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Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

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Land & Water Australia

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Rainforest CRC

Reforestation in the Tropics and Subtropics of Australia

Using Rainforest Tree Species

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

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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

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

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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

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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.

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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.

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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

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

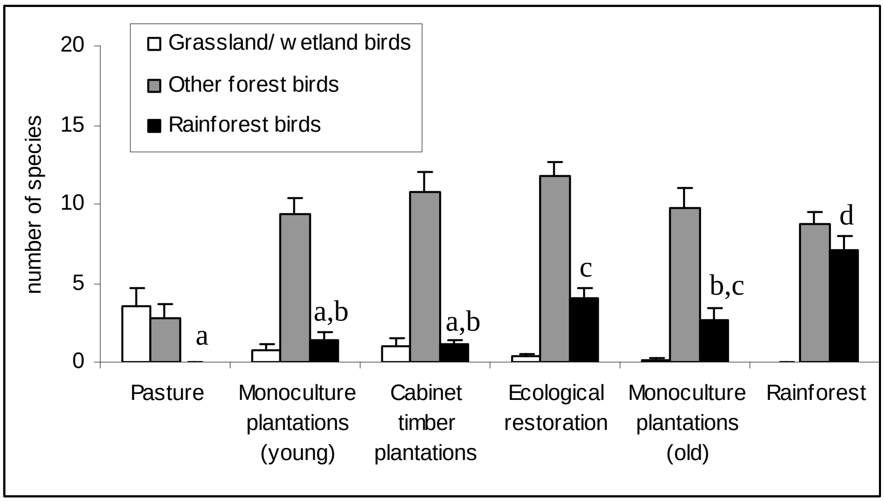
Birds, lizard and mite richness in timber plantations and rainforest plantings

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)

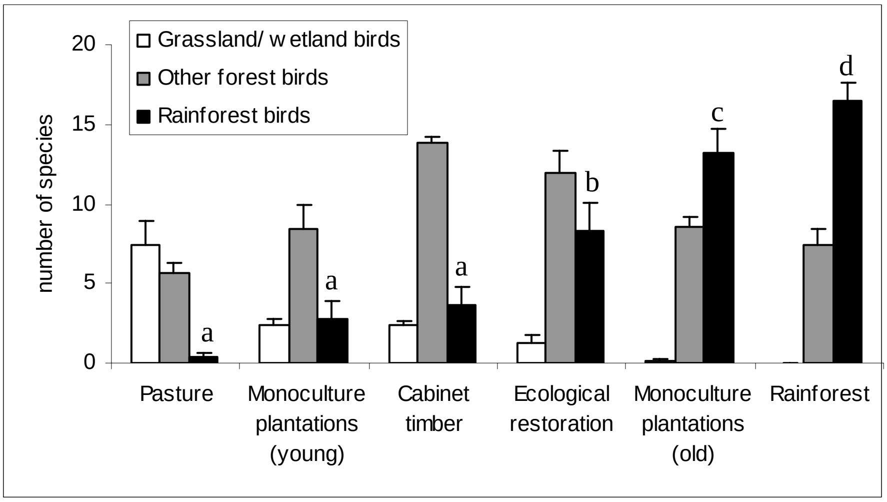


Figure 1 Bird species richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. ‘Rainforest’ birds = species largely confined to, or apparently dependent on, rainforest; ‘other forest’ birds = species found regularly across a variety of forested habitats, 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)

