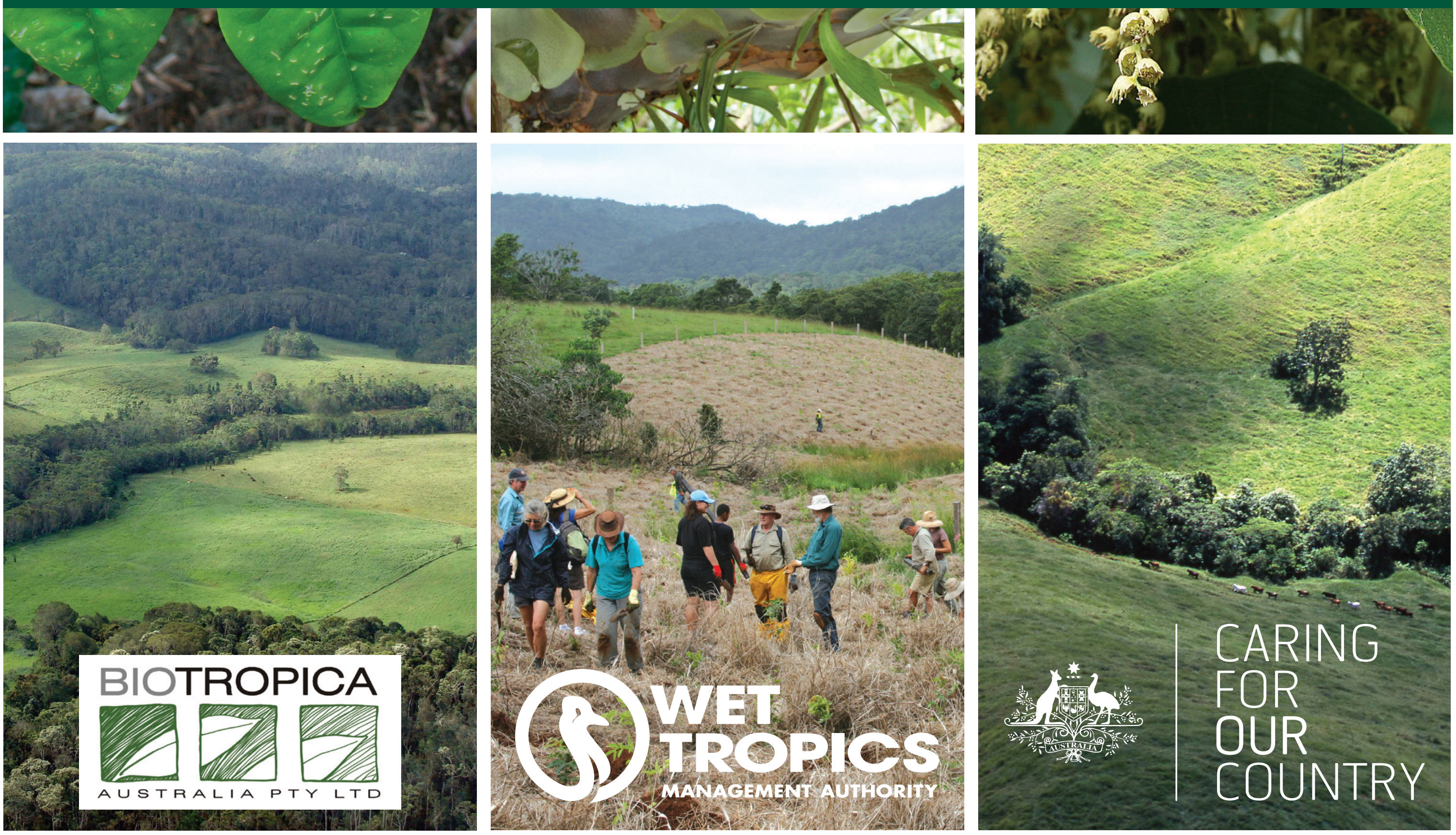
REPAIRING THE RAINFOREST

2nd Edition

Steve Goosem and Nigel I.J Tucker



A joint publication of the Wet Tropics Management Authority and Biotropica Australia Pty. Ltd.

National Library of Australia Cataloguing-in-Publication entry
ISBN 978-1-921591-66-2

Cite as:
Goosem, S. & Tucker, N.I.J. (2013). Repairing the Rainforest (second edition). Wet Tropics Management Authority and Biotropica Australia Pty. Ltd. Cairns.

Front Cover: Rainforest fruit (Photo: © Wet Tropics Images), flower of Nauclea orientalis (Photo: © Campbell Clarke), landscape corridor (Photo: © Lars Kazmeier), community tree planting (Photo: © Campbell Clarke), Macaranga leaf and flower (Photo: © Campbell Clarke).
Back Cover: Photo: © Kerry Trapnell

This publication is dedicated to Geoff Tracey, Peter Stanton, Joan Wright and Tony Irvine.

Acknowledgements
We would like to thank Prof Bill Laurance for contributing the foreword and Dr Susan Laurance and Campbell Clarke for reviewing the draft.

We are grateful to Mike Stott who assisted with preparation of the maps and Robert Koch for the cover design. Diagrams by Ross Robinson Creative.

We thank Michael Corley, Gemma Horner, Dan Keane and James Hill for assistance with species lists and background research.

We would like to particularly acknowledge: Campbell Clarke, Dan Metcalfe, Mike Trenerry, Martin Cohen, Daryn Storch, Deb Pople, Kris Kupsch, Lars Kazmeier, Biotropica Australia Pty Ltd., EPA, Tourism Queensland and the Wet Tropics Management Authority who kindly allowed use of their photographs.

Thanks to the amazingly dedicated, enthusiastic and knowledgeable members of TREAT and other rainforest restoration practitioners who kindly shared their passion, experience, insights and ideas.

AUSTRALIA

CARING FOR OUR COUNTRY

This project is supported by the Wet Tropics Management Authority, through funding from the Australian Government's Caring for our Country and Biotropica Australia Pty Ltd.

QAS INTERNATIONAL ISO 14001:2004 REGISTERED FIRM

Repairing The Rainforest was proudly printed in North Queensland by Bolton Print under ISO 14001 Environmental Certification. The cover was printed on a 55% Recycled mixed source stock with the text pages printed on an Australian made 50% Recycled and Certified Carbon Neutral stock.

About the authors

Steve Goosem has a background in protected area management and in botanical, soil and wildlife ecological research. His first experience with rainforest restoration involved flood mitigation tree plantings in the aftermath of the devastating 1974 Brisbane floods. Steve gained his PhD in ecology and botany from the University of Queensland in the early 1980s studying the dynamics of nitrogen in rainforest soils and plants during successional development. Prior to this Steve undertook postgraduate studies into the feasibility of utilising rainforests for treating sewage effluent and was a member of a scientific expedition to PNG undertaking rainforest canopy research. Following a five year stint as a Post Doctoral Research Fellow at the University of New England, Steve arrived in North Queensland in 1987 as a research scientist for the Queensland National Parks and Wildlife Service, where he met Nigel Tucker and which led to several collaborative rainforest restoration projects and many stimulating discussions.

Steve is currently Principal Scientist with the Wet Tropics Management Authority based in Cairns in North Queensland and is also an Adjunct Principal Research Fellow in the School of Marine and Tropical Biology at James Cook University.

Nigel Tucker has been active in the restoration and management of the Wet Tropics since 1984, working firstly with ecologist J. Geoff Tracey at CSIRO before joining the Queensland National Parks and Wildlife Service and being guided by the biogeographer J. Peter Stanton. His freedom to explore the ecological restoration process allowed him to gain experience across a wide range of tropical ecosystems at a time when knowledge of the process was in its infancy. Nigel worked with the community group TREAT (Trees for the Evelyn and Atherton Tablelands Inc), and landholders across north Queensland to better understand restoration, working from the Lake Eacham Nursery. He graduated from the University of Queensland in 1996, and completed his MSc at James Cook University in 2000. The evolving relationship between restoration ecology and conservation biology led to his ongoing research and publication association with Steve Goosem, beginning in 1989.

Nigel established the environmental consulting company Biotropica Australia P/L in 2002 and since that time has been active in forest restoration projects in south-east Asia, Papua New Guinea and tropical Australia. He serves as a Board member of the Society for Ecological Restoration Australasia and the journal Ecological Management and Restoration, and is an Adjunct Lecturer with James Cook University's School of Marine and Tropical Biology.

DISCLAIMER

WET TROPICS MANAGEMENT AUTHORITY

www.wettropics.gov.au

BIOTROPICA AUSTRALIA PTY LTD

www.biotropica.com.au

FOREWORD

In the hundred million years since rainforests first appeared on Earth, they have survived many challenges. But few environmental insults compare to the modern maladies of booming population growth, rising overconsumption and rapidly changing climates. Across the tropics, forests are falling at an alarming pace—at around forty football fields a minute over the last decade.

As the rainforests decline, so too do their remarkable biodiversity and invaluable ecosystem services—such as recycling rainfall, storing heat-trapping carbon and limiting destructive flooding. Rainforests are not merely disappearing, however; they are also being shredded, logged, mined and overhunted. Vast expanses of old-growth forest are being transformed into by human-dominated landscapes, where remnant fragments of rainforest are encircled by farms, urban sprawl, exotic tree plantations and selectively logged forests. To a great extent, the fate of biodiversity will depend on the capacity of such wounded landscapes to sustain forest-dependent species.

Given the mounting challenges to tropical environments, the importance of ecological restoration is abundantly clear. Replanting, restoring and repairing rainforests offers opportunities to staunch past ecological injuries, especially for high-priority areas where biodiversity once thrived and much damage has already been done. Those who restore rainforests can limit and even reverse the declines of wildlife and ecosystem services by establishing new faunal corridors, creating protective buffers around parks and restoring key ecological functions of forests.

