rainforest CRC 2004). Entering into agreements and funding landholders to protect biologically important habitats may be a cost effective way to protect these areas but more value could be added with integrated farm forestry measures. The regional NRM plans have the opportunity to enhance vegetation effectively, but are constrained by lack of regional experience in this. That is, most of the research undertaken into reforestation has been site-based, planning reforestation to achieve larger functional goals (eg. watershed protection) has not been resolved, and methods and costs for riparian reforestation have been dependant upon the local shires that have conducted it. It is hoped that some of the Wet Tropics investment plan directs money towards researching a variety of reforestation options to provide appropriate biological and social outcomes in the region. Some of these objectives could be provided by integrated farm forestry.

Conclusion - where to from here?

Reforestation with rainforest species will always be confined to small areas of Australia because of the limited availability of suitable sites. Until recently most of the best land at these high rainfall sites was being used by crops such as sugar, tobacco or industries such as dairying. Under these circumstances plantations or plantings of rainforest trees have been confined to cleared but un-used land such as on steeper slopes. But, at the time of writing, many of these traditional tropical industries are in decline or in trouble because of low international prices (e.g. sugar) or industry restructuring (e.g. dairying). These industries have sustained the economies of these regions for the last 100 years and now cover large areas, especially in northern Queensland. At this stage it is not clear what will replace them or maintain the communities they supported. At the same time, there is increasing concern over the effect of agricultural practices on the Great Barrier Reef. Erosion and nutrient run-off both seem to impact on the biota and health of the reef system, which is already stressed by climate change and increased water temperatures.

So, notwithstanding the rather modest increases in reforestation by landowners since the CRRP began to close down, perhaps some form of horticulture and timber tree growing might prove to be part of the solution to these several problems? Also, deforestation continues unabated in the tropical forests of the Asia-Pacific region, which suggests that a market niche for high quality species could easily develop within less time than the length of one plantation rotation. If so, the region needs a research effort comparable with that which gave rise to the sugar industry in the tropics and the pine industry in temperate Australia, to develop a successful farm-based rainforest timber plantation industry successful.

However, these potential opportunities are matched by some significant risks. One is that most of the key scientific organisations that initiated, managed or researched reforestation with high value tree species in northern Australia have ceased to exist or have been so transformed that they are unable to maintain the databases and scientific knowledge accumulated over the last decade. This lack of an institutional framework can pose major dilemmas for any research or development program that requires several decades to complete.

In one case these institutional changes almost led to a loss of the complete CRRP database. This occurred when a public servant in the government department previously responsible for the CRRP erased a computer hard disk containing all the records because they thought the program was finished. Fortunately a back-up copy was held on a personal laptop computer. Similarly, TREECARE records from DPI Forestry nurseries in south east Queensland were held on a database incompatible with the Windows computer operating system and hardcopy records have now been discarded

(M. Baxter pers. comm.). Another example comes from the Northern Territory where species provenance trials with *Khaya senegalensis* established over three years in the 1970s were handed to local government when the CSIRO research station was closed. Although the trial was on government-owned land it was partially harvested because it was not maintained, and subsequently appeared under threat from private development. With the recent interest in farm forestry, researchers were able to take cuttings from the trials and relocate the genetic material: A clonal seed orchard and clonal conservation orchard were established in Northern Territory in 2000 and 2001 (Reilly et al. In press), where this species is thought to have considerable potential in drier tropical areas. A subset of the material has also been planted in north Queensland (Beau Robertson pers. comm.). In the above examples, the absence of any long-term institutional framework almost led to a costly loss of knowledge.

Rainforest silviculture is more difficult than the silviculture of temperate region trees because of the diversity of tree species and the more complex biological ecosystems in which these grow. The last 10-15 years in tropical and subtropical Australia have seen a flourishing of experimentation. This has bequeathed us with a rich source of case studies. Some of this has been formally designed scientific trials but there has also been a much larger number of test plantings and trials by private landowners. These plantings include those established for strictly biodiversity purposes as well as those planted for biodiversity and production. If rainforest reforestation is to play any role in the conservation of tropical landscapes in Australia the most crucial next step is to continue learning from this huge array of trials and test plantings. Many of the answers to our most important questions will only emerge when the plantings become a little older. For example, what contribution can different types of planted forest make to regional biodiversity conservation? How does the location of these new forests affect their role in protecting watersheds or biodiversity? What functional groups of species form stable mixtures or communities and what species do not? What are the more important insect pests and diseases likely to affect these trees? The summary in Table 1 of what we have learned and what still remains to be learned, shows just how little progress we have really made. It is our hope that by summarizing what we have learned to date, this book will at least partially overcome the risks imposed by the lack of a long-term institutional framework for research in rainforest reforestation. We also hope it will provide a springboard for much future work.

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Index

This index focusses on the tree species grown, the programs and regions which have supported farm forestry, and some general topics relevant to reforestation in the tropics and subtropics of Queensland and northern New South Wales. The reader may also wish to consult the references listed at the end of each chapter, which give further information on a range of subject areas. These references include a range of publications by the Rainforest Cooperative Research Centre, the Joint Venture Agroforestry Program (reports published by Rural Industries Research and Development Corporation), Australian Centre for International Agricultural Research, and DPI&F (previously Queensland Forestry Research Institute and Qld Department of Forestry), who have supported much of the research presented in this book.

Joint Venture Agroforestry Program

RIRDC Publication No 05/087   Project No WS023-20

Reforestation in the Tropics and Subtropics of Australia Using Rainforest Tree Species

This peer-reviewed book reviews research and experience in reforestation with rainforest and tropical species in eastern Australia.

It covers some of the history of rainforest reforestation and planting schemes, and the methods used to propagate and establish rainforest tree species. It presents growth rates for a wide variety of species planted in different regions, knowledge about the pests and diseases found in rainforest plantations, and discusses the management challenges of mixed species stands.

The book offers future directions for rainforest plantation research and insights into how our Australian experience can be applied more widely throughout the altered rainforest landscapes of the tropical world.

Agroforestry and Farm Forestry

The Joint Venture Agroforestry Program (JVAP) is funded by the Rural Industries R&D Corporation, Land & Water Australia, Forest and Wood Products R&D Corporation, and the Murray-Darling Basin Commission, with support from the Natural Heritage Trust, the Grains R&D Corporation and the Australian Greenhouse Office.

The Joint Venture Agroforestry Program works to develop practical agroforestry systems and strategies for the combined purposes of commercial production of tree products, increased agricultural productivity, and sustainable natural resource management within the agricultural environment. The JVAP is helping to provide the knowledge base that landholders need to invest with confidence in agroforestry. The program is managed by the Rural Industries R&D Corporation.

research our website at: **www.rirdc.gov.au**

RIRDC

PO Box 4776
Kingston ACT 2604

Tel: 02 6272 4819
Fax: 02 6272 5877

Email: rirdc@rirdc.gov.au
Web: www.rirdc.gov.au