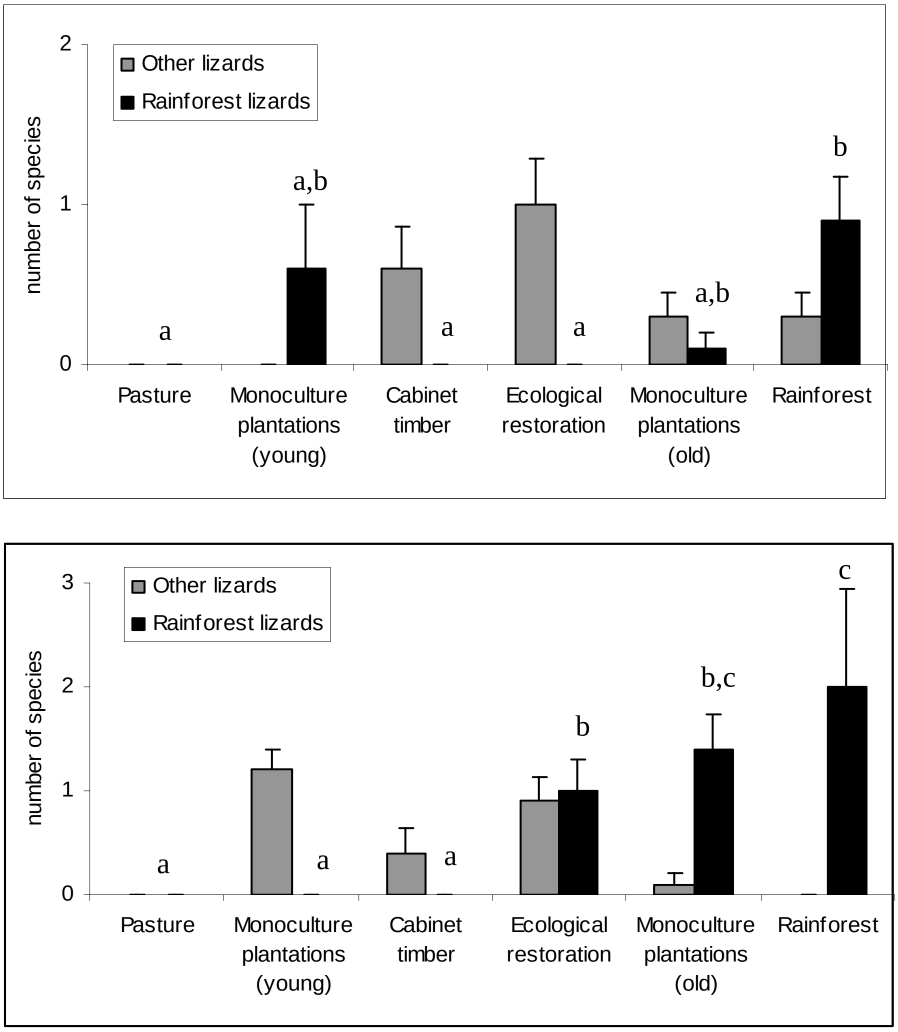


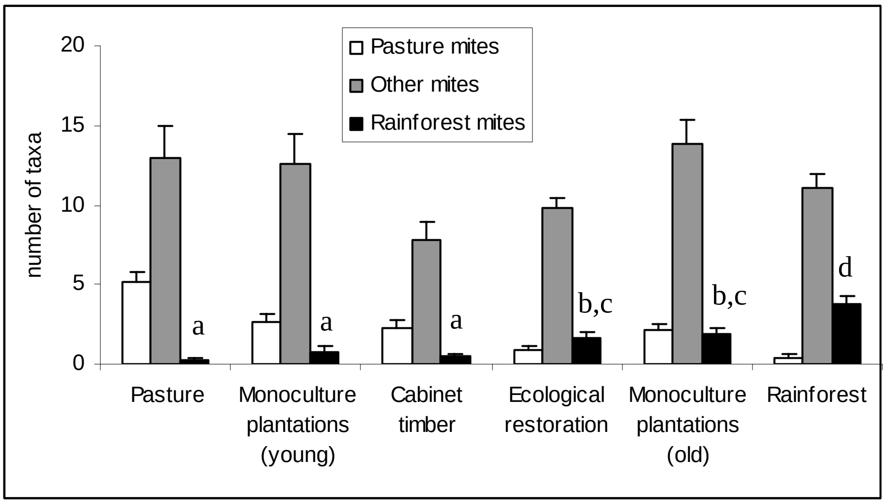
Figure 2 Lizard species richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. 'Rainforest' lizards = species largely confined to, or apparently dependent on, rainforest; 'other lizards' = species found regularly across a variety of habitats. Treatments 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