For those interested in environmental restoration, *Repairing the Rainforest,* now in its second edition, is an invaluable and timely synthesis. Its authors, Stephen Goosem and Nigel Tucker, are highly respected ecologists and restoration experts, who collectively have accumulated more than seven decades of experience in the theory and practice of restoring rainforests and other damaged ecosystems.

Focusing primarily on the Wet Tropics region of Australia, *Repairing the Rainforest* highlights key ecological principles for restoring rainforest biodiversity and functioning. These include, among others, the vital role of animal seed-dispersers in rainforests and the traits of plants that help or hinder their dispersal. Also highlighted are the importance of understanding successional trajectories to accelerate forest recovery and principles of landscape ecology for optimizing tree-planting investments.

Repairing the Rainforest covers far more than theory, however; it is also an invaluable primer of hard-won, practical methods for actually growing and restoring rainforests. These include species lists of rainforest plants that are best suited for differing environmental conditions in the Wet Tropics region and tried-and-tested strategies for effectively propagating seedlings in nurseries. A particularly inspired strategy the authors detail is to plant certain tree species that attract key seed-dispersing animals that in turn bring in more plant species, supercharging forest recovery both for plant communities and native fauna.

While it emphasizes the Australian Wet Tropics, the principles embodied in *Repairing the Rainforest* apply to virtually any tropical forest environment. It is an invaluable tool for those who wish to restore and replenish rainforests, and I heartily congratulate the authors for producing such an eminently useful and important work.

William F. Laurance

Distinguished Research Professor & Australian Laureate
James Cook University, Cairns, Australia

Prince Bernhard Chair in International Nature Conservation
Utrecht University, Netherlands

CONTENTS

PART 2. PRACTICE

PART 3. WHAT TO PLANT WHERE

1. INTRODUCTION

It is instructive to set the scene for this book on rainforest restoration by first taking stock of the extent of human influence on the earth's rainforest ecosystems and the consequences of these impacts for biodiversity and the provision of ecosystem goods and services. Ecosystem goods and services provide a wide range of benefits for society. The most important of these services are those which are essential for life and those which prevent, limit, minimise or correct environmental damage to water, air and soil. There is also a growing recognition of the importance to society that ecosystem goods and services provide for the health, social, economic, cultural, spiritual, educational, recreational or medicinal needs of human societies.

Tropical rainforests occur in four main regions:

- Central and west Africa
- Central and south America
- South east Asia
- North east Australia.

Tropical rainforests are home to more than half of the earth's terrestrial species within just seven percent of the earth's land surface. They also store more than a third of the earth's terrestrial carbon and are responsible for a third of the earth's terrestrial net primary productivity (Wright 2010, Schnitzer & Bongers 2011). Efforts to improve human welfare and to generate wealth have resulted in the domestication and explotation of much of the earth's rainforested landscapes. As a consequence, it is now accepted that our planet is currently facing its sixth major extinction crisis, due to the cumulative widespread loss of both habitats and species (Barnosky *et al* 2011). The current massive extinction crisis is the first for 65 million years (Wilson 2002) and is the first that can be attributed to the snowballing effects of human actions. Since rainforests are the major storehouse of the planet's terrestrial biodiversity, it is not surprising that their rapid and continuing loss and the current tropical biodiversity extinction crisis (Laurance 1999, Pimm & Raven 2000) is a matter of international concern. At a more local scale, the loss of rainforests and their declining condition has resulted in environmentally and aesthetically impoverished landscapes.

The enormity of recent rainforest deforestation can be appreciated when one realises that half of the world's tropical rainforests have disappeared since World War II. Despite increased awareness of the importance of tropical rainforests, their loss is still occurring at an alarming rate with 10 million hectares being lost each year, which Laurance (2011) has described as being the equivalent of 40 football fields every minute. Much of this destroyed rainforest is attributable to the illegal logging trade or the conversion of entire landscapes to oil palm monocultures. In Latin America and in Asia the loss of rainforest is occurring at a rate approaching two percent per year, while in Africa the pace is just under one percent per year (Laurance 2011).

Associated with this large-scale loss of the earth's rainforests, the Living Planet Index, which is produced by the World Wide Fund for Nature and the Zoological Society of London (WWF 2012), found that in a 48 year period between 1970 and 2008, there was a 44 percent loss in terrestrial species abundance in the tropics. They found that wildlife populations and species abundance in the tropics are declining due to a number of large-scale human impacts including ongoing deforestation, habitat degradation, pollution, agriculture, invasive species, disease, climate change, dams, mining, and other industrial projects. Wildlife populations in tropical Africa were found to have dropped by 38 percent, by half in the Neotropical region (Central and South America), and by 64 percent in the Indo-Pacific region (including India, Southeast Asia, Australia and Pacific Islands) (WWF 2012).

In the light of these pressures on the Earth's rainforests, it is imperative that we not only conserve remaining tracts of rainforest, but also, wherever possible, attempt to restore and rebuild productive rainforest ecosystems. Worldwide, increasing attention is being given to the need for ecosystem restoration to re-establish both ecosystem functioning and the provision of ecosystem services (SCBD 2010, TEEB 2010). The Economics of Ecosystems and Biodiversity (TEEB) cite ecological restoration as the top priority for global society (TEEB 2011). Clearly, the role of rainforests as both sanctuaries of biodiversity and as providers of ecosystem services cannot be over estimated.

As with any text on rainforest ecology and restoration, it is inevitable that knowledge develops, processes change and technology advances. In this second edition of *Repairing the Rainforest* we aim to strengthen the ties between ecological theory and restoration practice on the basis that restoration is fundamentally the management of ecological processes. For restoration to succeed and if landscapes are to be recovered, then their success will improve where ecological principles are employed. The practice of rainforest restoration is the litmus test of how well we understand not only how rainforest ecosystems are assembled and held together, but also how they change and develop over time. Although it is beyond our capacity to restore a truly natural rainforest ecosystem we can assist nature by bringing together and attracting the basic components and characteristic plants and animals of an area. Assisted by this 'kick-start', natural processes will take over and other components of the natural system will naturally invade the restored system.

Although we give special attention to the rainforests of Australia's Wet Tropics, it has become increasingly clear, since the publication of the first edition of *Repairing the Rainforest* in 1995, that the general concepts and practices outlined in the first edition are widely applicable (Elliott *et al* 2006).

The following quote from a speech to the general assembly of the International Union for Conservation of Nature in 1968 by the Senegalese environmentalist Baba Dioum concisely sums up the aim of this book: *"In the end, we will conserve only what we love, we will love only what we understand, and we will understand only what we are taught."* Appreciation through knowledge allows people to better understand, respect and cherish the extraordinary biological richness, complexity and natural beauty that are the world's rainforests and to recognise the importance of their conservation and restoration.

WHAT IS ECOLOGICAL RESTORATION?

In attempting to restore rainforest ecosystems, we need to ask the question: "What would nature do?" In the natural world ecosystems are balanced, efficient, resilient and responsive. In a different context but equally relevant to ecological restoration, Benyus (1997) proposed ten primary principles of natural sustainability:

1. Nature runs on sunlight.
2. Nature uses only the energy it needs.
3. Nature fits form to function.
4. Nature recycles everything.
5. Nature rewards cooperation.
6. Nature banks on diversity.
7. Nature demands local expertise.
8. Nature curbs excesses from within.
9. Nature taps the power of limits.
10. Nature is beautiful.

Placing these ten principles into an ecological restoration context we could infer that an ecosystem runs on sunlight and uses only the energy it needs. It fits form to function, and a stable system recycles everything. In a natural ecosystem cooperation and diversity are rewarded, which demands local specialisation and interconnected webs of interactions. A stable ecosystem curbs excesses from within and taps the power of limits, choosing to optimise rather than maximise. And finally, nature is inherently beautiful.

Ecological restoration is much more than planting trees; it is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). It is a process that initiates or accelerates recovery of an ecosystem with respect to its structure (species composition, abiotic requirements and physiognomy); functional properties (productivity, energy flow, nutrient cycling); and exchanges with surrounding landscapes (SER 2004, SCBD 2011). Ecological restoration aims to re-establish a functional ecosystem with a level of species diversity and species interactions typical of its geographic, geological and climatic setting. The most fundamental restoration goal, therefore, is to recover species composition and structure and to return damaged ecosystems to some set of conditions considered functional, sustainable and natural.

Ecological restoration affects the landscape in a variety of ways, it can:

- help maintain a diversity of plants and animals in an area
- create lower maintenance landscapes
- improve water quality
- help minimise soil erosion
- create a healthier, sustainable mosaic of land uses
- help maintain the gene pool of particular plant and animal species, promoting hardiness, disease resistance, and adaptability
- create positive, progressive and constructive attitudes about our natural environment.

Ecology is the study of how organisms interact with each other and with their environment. It is, therefore, useful to have some basic knowledge of ecology if you wish to better understand rainforest restoration and to perhaps change the way you look at and appreciate the landscape. The first part of this book provides a compact introduction to some fundamental concepts of ecology relevant to the science and practice of rainforest restoration, without going into detailed literature reviews or technical detail. The second part applies these concepts to the practice of rainforest restoration, while the final section provides lists of rainforest plant species that are suitable for planting under different environmental conditions.