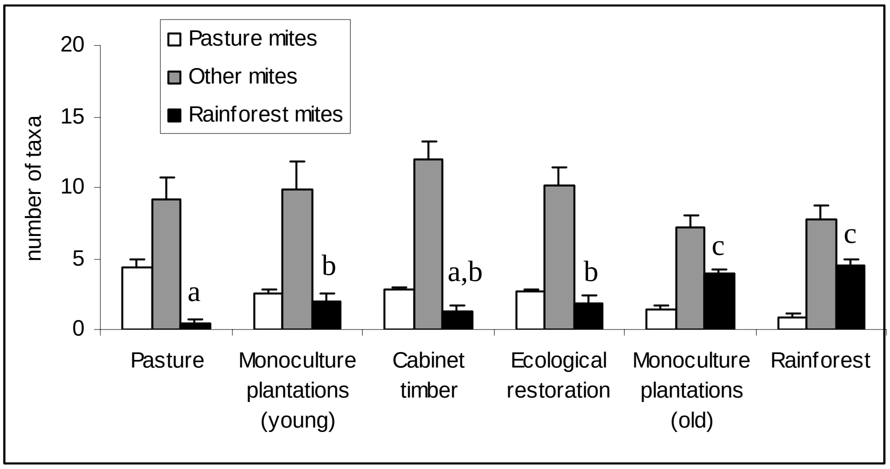


Figure 3 Mite taxon richness (mean, s.e.) in rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. Mite families were categorised by habitat associations according to their frequency of occurrence in pasture and forest sites (see text). Treatments with the same letters are not significantly different in rainforest mite richness.

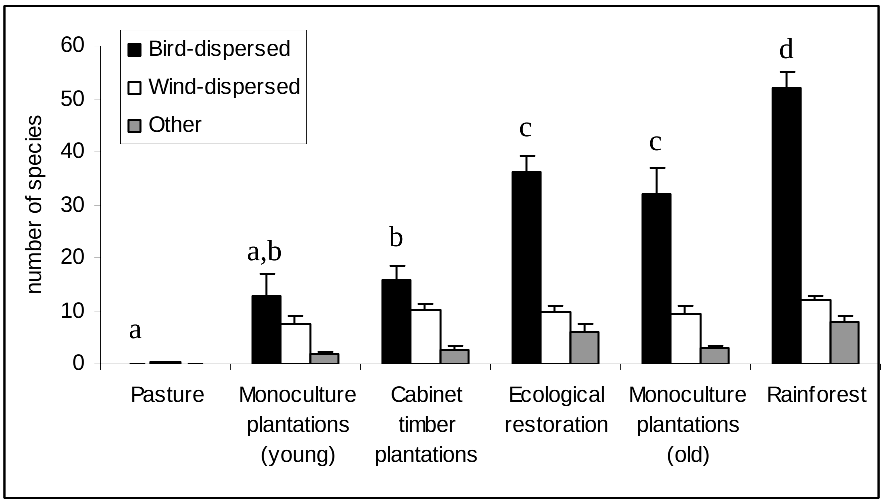
Habitat attributes of timber plantations and rainforest plantings