Ecological restoration is both a knowledge and practice-based undertaking that uses science and other forms of knowledge along with lessons learned from practical experience. This book is designed to provoke ideas of ways and approaches of restoring rainforested landscapes based upon some basic theoretical concepts, it is not meant to be prescriptive. The process of ecological science is creative and flexible. There is no single restoration method used by all practitioners. Similarly, there is no single scientific method or theory used or accepted by all scientists. Rather, both ecologists and restoration practitioners use a variety of tools, knowledge and techniques to both test their hypotheses about the natural world and to refine and improve their understanding. As Carl Sagan (1997) observed, *"Science is a way of thinking much more than it is a body of knowledge."*

PART 1. THEORY

"Delight itself, however, is a weak term to express the feelings of a naturalist who, for the first time, has wandered by himself in a Brazilian [rain] forest. The elegance of the grasses, the novelty of the parasitical plants, the beauty of the flowers, the glossy green of the foliage, but above all the general luxuriance of the vegetation filled me with admiration". Charles Darwin 29 February 1832.

2. AUSTRALIAN RAINFORESTS

Only about twenty percent of the Australian continent is covered by native forest, of which just under two percent or three million hectares is rainforest (Stork *et al* 2008). In Australia, rainforest communities mainly occur in a narrow arc along the east coast from Cape York Peninsula in the northern tropics to the cool temperate rainforests of Tasmania in the south, and usually within 100 kilometres of the coastline in areas receiving more than 1,200 millimetres of annual rainfall (Stork *et al* 2011). The largest area of remaining rainforest in Australia is located in Queensland's Wet Tropics region **(Table 1).** Small rainforest outliers can also be found scattered along the northern tropical coasts of the Northern Territory and Western Australia, and in moist, fire-proof gorges and other specialised moist environments within the more arid parts of tropical and subtropical Australia (Stork *et al* 2011).

Table 1. *Distribution of rainforest in Australia (km2)*

	Area (km2)	Proportion (%)
Continent		
• Australia	30,231	100
States and Territories		
• Victoria	407	1.3
• Western Australia	16	0.1
• New South Wales	2,218	7.3
• Northern Territory	977	3.2
• Tasmania	7,055	23.3
• Queensland	19,558	64.7
Region		
• Wet Tropics	8,340	27.6

Source: *National Land & Water Resources Audit (2001), Stork et al (2008), Stork et al (2011).*

Massive changes have been wrought on the Australian landscape in the two centuries since European settlement, including the clearing of about 13,000 km2 of Australia's rainforests (National Land and Water Resources Audit 2001). Historically, rainforests were among the earliest Australian vegetation communities to be exploited for timber and agriculture. A legacy of the pattern of this past exploitation is that most of the remaining larger blocks of rainforest are now confined to steep or rugged terrains. Examples of extensive past rainforest clearing include the decimation of the 'Big Scrub' rainforests in northern New South Wales (Floyd 1987), the Illawarra rainforests, the hoop pine scrubs of south-east Queensland (Young & McDonald 1987), the rainforests of the Atherton and Eungella Tablelands, the coastal floodplain rainforests of the Daintree, Mossman, Barron, Johnstone, Tully–Murray, Herbert, Proserpine and Pioneer rivers in north-east Queensland, and extensive areas of Brigalow Belt vine thickets in Queensland and New South Wales (Sattler & Williams 1999, Stork *et al* 2011).

The broad range of ecological community types classified under the umbrella term rainforest masks the level of depletion of some rainforest types. In the Wet Tropics for example, the steep escarpment and rugged highland rainforest communities remain largely intact, whereas the coastal lowland and upland tableland rainforest communities on fertile alluvial and basalt derived soils have been severely depleted (Stork *et al* 2011) and now remain as scattered fragments.

Although Australian rainforests are very limited in extent, they nevertheless contain a large proportion of the country's biodiversity capital. During the 1980s substantial advances were made towards the conservation of Australia's remaining rainforests. In recent decades there has been a large community driven expansion of rainforest restoration projects in Australia. These projects have been initiated for many different reasons, including improvements in:

- biodiversity
- habitat and corridors for iconic wildlife species
- catchment management
- stream and riparian health
- water runoff filtration
- health of freshwater and marine ecosystems
- erosion control
- landscape aesthetics
- noise and light barriers
- windbreaks
- landscape repair following construction and maintenance of community infrastructure such as roads, powerlines and pipelines.

3. QUEENSLAND'S WET TROPICS

The Wet Tropics of Queensland is essentially a long, narrow mountainous biogeographic region with a narrow coastal plain. The region is largely delineated on the basis of the climatic limits to the distribution of rainforest communities. The Wet Tropics is the wettest region in Australia (Turton et al 1999) and, in comparison with other tropical rainforest areas in the world, the wetter parts lie at the 'wet' to 'extremely wet' end of the hydrological spectrum (Turton *et al* 1999). The region's high rainfall and diverse, rugged terrain has allowed a wide range of forested ecosystems that vary enormously in structure, physiognomy and composition to flourish.

The rainforests of the Wet Tropics are one of the earth's extraordinary treasures. Recognition of the global significance of the region's forests occurred in 1988 when 900,000 hectares of forested landscapes between Townsville and Cooktown were declared World Heritage. The declaration was made on the basis of all four World Heritage natural area criteria.

BIOLOGICAL DIVERSITY

Australia is recognised by the World Conservation Monitoring Centre as one of the world's 17 mega-diverse countries, which collectively harbour 75 percent of the earth's total biological diversity (Williams *et al* 2001). Queensland's Wet Tropics has been recognised, in its own right, as a mega-diverse region, being represented on *'The Global 200'* list (Olson *et al* 2000) - a collection of the earth's 200 most outstanding, important and diverse terrestrial, freshwater and marine habitats. Although Queensland's Wet Tropics may only occupy 0.26 percent of the land surface of Australia, it contains a disproportionately large share of its biodiversity (Stork *et al* 2011).

Life Form	% of Australia's Total
Vascular plants	18
Ferns	65
Cycads	21
Conifers	37
Orchids	30
Mammals	36
Marsupials	30
Bats	58
Rodents	25
Birds	50
Frogs	25
Reptiles	23
Freshwater fish	37
Butterflies	60

Metcalfe and Ford (2009) calculate that within an area of 20,000 km2 the flora of the Wet Tropics (both rainforest and non-rainforest) comprises some 4,035 species in 1,369 genera. This compares favourably with that of New Caledonia (2,422 species in an area of 19,000 km2) and Costa Rica (5,250 species in an area of 51,000 km2). The Wet Tropics is second only to New Caledonia in the number of endemic genera conserved per unit area.

The rainforests of the Wet Tropics have more plant taxa with primitive characteristics than any other area on earth. Modern phylogenetic taxonomy has substantially revised our understanding of which families are old and which families are much younger, but may retain primitive features. Based on a modern phylogeny, Metcalfe and Ford (2009) calculate that of the 28 near-basal angiosperm lineages, 16 are represented in the rainforests of the Wet Tropics (Table 2). This is a similar level of representation found for the floras of New Caledonia and Costa Rica. However two primitive families, Austrobaileyaceae and Idiospermaceae are endemic to the Wet Tropics (Idiospermaceae is considered by some authorities as being synonymous with the family Calycanthaceae).

Photo 1. *The primitive Uvaria concava is a robust lowland rainforest climbing vine which produces large showy dark red flowers (4-5 cm diameter). Note the leathery nature of the petals. Photo: © D. J. Metcalfe.*

This large number of angiosperm families with primitive characteristics are a great repository of evolutionary history. The rainforests of the Wet Tropics, New Caledonia and New Guinea share East Gondwanan origins, significant plant taxa with primitive characteristics in their floras and their high levels of regional endemism. This suggests the persistence of rainforests in the region over millions of years and their long isolation from developing floras in other parts of the tropics.

Photo 2. *Idiospermum australiense (idiot fruit, ribbonwood or Idiospermum) is a Wet Tropics endemic primitive angiosperm which is restricted to very wet lowland rainforests between Hutchinson Creek and the Daintree River and to a small area of the Harvey Creek section on the Bellenden Ker Range. Photo: © Wet Tropics Images.*

Diversity and regional endemism within the fauna of the Wet Tropics are also very high with 107 mammal species, including 11 endemic species and two monotypic endemic genera found in the region. There are 368 bird species, of which 11 species are endemic. There are also 113 reptile species of which 24 species are endemic; the three endemic reptile genera are each represented by only a single species. The diversity of amphibians includes 51 species of which 22 are endemic species (Williams 2006, Stork *et al* 2011).

It needs to be emphasised that the diversity of a rainforest is far more than lists of plant and animal species that are found there, and also includes consideration of the complex interactions such as food webs, dispersal systems and mutual interdependencies.