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

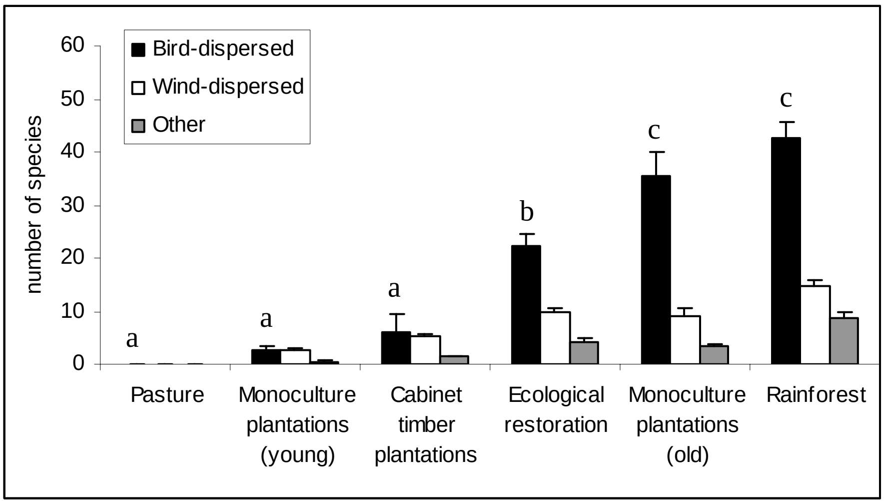
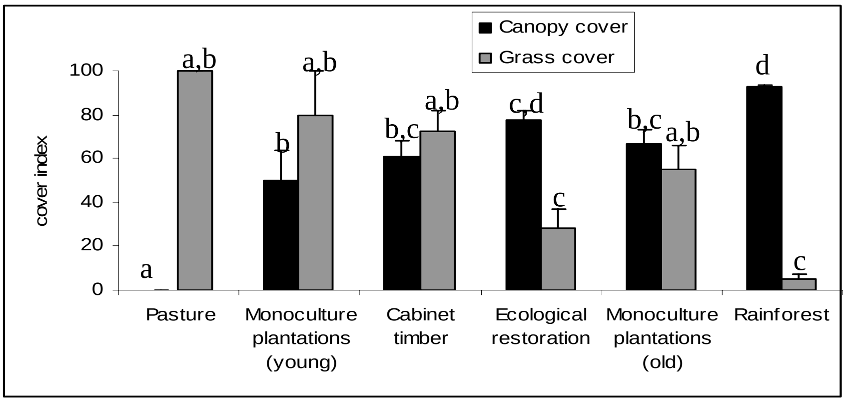


Figure 4 Plant species richness (mean, s.e.) in the canopy and midstorey of rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. Plants were categorised by the dispersal mode of the seed (bird dispersed = fleshy fruited drupe, berry or arilate seed; wind dispersed = winged or plumed seed). Treatments with the same letters are not significantly different in the richness of bird-dispersed plants.

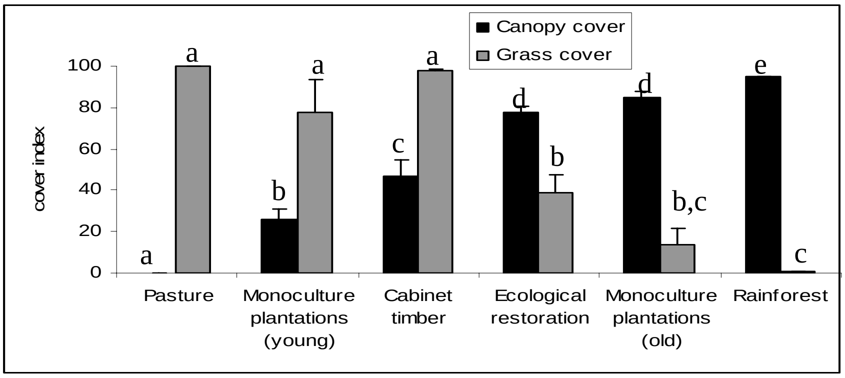
Forest structure

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.

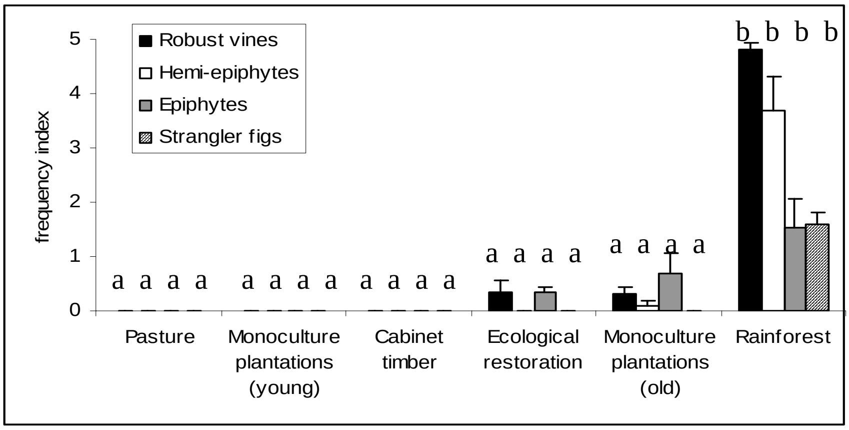
(i) a)



(b)



(ii) a)



(b)

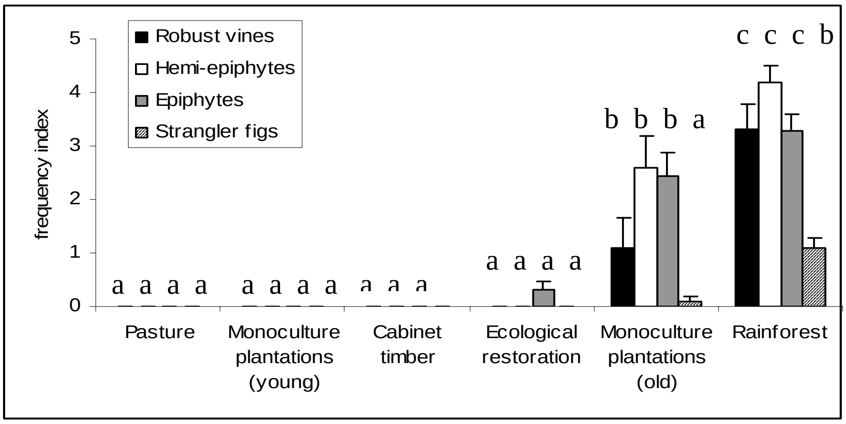


Figure 5 Selected aspects of the physical structure of the vegetation (mean, s.e.) of rainforest plantings, pasture and intact rainforest sites: a) subtropics; b) tropics. (i) Canopy cover and grass cover: a) subtropics; b) tropics. Canopy cover = projective cover of vegetation > 2 m above ground; grass 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.

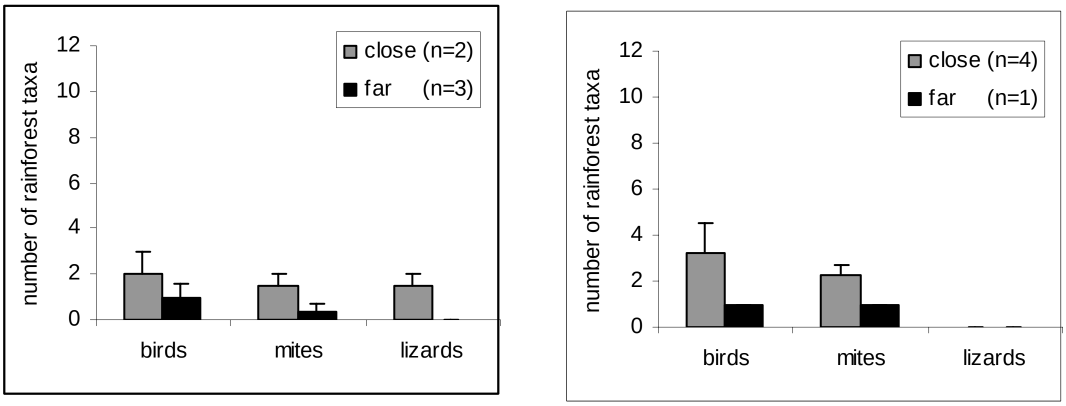
Habitat attribute	Rainforest bird richness		Rainforest lizard richness		Rainforest mite richness	
	Subtropics	Tropics	Subtropics	Tropics	Subtropics	Tropics
Plant richness in canopy and midstorey	**r = 0.59, P = 0.002**	**r = 0.62, P = 0.004**	r = -0.28, P = 0.18	**r = 0.46, P = 0.043**	r = 0.15, P = 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.