Table 2. *The 16 families and 46 genera of primitive dicots in the Wet Tropics. Numbers in parentheses refer to the number of Wet Tropics species represented per family or genera (after Metcalfe & Ford 2009)*

Family	Genera
1. Annonaceae (30)	1. Cananga (1) 2. Desmos (2) 3. Fitzalania (1) 4. Goniothalamus (1) 5. Haplostichanthus (5) 6. Meiogyne (3) 7. Melodorum (4) 8. Miliusa (2) 9. Polyalthia (4) 10. Pseuduvaria (5) 11. Uvaria (1) 12. Xylopia (1)
2. Aristolochiaceae (6)	1. Aristolochia (2) 2. Pararistolochia (4)
3. Atherospermataceae (3)	1. Daphnandra (1) 2. Doryphora (1) 3. Dryadodaphne (1)
4. Austrobaileyaceae (1)	1. Austrobaileya (1)
5. Cabombaceae (1)	1. Brasenia (1)
6. Ceratophyllaceae (1)	1. Ceratophyllum (1)
7. Eupomatiaceae (2)	1. Eupomatia (2)
8. Hernandiaceae (2)	1. Hernandia (2)
9. Himantandraceae (1)	1. Galbulimima (1)
10. Idiospermaceae (1)	1. Idiospermum (1)
11. Lauraceae (82)	1. Beilschmiedia (9) 2. Cassytha (1) 3. Cinnamomum (4) 4. Cryptocarya (28) 5. Endiandra (29) 6. Lindera (1) 7. Litsea (8) 8. Neolitsea (2)
12. Monimiaceae (23)	1. Austromatthaea (1) 2. Endressia (1) 3. Hemmantia (1) 4. Hedycarya (1) 5. Levieria (1) 6. Palmeria (2) 7. Steganthera (6) 8. Wilkiea (10)
13. Myristicaceae (2)	1. Myristica (2)
14. Nymphaeaceae (2)	1. Nymphaea (2)
15. Piperaceae (14)	1. Peperomia (5) 2. Piper (9)
16. Winteraceae (7)	1. Bubbia (4) 2. Tasmannia (3)

Photo 3. *Pseuduvaria hylandii is a primitive small tree restricted to a small area in the upper catchments of the Mulgrave and Russell Rivers. It is usually confined to wet, very well developed rainforest on basalt soils. Photo: © D.J. Metcalfe.*

4. WHAT ARE RAINFORESTS?

Rainforest is an umbrella term describing a broad range of vegetation community types. Rainforests have been simply defined as tree-dominated, water-loving ecosystems that occur in the non-seasonal tropics (Hill and Hill 2001), with a vegetation cover of greater than 80 percent (Specht 1970). Characterising rainforests in such simple terms fails to provide any idea of the basic properties that distinguish rainforests from other vegetation types. Floristically, Australian rainforests are almost completely unrelated to adjacent sclerophyll vegetation communities (Adam 1992). In general, rainforests are moisture loving communities of closely spaced trees with high floristic diversity. They are distinguished by the prominence of characteristic life-forms such as epiphytes, lianas and stranglers, root and stem structures such as buttresses. Annual herbs or grasses are absent on the forest floor. It is also a general characteristic of tropical rainforests that, at any locality, the number of species is very large and the frequency of almost all of them is very low. Diversity coupled with relative rarity is the hallmark of most tropical rainforests. It is the diversity of life-forms and the structural complexities that are the key features distinguishing rainforests from other vegetation types while the fundamental characteristic of rainforests that makes all the special life-forms that are unique to rainforests possible is the closed canopy and its effects on light quality and quantity and microclimate.

Another consequence of the closed canopy which characterises a rainforest is that many rainforest seedlings must be tolerant of the low light conditions encountered on the forest floor if they are to survive or be competitive. Many rainforest understorey species are able to open their stomates and respond rapidly to very short pulses of increases in light resulting from small canopy gaps and sunflecks. At the floor of a `typical' Wet Tropics' rainforest, average radiation levels may be as low as 0.5 - 0.2 percent of the radiation intercepted by the canopy (Yates *et al* 1988). Many seedlings on the forest floor experience these low levels of radiation for days or weeks at a time and are exposed only very briefly or perhaps seasonally (if there are deciduous canopy species nearby) to high levels of radiation. The occurrence of sunflecks appears critical to the survival of many plants found on the forest floor. Bjorkman and Ludlow (1972) found that of the radiation reaching the forest floor in a southern Queensland rainforest, 62 percent occurred in sunflecks which only occurred during a few minutes of the day. Turton (1988) reports similar figures for rainforests growing on the Atherton Tableland in the Wet Tropics where, at the equinox, sunflecks contributed 60.9 percent and 50.8 percent of forest floor radiation under a closed canopy and in a small gap respectively. Consequently, leaves of an individual understorey rainforest plant may experience fluctuating average maximum radiation levels differing by a factor of 100 to 200 times (Yates *et al* 1988).

Photo 4. *Sunflecks are important in sustaining the dense understorey growing in this small rainforest gap.*
Photo: © Campbell Clarke.

Rainfall amount and seasonality are the key drivers determining the distribution of rainforests. Secondary drivers of distribution include soil type and topography, temperature and disturbance regime. These factors determine structural complexity and formation type, with the most structurally complex and biologically diverse rainforest types occurring on deep, fertile soils in high rainfall zones. The more seasonal the environment or the more stressful the environment (for instance, poorly drained, infertile, shallow soils), the more structurally simple and lower the diversity of rainforest community types.

The more complex rainforest types are usually associated with a higher diversity of both plants and animals. It is common, in the better developed rainforests, for tall emergent trees to tower above the main closed canopy. Below the scattered emergent tree canopies is an upper canopy, which forms the main light intercepting layer of leaves and is composed of a large variety of mature tree species. The canopy is where most of the energy from sunlight is captured and is the major forest layer that powers the whole rainforest ecosystem. Below this upper canopy is a mid-canopy layer of suppressed, light demanding species and shade-tolerant trees, waiting for an upper canopy gap to eventually occur so that they can exploit the increased light and fill the gap. Below these layers is often a rich, high density understorey of suppressed tree seedlings, saplings, shrubs, ferns and herbs. Wet tropical rainforests also support a large biomass of epiphytes and lianas, and a huge variety of different life-forms. The three dimensional structural complexity of a rainforest provides a wide assortment of niches that support a high diversity of faunal species, with different groups of animal occupying and exploiting different canopy layers.

RAINFOREST TYPES

Classifying rainforest communities has been approached in many different ways, depending upon the purpose (Adam 1992). Broadly speaking there are three different approaches to classifying regional vegetation – the floristic association approach, the broad habitat approach (for example riparian, littoral and montane), or the ecological framework approach. For ecological restoration planning purposes, and for understanding the underlying vegetation pattern in an area, it is argued that the ecological framework approach is more generally useful.

Rainforests, particularly wet tropical rainforests, have generally defied floristic composition-based classification attempts because any classification based on species becomes extremely unwieldy, hugely complex and arbitrary due to the large diversity and highly variable nature of rainforest communities. Hundreds of tree species coexist in most tropical rainforests with the result that most rainforest communities cannot be considered to be highly organised floristic units. In general, rainforest communities can be viewed as being composed of temporary, fortuitous, co-occurrences of plant taxa rather than stable, recurring floristic communities. The actual species present at any time can be viewed as transitory occupants of a site with self-replacement following death an improbable occurrence. In other words, rainforest species are found together due to chance, and there is generally no recurring relationship between species - they are only found together because they are part of a pool of species which have similar environmental requirements. Different environments have differences in their potential pool of species. Different pools of species are adapted to different combination of environmental conditions.

In order to deal with these species-based limitations, Webb (1959, 1968) developed a method of classifying rainforests based upon easily recognisable features of a rainforest community as a whole. Webb's structural classification was further developed using mathematical modelling techniques in a series of papers by Webb, Tracey, Williams and Lance (e.g. 1967, 1970, 1976), producing a more refined classification based upon a reduced list of significant features (Webb 1978). Webb's rainforest classification system is based on structural features (such as tree layers, evenness of canopy outline, crown depths and shapes), physiognomic features (including leaf size, type and deciduousness, colour and texture of bark, and buttressing) and special life forms (such as vines, palms, ferns, mosses and epiphytes). Webb's classification recognises that different combinations of structural features characterise different types of environments. Single features and life-forms may be found in more than one environmental type.

Leaf size is a very diagnostic feature in Webb's rainforest classification system. Webb noted that there are a large number of diagnostic features that are linked with changes in leaf size and that different combinations of them can be correlated with environmental gradients. A decrease in the availability of moisture and increased periods of seasonal drought is correlated not only with an overall decrease in leaf size, but also an increase in deciduousness, a reduction in canopy height, a loss of plank buttressing, an increase in the prevalence in flaky and scaly barks, an increase in thorns and prickles, and increases in shrub-like life forms. The size of leaves of most species in the canopy of a rainforest was also found to decrease at higher altitudes and higher latitudes, and on soils of lower moisture and nutrient status.

The vegetation of the Wet Tropics has recently been remapped and reinterpreted by Peter and David Stanton and hierarchically reclassified and digitised by the Wet Tropics Management Authority. This recent mapping recognises 79 rainforest types and is based on the Tracey and Webb (1975) and Tracey (1982) classification framework (see **Appendix 1**). In this framework, vegetation units are initially classified into structural types and then subdivided into broad communities on the basis of the climate zone, altitude zone, and soil parent material and soil drainage situation in which the vegetation unit is consistently found. When planning rainforest restoration projects, sites can be initially classified in terms of these environmental parameters which can then be used to predict the type of rainforest and the selection of the appropriate pool of species suitable for planting at a particular site (see **Part 3**).

Australian rainforests attain their peak development as complex mesophyll vine forests. These communities are found on very wet and wet lowlands and foothills where soil parent materials range from riverine alluvia to basalts and basic volcanic rock types (**Appendix 1**). These communities are characterised by canopy tree species whose sun exposed leaves are dominated by large, mesophyll-sized leaves (12.5 cm to 25.0 cm long), exhibit an uneven canopy extending to between 20 to 40 metres with many tall emergent trees such as figs, with large spreading crowns a common feature. Species composition and the variety of life forms in this rainforest community is the most complex of any terrestrial vegetation type in Australia. Plank buttressing is common, robust woody lianes, vascular epiphytes and palms are typical, and fleshy herbs with wide leaves such as gingers and aroids are generally conspicuous (Tracey 1982). Exposed sites such as ridges and seaward-facing slopes often exhibit cyclone disturbed or broken canopies with 'climber towers' and dense vine tangles, often dominated by Captain Cook vine (*Merremia peltata*). These are sometimes referred to as 'cyclone scrubs' (Webb 1958). Within complex mesophyll vine forest communities, variation in site factors results in conspicuous structural differences such as the increase in palms on sites with impeded drainage, and gingers and aroids in gullies and along creek banks which are permanently saturated with water (Tracey 1982).

Photo 5. *A well developed complex rainforest takes a very long time to mature. Complexity is characterised by a range of trunk sizes including large trees, trunk buttressing and special life forms such as vines, palms, ferns and epiphytes. In this photo the roots of this tree are providing a range of microhabitats and specialised niches. Photo: © Wet Tropics Images.*

The notophyll vine forest and thicket categories include a structurally and floristically diverse group of communities (Types 6, 7, 8, 9, 10, 11, 12 and 13; Appendix 1). They occur on small areas of basic volcanic parent materials on cool wet uplands and highlands and on a range of drier sites at various lower elevations. Notophyll vine forests and thickets are also a feature of sand beach ridges in drier coastal areas. It is also the most extensive rainforest type clothing the granite escarpment and mountain ranges at altitudes between 400 to 1000 metres. These communities, while extraordinarily variable, are characterised by medium-sized (7.5 cm to 12.5 cm long) sun-exposed canopy leaves; a canopy tree height range of 12 metres to 45 metres; rattans or palm lianes such as *Calamus* spp.; strangler figs; frequently conspicuous epiphytes; variable amounts of ferns; walking stick palms such as *Linospadix* spp.; and fleshy perennial herbs.

Photo 6. *An example of a complex notophyll vine forest on the Carbine Tableland. Photo: © M. Trenerry.*

Photo 7. *A notophyll vine forest growing on beach sands. Despite being in a high rainfall area, this rainforest is simple in structure and is characterised by its low stature, an absence of large stems, the presence of wiry vines, an open understorey and the paucity of special life forms such as aroids, gingers and epiphytes. Photo: © D. J. Metcalfe.*

Simple microphyll fern forests or thickets dominate towards the upper end of the altitudinal spectrum, on the summits and upper slopes of the higher peaks which are frequently enshrouded by cloud and often exposed to strong winds (Appendix 1). These often possess a conspicuous aerially suspended moss component and are sometimes referred to as cloud forests or wet montane forests (Werren *et al* 1995).

Photo 8. *A simple microphyll vine thicket growing on a highland summit. Photo: © D.J. Metcalfe.*

Areas which experience significant water stress during the dry season support communities characterised by the occurrence of taxa which are semi-deciduous to deciduous (Appendix 1). Semi-deciduous mesophyll vine forests are restricted to minor occurrences in the Wet Tropics. The canopy is usually comparatively even to a height of 25 metres to 32 metres with deciduous emergents to 36 metres. Figs, including cluster (cauliflorous) and strangler types, and lianes (rather than rattans) are generally conspicuous. Epiphytes are uncommon. There are sporadic occurrences of deciduous microphyll vine thickets on fire-free rocky sites and exposed headlands with constituent species mainly multi-stemmed and fully deciduous. The canopy of these communities is generally uneven and around 3-5 metres with emergents rising to 10 metres. Scrambler vines and shrubs (usually with thorns) are common (Werren *et al* 1995).

Photo 9. *An example of a sclerophyll/rainforest transition. This former Eucalyptus grandis forest has advanced to a stage where it is both structurally and floristically a rainforest community and conditions are no longer suitable for the germination and growth of non-rainforest species. Photo: © D.J. Metcalfe*

Sclerophyll/rainforest transitions (Appendix 1) represent different stages of post-disturbance succession (such as fire or cyclones). In many parts of the Wet Tropics, where the rainfall is greater than 2000 millimetres per year, these transitional communities are the result of an extended major disturbance free period. Their composition varies greatly, with each sub-type characterised by certain sclerophyll species such as eucalypts and wattles being a dominant canopy or emergent component. These communities have advanced to a stage where they are structurally and floristically rainforest communities with the conditions generally unsuitable for the germination, growth and perpetuation of sclerophyll species. The sclerophyll species in these wet climate zones behave in a similar way to an early successional/ pioneer species (see Chapter 7), with their persistence dependant upon high frequency, high intensity disturbance caused by regular burning regimes. In the absence of fire, there is a transition to a progressively more diverse and complex rainforest community and a progressively more unfavourable environment for the germination, establishment or growth of sclerophyll species.

5. ECOSYSTEM ECOLOGY

'Ecology is often the painful elaboration of the bloody obvious' (J. G. Tracey 1984).

Ecosystem ecology is the study of the interactions among organisms and their environment as an integrated system. Geoff Tracey in his book *Vegetation of the Humid Tropics of North Queensland* (Tracey 1982) employed a 'state factor' ecological framework to explain the different types of rainforest vegetation he described for the Wet Tropics. His explanatory framework is broadly based on the concept of Jenny (1941, 1958) who suggested that a number of independent, interactive state factors control soil and ecosystem properties (**Figure 1**).

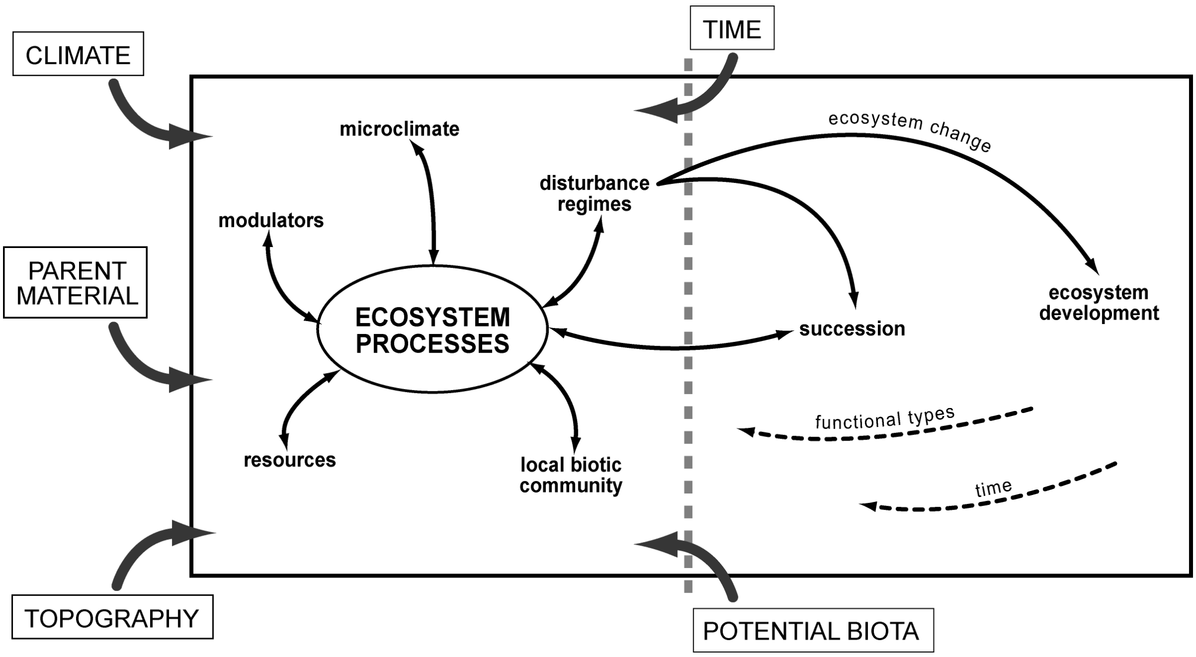


Figure 1. *Conceptual relationships between the five state factors (outside the rectangle), interactive controls (inside the left hand square) and ecosystem processes. The rectangle represents the boundary of an ecosystem. State factors are static over ecological time scales and constrain interactive controls. Interactive controls both regulate and respond to ecosystem processes. Disturbance and other factors can push the system towards a new state (ecosystem change) or initiate a new cycle of succession. The right hand square represents successional processes and the interaction between the scale of disturbance and the subsequent degree of ecosystem change, time scales of responses and the availability of potential biota with which to respond. The figure is adapted from Chapin et al (1996)*

STATE FACTORS

The state factor approach emphasises the variables that control ecological processes rather than simply descriptions of spatial pattern. **Climate** is the most influential state factor that determines ecosystem processes and structure while **soil parent material** strongly influences the types and fertility of soils and variations in ecosystem processes; **topographic** relief influences microclimate and soil development at smaller scales while **potential biota** represent the pool of organisms present in a region that could potentially occupy a site. **Time** influences the development of soils and the evolution of organisms (geological time scales), and influences successional processes and patterns (on ecological time scales). It also determines the response of ecosystems to past disturbances and environmental changes over a wide range of time scales.

Together these five factors determine the characteristics of an ecosystem while the interaction of these factors with each other controls the formation of different types of ecosystems (Jenny 1958). Factors such as soil parent material have relatively distinct boundaries and can be readily delineated on the ground and unambiguously mapped. Other factors, such as climate and topography, vary more or less continuously and do not have distinct boundaries. These continuous factors can be simplified and better visualised using the Tracey and Webb (1975) approach of segmenting these continuous factors into 'zones' encompassing defined ranges of variation (see also the explanatory notes at the end of **Appendix 1**). This concept of underlying controlling factors forms the logical basis for the species lists presented later in **Part 3** and for determining the type of rainforest that is the aim of a restoration project (see **Chapters 15** and **16**).

Ash (1988) classified the threshold boundary limits of rainforest distribution on the Atherton Tableland in terms of mean annual rainfall, geologic substrate and topography (**Table 3**), and this provides a good example of how these state factor controls interact. It is evident that rainforest communities extend into lower rainfall areas on fertile basaltic soils, and the wetter limits of open canopied sclerophyll forest vegetation are associated with rugged topography on acid volcanic, granitic and metamorphic derived soils. The favourability of different soil parent materials for rainforest can be ranked such that: granites are less favourable than metamorphic sedimentary rocks, which are less favourable than alluvium which, in turn are less favourable than weathered basalt. Young, unweathered, stony basalt allows rainforest to persist in areas receiving much lower rainfall than on other substrates (such as at Tolga Scrub Reserve and Curtain Fig National Park). The parent materials differ not only in their soil chemical and physical properties, but also in their topography. For example, granitic and metamorphic rocks typically produce a more rugged/dissected topography than is found in basalt or alluvial landscapes.