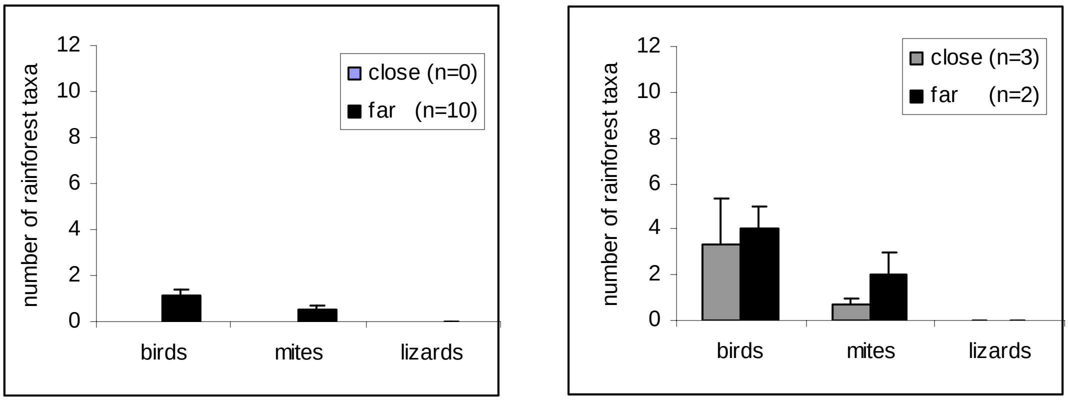
Effect of proximity to intact forest on the occurrence of rainforest biota in young rainforest plantings

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

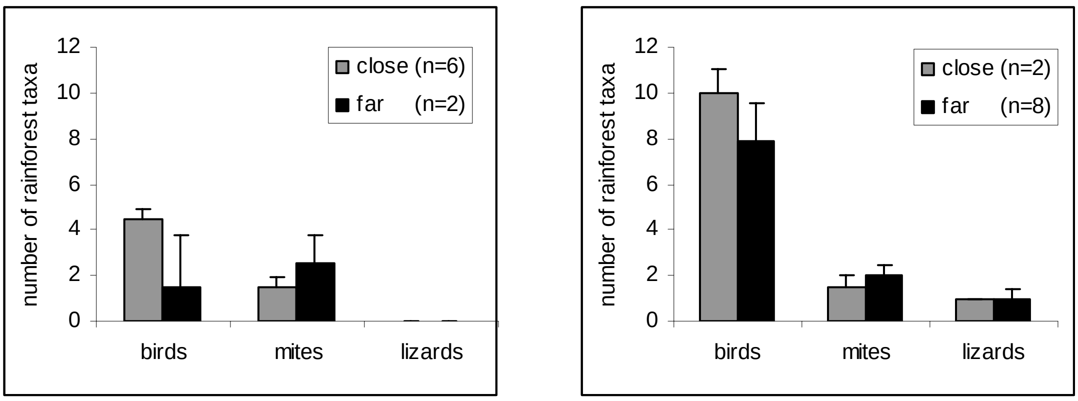


Figure 6 Richness of rainforest birds, lizards and mite taxa (mean, s.e.) in young rainforest plantings in the subtropics and tropics in relation to proximity to intact rainforest. Close = within 400 m of extensive or remnant (> 5 ha) rainforest; distant = more than 400 m.

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’ nontimber 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.

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