Table 3. *Lower mean annual rainfall limit (mm) for rainforest distribution on the Atherton Tableland based on parent material and topography (derived from Ash 1988)*

Substrate	Terrain Gentle	Terrain Rugged
Acid volcanics	1750	2000
Granites	1700	2000
Metamorphics	1550	1900
Alluvium	1500	na
Scoria	1110	1270
Basalt (weathered)	1050	na
Basalt (stony)	800	na

na = not applicable

INTERACTIVE FACTORS

In addition to the 'independent' state factors determining the broad distribution of species and vegetation communities, there is also a set of interactive controlling factors (Jenny 1958) that both *control* and are *controlled by* ecosystem characteristics (**Figure 1**). It is the activity of these interactive factors that helps to explain or predict the trajectory, and the success or failure of restoration efforts. Important interactive controls include:

- the supply of **resources**
- **modulators** that influence the rates of ecosystem processes
- **disturbance regimes**
- **biotic communities**
- **human activities.**

Resources are the energy and materials in the environment that are consumed by plants to support their growth, maintenance and reproduction (such as water, nutrients, carbon dioxide). Resources that are consumed by a plant deplete their abundance or availability in the environment. Light availability, for example, depends on the state factors of climate and topographic position but is also sensitive, especially in a rainforest community, to the quantity of shading by vegetation as it develops (an interactive factor).

Modulators differ from resources in that while exerting their influence on the activities of organisms in the environment they are neither consumed nor depleted. Modulators include such physical and chemical properties as temperature and soil pH. Modulators like temperature are constrained by climate (a state factor) but are sensitive to ecosystem processes, such as shading and evaporation by the developing plant community. Similarly, soil pH depends on both the type of soil parent material and time, but also responds to vegetation composition and organic matter decomposition.

Landscape-scale **disturbances** include phenomena such as cyclones, diseases, fire, wind, and floods. This category of disturbance is an important determinant of the structure and process rates in ecosystems. Like other interactive controls, disturbance regimes depend on both state factors and ecosystem processes.

The nature of the **biotic community**, or the functional types of organisms that occupy the ecosystem, (including the types of species present, their relative abundances, and the nature of their interactions), can influence ecosystem processes. Functional types are groups of species that are similar with respect to their role in community or ecosystem processes.

Human activities have an impact on virtually all the processes that govern the properties of ecosystems. The cumulative impact of human activities can affect state factors such as climate, through changes in atmospheric composition, and potential biota, through the introduction of non native species and the extinction of native species. Human activities also include activities aimed at restoring ecological processes.

6. THE ROLE OF CANOPY GAPS IN RAINFOREST REGENERATION AND SUCCESSION

Disturbance occurs at a variety of spatial and temporal scales and can be crudely described as a change of environmental conditions, which alters the functioning of a biological system. Rainforest regeneration cycles are driven by disturbance. When a tree falls, carving its way through the forest canopy, it produces a canyon of light and an avenue of change into the gloom of the understorey. The new patch of sunlight immediately stimulates great changes in the life of the forest floor. Light is energy and energy brings change. Given the dense nature of rainforest canopies, the creation of a gap in the canopy is a significant event. The creation of a canopy gap results in normally limiting resources such as light and growing space being made available. Canopy gaps are usually created by a disturbance event such as tree falls of over-mature canopy trees, through to large, extensive canopy gaps created by high intensity winds associated with storms or cyclones. Gap creation sets in train a complex rebuilding process involving rainforest succession (see also Chapter 7). This rebuilding process is also referred to as gap-phase dynamics (Osborne 2000).

Photo 10. *Tropical rainforests are characterised by their closed canopy. Note the presence of several small gaps of different sizes, shapes and orientations. Photo: © Queensland Government.*

Tree fall gaps are important and complicated resources in a rainforest. Most rainforest trees are entirely dependent on these gaps to reach maturity. Treefall gaps vary greatly in size, shape, orientation and the height of the surrounding vegetation. This results in differences in sunlight penetration, temperature, moisture, humidity and wind regimes within gaps of different dimensions. Principal differences between the environment within a gap and the environment below a rainforest canopy are an increase in light and a change in its spectral quality, an increase in both soil and air temperature and a decrease in humidity (Whitmore 1978).There are also increases in nutrients as dead plant material decays, a temporary decrease in root competition and sometimes changes in micro-relief and soil profile characteristics (Whitmore 1975). Due to the temporal and spatial differences in gap formation, every patch of rainforest consists of a complex patchwork of trees and forest of different sizes, ages and stages of maturity.

There are two alternative starts to regeneration within a gap. Either existing suppressed tree seedlings or saplings are stimulated to commence upward growth, or new trees establish from seeds germinating in the gap. In general, suppressed seedlings most often grow to maturity in small gaps where the external stimulus of microclimate change and other fluctuations in resource availability are not too extreme but are adequate to stimulate apical growth. In nature, small gaps in the canopy are, of course, far more common than large gaps, and many rainforest trees are adapted to grow under these small gap conditions. Small-gap adapted species usually have larger seeds that are dispersed less widely than the large-gap adapted species since their targets are closer and more abundant. Large seeds facilitate rapid development of large root systems, which in turn result in larger more robust seedlings (see also Chapter 8). The store of carbohydrate reserves in large seeds enable seedlings to wait for a gap to occur.

Photo 11. *The proliferation of seed germination in the gap formed following the death and collapse of a large rainforest canopy tree. Photo: © Campbell Clarke.*

By contrast, the dramatic microclimate changes and other environmental fluctuations following the formation of a large gap will result in the death of all or many of the pre-existing suppressed plants. Large gaps are typically colonised by groups of species absent from the understorey of the mature forest which have evolved to exploit open sites and include the pioneer, early successional or generalist species (see also Chapter 7). Large-gap specialists require the intense light and high temperatures of large holes in the canopy for germination and growth because their seedlings cannot tolerate shade. These large-gap specialists can use high intensity sunlight far more efficiently than understorey and small-gap specialist species. Intolerance of low light conditions and the unfavourable balance of far-red to red wavelength radiation effectively prevent regeneration of large-gap adapted species under a closed canopy or in small gaps. Large-gap colonists typically grow rapidly and possess umbrella-like crowns to capture the maximum amount of sunlight. Large-gap species are often prolific producers of fruits packed with many tiny seeds, and they usually bear fruit throughout much of the year. This shotgun reproductive strategy enhances the likelihood of large-gap specialist species having their seeds present when a less common large gap in the canopy appears.

There is an element of randomness in the system – in a tropical rainforest with hundreds of tree species and a large number of dispersal agents, virtually every gap will be contested by a unique combination of species. It is unlikely that a fallen tree will be replaced by a member of the same species. It seems appropriate to view a rainforest as a patchy, constantly changing mosaic generated in large part by unpredictable tree fall gaps.

Light is a key stimulus for a range of biological functions. It is now known, for example, that a single, very key hormone co-ordinates how a plant grows. Among other things, the hormone strigolactone determines whether a plant grows long and skinny or broad and bushy (Gomez-Roldan *et al* 2008). When light levels or nutrient levels are low, strigolactone levels rise, suppressing the development of buds into branches, resulting in a tall, thin plant which enables it to reach more light and also maximises the amount of energy that goes into reproduction. Energy is therefore focused on producing flowers and seeds, rather than vegetative growth (Gomez-Roldan *et al* 2008). Conversely, when there is a lot of light and nutrients available, strigolactone levels fall, encouraging branching and making a plant that is broad and bushy and able to make the most of abundant resources. In addition, when strigolactone levels are high, not only does this stop buds from turning into branches, but it also causes stem thickening which ensures that a plant growing tall to reach the light also has the structural strength to do so (Gomez-Roldan *et al* 2008).

7. PLANT SUCCESSION

WHAT IS ECOLOGICAL SUCCESSION?

Succession is the process by which the component species of a community change over time. Within any plant community some species may progressively become more or less abundant over time. They may even appear anew or vanish from a site altogether. In simple terms, this change in what is living at a particular site is ecological succession. Species have sets of environmental conditions under which they will grow and reproduce most optimally. When these environmental conditions change, the relative competitiveness of species also changes. The engine which drives succession is ecological change or disturbance. Following a disturbance, an ecosystem generally progresses over time from a simple system with only few dominant species to a more complex system with many interdependent species.

Rainforest restoration is deeply rooted in ecological succession and there are many practical benefits and insights to be gained from taking a closer examination of succession. Succession and restoration are intrinsically linked because succession encompasses species and environmental change over time while ecological restoration is the purposeful manipulation of that change (Palmer *et al* 1997). Successional theory can also provide a framework to enhance restoration efficiency since restoration actions can alter species colonisation, establishment and accumulation and through these alterations affect the trajectory and rate of ecosystem development. Harnessing natural successional processes in rainforest restoration projects will result in a greater chance of success than elaborate attempts to reconstruct a mature fully functional rainforest ecosystem manually.

As succession proceeds, a rainforest restoration site will experience changes in biomass, structure and plant species composition. Significant changes also occur to soil properties, soil organisms and nutrient cycling. Wildlife species track these environmental changes and recolonise the regenerating forest as suitable habitats develop and food and other resources become available (Tucker & Simmons 2009). In addition, as the forest develops in height, a greater number of feeding niches develop. This vertical partitioning of foraging heights also contributes to the high species diversity found in rainforests.

KEY SUCCESSIONAL PROCESSES FOLLOWING DISTURBANCE

Dispersal and colonisation

The first stage of a natural succession involves the successful dispersal of plant seeds to a site - equivalent in many ways to the deliberate introduction of plants as seedlings or seeds to a rainforest restoration site.

The dispersal ability of most rainforest plant species is generally quite limited so, in many instances, dispersal limitation may be a major obstacle to colonisation. Barriers such as distance or inhospitable intervening habitats can limit dispersal of seed to a site. There are several ways to enhance the rate of colonisation of a site by rainforest species. The usual method is to plant rainforest trees which over time provide resources such as food, shelter or perches which attract seed dispersing birds and flying foxes while creating conditions which enhance germination and protect the resulting seedlings. For example, Martinez-Garza and Howe (2003) showed that planting trees speeded-up the process of succession by at least three decades. Other ways that have proved successful in increasing rainforest tree dispersal and colonisation to a site include the installation of artificial perches to create focal points of bird dispersed seeds (Toh et al 1999, Holl *et al* 2000). The nucleation process ensuing from the provision of perching structures has been found to accelerate the colonisation and establishment of rainforest species (Slocum & Horvitz 2000).

Establishment

Plant establishment is assisted by factors that trap seeds, and by 'safe-sites' which both increase the chances of successful seed germination and provide protection of the resulting seedling. One method to increase the number and variety of safe-sites is to create physically heterogeneous restoration sites. As much of the existing physical heterogeneity at a restoration site as is logistically and practically feasible should be preserved. The physical diversity of a site can also be augmented by the introduction of logs, rocks and hollows.

Over time establishment can also be progressively enhanced through biological facilitation which is the process by which established plants improve the performance of other plants (Cardinale *et al* 2002). Improved performance may be achieved through physical processes such as when established plants improve soil moisture availability, temperature, or light conditions or reduce exposure to wind. Plants which help facilitate seedling establishment are sometimes referred to as 'nurse plants' (Henriquez & Lusk 2005). Several rainforest restoration methods take advantage of such biological facilitation.

Seed and seedling predation during establishment can sometimes be a major cause of restoration failure. In some locations, plantings may need to be protected from herbivores by fences or individual protective exclosures until they become established. Natural structural and chemical plant defences against herbivory generally increase during succession as a function of changing species composition and increasing age of individuals. Because palatable, undefended plants often dominate the earlier stages of succession, herbivory can severely retard initial site capture and increase the length of time that a site requires expensive maintenance. Rainforest restoration plantings provide a smorgasbord of flavours and young tender tissue to wildlife, and some species, such as young Bleeding heart (*Homalanthus novoguineensis*), are commonly subjected to serious herbivory by pademelons (T*hylogale stigmatica*).

Breakdowns in the successional process

It is important to recognise that disturbance does not necessarily initiate a constructive or progressive secondary succession. Regressive, arrested or deflected successions are widespread and culminate in rainforest types completely unlike the original mature phase community (Connell & Slatyer 1977, Niering 1987).

There are three main types of barriers limiting successional processes. These barriers directly or indirectly affect how succession proceeds by either influencing a species' arrival or its establishment in a community (Chazdon 2003):

- Landscape features such as the area and spatial arrangement of forest patches and the nature of surrounding land uses will influence the probability of dispersal of plant species to a site (Chazdon 2003).

- Biotic and abiotic characteristics such as seed predation, rainfall, soil condition and the history of land use will determine which species initially establish and survive at a site (Letcher 2009).

- Finally, as a consequence of succession, species interactions will increase in importance and will influence which species will successfully assemble into a community (Chazdon 2008, Letcher 2009).

Regressive, deflected or arrested succession can also result from a variety of altered physical or biological site factors including:

- Physical site factors such as:
  - soil compaction
  - soil porosity
  - microclimate
  - soil fertility (Niering 1987, Ganade & Brown 2002, Chazdon 2003)
  - water table levels (Maggs & Hewett 1993).

- A lack of later successional species in the seed-rain. Rainforest succession on many abandoned areas now appears to be arrested at an early secondary stage due to dispersal limitation of large seeded later successional species (Hopkins 1981).

- Invasive species monopolising a site preventing the establishment of late phase species (Webb 1959, Uhl *et al* 1988, Erskine *et al* 2007).

- Geographical barriers - dispersal limitation and a paucity of available seed is likely when the distance between patches of rainforest is large (Hopkins 1981).

- Human activities that maintain the occupation of a site by invasive weeds or early successional native species such as permanent openings of the forest canopy for roads, tracks and other infrastructure.

- Frequent disturbances altering the stability of a system. A high frequency of destructive cyclonic activity for example, may prevent the re-establishment of mature rainforest and maintain a deflected succession.

The study of succession provides valuable lessons for improving the success of rainforest restoration projects. In many cases, communities are able to recover following mild to moderate disturbances. Restoration in these circumstances should be focused on hastening natural successional trajectories. However, a system that has experienced severe disturbance may require intensive restorative efforts to recreate environmental conditions that favour natural successional processes. Restoration tactics should focus on site preparation, improving establishment success, and protecting planted species from herbivory and competition during their development. Incorporation or preservation of physical heterogeneity during site preparation should help to provide safe-sites for seedling establishment and foster mosaics of vegetation that better mimic natural landscapes. Importantly, if rainforest restoration practices are to create functional systems, it is essential to design into the system natural small-scale disturbance to mimic the initiation of successional processes. One way to promote natural disturbance is to plant a percentage of pioneer or early successional species which have short life cycles. Incorporating a proportion of naturally short-lived trees creates a temporal mosaic of disturbances as they tend to shed foliage and branches during their growth before senescing and dying at an early age. In this way a spatial and temporal patchwork of small-scale disturbances becomes integrated into the rainforest restoration site as a series of natural events (see also **Chapters 6** and **9**).

8. LIFE HISTORY STRATEGIES

Numerous systems have been developed for classifying species into different successional stages based on their life-histories. A major criterion in these classifications has been whether a species 'requires a gap' for successful regeneration and the assumption that species differ in the size of gaps and the sites within gaps where they can regenerate (Hartshorn 1980, Whitmore 1982, Denslow 1987). 'Gap' and 'shade tolerant' life history patterns for tropical trees have been thought to involve contrasting suites of correlated traits. In general an adaptive trade-off is expected between the ability to survive in the shaded understorey and the capacity for rapid growth in large gaps (Hartshorn 1980, Denslow 1987, Poulson & Platt 1989). Shade tolerance may also vary with tree age and with environmental conditions. For example, trees tend to show greatest shade tolerance in their youth and those on good sites tend to be more tolerant of shade than those on poorer sites (Baker 1950).

LARGE-GAP TRANSIENT SPECIES

Species adapted to survival in large-gaps are unable to establish under shade. A characteristic of large-gap rainforest species is their rapid growth rates, short life-spans, and high mortality in the shade (Swaine & Whitmore 1988). Large-gap rainforest species in general produce large numbers of small seeds. Their seeds are often produced without regard to season and most have a dormancy period (Whitmore 1978). The seeds of most transient species only germinate in gaps large enough for sunlight to reach the ground for at least part of the day and require high irradiance levels for both seedling establishment and growth (Goosem 2003, 2008). Seedlings and young plants of these species are never found under a closed canopy since their germination is generally inhibited by far-red light wavelengths, which dominates beneath a closed rainforest canopy (Vazques-Yanes 1976). Fluctuating temperatures associated with increased sunlight also often enhances the germination of large-gap rainforest species (Whitmore 1975).

Large-gap transient species include pioneer and early successional stage species which are also sometimes referred to as generalist species. Pioneer species are short-lived, shade intolerant perennials that grow to a maximum height of 8 metres. They begin the regeneration process in areas of medium to large disturbance (examples include *Wikstroemia indica, Rubus rosifolius*). Early successional species are fast growing perennial trees (10-25 metres high) living for 15-50 years. With environmental modification these may sometimes predominate and form a closed canopy (examples are *Melicope* spp., *Polyscias* spp., *Dendrocnide* spp., *Alphitonia* spp., *Rhodomyrtus* spp. and many members of the Euphorbiaceae family). The growth rate of transient species is rapid because their saplings have to be capable of reaching the upper strata during the lifespan of a single large gap.

Transient tree species are often ubiquitous and widespread with the same pool of species often a conspicuous component of a wide range of different rainforest community types (Barlow *et al* 2007, Norden *et al* 2009). Often they are not only tolerant of high light levels but also tolerate a wide range of soil fertilities, temperatures and soil moisture levels, and most have a wide latitudinal and altitudinal distributional range. These characteristics have led some to refer to such species as generalist rather than specialist species.

Many pioneer and early successional plants grow and produce new leaves, flowers and fruit throughout the year. Well lit areas of the rainforest such as riverbanks and disturbed edges where these plants thrive are attractive, reliable food resource areas for many animals. The premium placed on rapid growth by pioneer and early successional species is often at the expense of producing chemical defences. Herbivores ranging from insects to tree kangaroos avail themselves of these islands of undefended, palatable foliage. Groups of birds may, in turn, flock in response to high insect densities. The high insect densities associated with the undefended, palatable foliage, in combination with the elevated temperatures associated with sunlight penetration, may also draw reptiles such as lizards and skinks into tree-fall and other larger gaps in the rainforest. These are important, dynamic, resource rich places with many interacting food webs.

Photo 12. *The early successional Macaranga tanarius is a typical regrowth species which is favoured by disturbance and grows in large rainforest gaps or on rainforest margins. M. tanarius is wind pollinated with flowering and fruiting occurring several times a year. It has a typical early successional 'shotgun' reproductive strategy, producing huge numbers of small easily dispersed seeds. Photo: © Campbell Clarke.*

Pioneer species comprise only a very small proportion of the flora in any tropical rainforest (Whitmore 1984). This is also the case in the Wet Tropics where there are only a handful of native rainforest pioneer trees, most of which have very wide geographical distributions. The relatively low proportion of pioneer tree species is a common feature of tropical rainforests, which are generally very resilient to small-scale natural disturbances but are not well equipped to handle large-scale artificial disturbances, having a generally impoverished pioneer flora with which to respond (Goosem 2003, 2008).

SMALL-GAP PERSISTENT SPECIES

In contrast to the light demanding transient species, seeds of most later successional stage rainforest trees are able to germinate in the light and temperature conditions found beneath a closed rainforest canopy. Species typical of later seral stages are characterised as a class by large seeds with substantial food reserves and are able to establish and persist in deep shade. Their seeds are generally produced periodically in response to climatic stimuli and they have either no or brief dormancy (Hopkins *et al* 1976). Importantly, their seedlings can often persist, growing slowly or not at all in dense shade - marking time till a suitable light gap occurs. Small-gap persistent species comprise the great majority of rainforest tree species.

Small-gap, small disturbance adapted species include late secondary and mature phase species. Wet Tropics' examples of late secondary species include: *Acronychia* spp., and *Diploglottis* spp., while examples of mature phase species include: *Cryptocarya* spp., *Sloanea* spp., *Elaeocarpus* spp., *Argyrodendron* spp., *Syzygium* spp. and *Acmena* spp. Small-gap species (Table 4), have seedlings and saplings capable of surviving low understorey light conditions. They are, however, dependent on some canopy disturbance for substantive growth and for reproduction, although their growth is slow even under optimal light conditions. High light levels before maturation may damage leaves and meristems so that maximum growth is usually attained in small gaps or on the shaded edges of large gaps. It may take many years before the mature phase species produce a fruit crop, so that rainforest restoration sites may take a hundred years to become reproductively independent of the adjacent primary forest.

The late secondary group includes many of the emergent tree species which, while shade tolerant as juveniles, switch to being shade intolerant when an appropriate sized gap occurs. When this switch occurs they need to grow quickly enough to overtop the canopy during the life span of the gap. As a group these species have a number of other anomalous features. Many have winged, wind dispersed seeds and many are found in gregarious congregations that can form conspicuous coloured patches across the landscape when in flower or in leaf flush. Several members of the Proteaceae family, some *Argyrodendron* spp. and *Flindersia* spp. fall into this group as do the Kauri pines (*Agathis* spp.) and the Hoop pine (*Araucaria cunninghamii*). Dispersal of the winged seed common to many late secondary rainforest species is by gyration (or gravity) and tends to be limited, with the majority of seeds falling beneath or close to the canopy of the mother tree.

SURVIVAL STRATEGIES AND THEIR ROLE IN SUCCESSION

For rainforest restoration purposes it is helpful to adopt a scheme such as that developed by Hopkins *et al* (1976) and Webb and Tracey (1981) who divided rainforest species into four major regeneration guilds, on the basis of their survival strategies and their role in the successional process (Table 4). Recognising its overwhelming importance, the life history characteristics of rainforest species can be arrayed along a continuum of adaptive responses to the patterns of light availability. This continuum ranges from shade intolerant pioneer and early successional species (transient or generalist species) through light requiring species with some shade tolerance (early secondary to late secondary species; Table 4), to the persistent, highly shade tolerant, slow growing species (late secondary to mature phase species; Table 4).

There is evidence that plant species differ in the proportion of their net primary production which is devoted to reproductive effort. Species occupying the earlier phases of succession have a high reproductive effort, usually in the form of a large number of seeds and a correspondingly high intrinsic rate of population increase (Harper *et al* 1970). These species have an r-oriented character syndrome *(sensu* MacArthur and Wilson 1967). Later seral stage species expend less on reproductive effort and possess a K-oriented character syndrome. A greater part of their available energy resources is devoted to persistent vegetative organs; this confers advantage in the long-term struggle for existence in crowded, resource limited, stable environments (Harper *et al* 1970).

The capacity of rainforest restoration to restore the composition and function of an original forest depends primarily on the availability, either as planted seedlings or in the seed rain, of species representing all the elementary canopy tree types (and other life forms such as epiphytes and lianes). Restoration speeds the process by direct planting late secondary and mature phase species to a site. The length of time before a planted tree produces fruit is a function of its life history, as typified by its 'successional stage', and its position within a restoration site. Species with more access to light, such as those on a margin or emergents, will generally produce earlier and more abundant fruit crops (Tucker & Simmons 2004).

Table 4. *Life history strategies of plant species typical of different stages in the ecological succession of rainforests*

	Large-gap transient or generalist species		Small-gap persistent species	
Life history strategy	**Pioneer species or opportunist species**	**Early secondary species or large gap species or long-lived pioneer species**	**Late secondary species**	**Mature phase species or small-gap species**
Shade tolerance	Very shade intolerant	Shade intolerant	Shade tolerant when young but shade intolerant when mature.	Shade tolerant. Low light requirements.
Life span	Short-lived, often herbaceous or soft-wooded perennials. Mature rapidly. Live for 1-15 years	Perennial trees, fast growing, live for 15-50+ years.	Perennial trees, slower growing, may live for over 100 years.	Long-lived, slow maturing, growing for 100 – 1000+ years.
Growth rates	Very fast	Fast	Moderate	Slow
Height	To 8 metres	10 – 25 metres	Grow to large stature (includes emergent trees)	Grow to moderate stature (25+ metres)
Flowering	Generally flower profusely then die, or flower continuously	Often flower throughout the year.	Flower regularly but only once or at most twice a year.	Either flower regularly or irregularly, sometimes only once every several years.
Seed production	Produce large numbers of small effectively dispersed seed. Herbaceous species generally wind dispersed; woody perennials generally fleshy-fruited.	Regularly produce large numbers of small well dispersed seeds. Generally fleshy-fruited.	Produce fruit most years. Proportion of wind dispersed species.	Tendency for 'mast' years. Irregular fruiting, seed dispersal poor. May take 40-50 years to reach fruiting stage. Seeds generally large and few. Generally fleshy-fruited.
Seed viability	Long, may require scarification. Requires light for germination	Long, up to 30 years.	Generally short, 3-4 months.	Often limited to a few weeks.
Germination	High ratio of red to far-red light wavelengths stimulates germination (phytochrome) High temperatures stimulate germination (thermoblastic). Frequently persist as dormant seed in soil seed banks.	Require light for germination. Generally persist in soil seed banks until large canopy gap opens.	Able to germinate in shade or in the sun. Persists in seedling banks not as soil seed banks until medium canopy gap opens.	Able to germinate in deep shade or in the sun. Can persist for many years as suppressed juveniles (seedling banks) until small canopy gap opens.
Mode of germination	Phenerocotylar	Phenerocotylar	Mainly phenerocotylar but some cryptocotylar species	Predominantly cryptocotylar but some phenerocotylar species.
Wood density	Very low	Low	Moderate (but variable)	High
Evolutionary strategy	r-adapted	r-adapted	K-adapted	K-adapted
General	Not usually a component of the primary forest – needs large disturbance. Simple branching architecture with a monopodial shoot.	Usually present in primary forest.	Includes most emergent rainforest tree species Often dominate rainforests of drier areas.	Species of the complex rainforest. Complex branching architecture, large woody limbs.

Large-gap transient or generalist species				Small-gap persistent species		
Life history strategy	**Pioneer species or opportunist species**		**Early secondary species or large gap species or long-lived pioneer species**	**Late secondary species**		**Mature phase species or small-gap species**
Characteristic genera	Breynia Pipturus Rubus Trema Wikstroemia Merremia Maclura Lycopodiella Various vines and ground ferns	Alphitonia Dendrocnide Homalanthus Macaranga Mallotus Neolitsea Schefflera	Ailanthus Aleurites Albizia Blepharo-carya Brachychiton Chionanthus Darlingia Glochidion Grevillea Guioa Litsea Lophostemon Melia Melicope Millettia Pittosporum Polyscias Semecarpus Synoum	Aglaia Alectryon Alloxylon Alstonia Brachychiton Buckinghamia Canarium Cardwellia Castanospermum Davidsonia Diploglottis Elaeocarpus Eupomatia Euroschinus Halfordia Harpullia Helicia Hernandia Hodgkinsonia Jagera Melicope Microcitrus Mischarytera Musgravea Polyosma Ristantia Rockinghamia Sarcopteryx Sarcotoechia Stenocarpus Terminalia	Acronychia Agathis Araucaria Archidendron Arytera Athertonia Atractocarpus Caldcluvia Carnarvonia Ceratopetalum Cupaniopsis Diospyros Dysoxylum Elaeocarpus Flindersia Geissois Hicksbeachia Hollandaea Mischocarpus Opisthiolepis Oreocallis Palaquium Podocarpus Pseudowein-mannia Sterculia Sundacarpus Symplocos Synima Toona Waterhousea Xanthostemon	Acmena Argyrodendron Backhousia Beilschmiedia Bubbia Cerbera Cinnamomum Corynocarpus Cryptocarya Daphnandra Endiandra Gmelina Harpullia Idiospermum Myristica Niemeyera Ostrearia Placospermum Planchonella Prunus Pseuduvaria Sloanea Syzygium
Characteristic families		Many Euphorbiaceae		Many Sapindaceae, Rutaceae, Proteaceae		Many Lauraceae, Myrtaceae
		Ficus				

(modified from Hopkins et al 1976)

SEED PRODUCTION

Seed production by the pioneer and early secondary species occurs regularly with the production of large numbers of seeds with long viability. The majority of seeds in the soil seed bank in a rainforest are from the pioneer and early secondary groups. Late secondary species fruit most years but their seed viability is mostly limited to several months. Mature phase species are characterised by infrequent gregarious flowerings which often produce massive quantities of fruit (Hopkins 1975). However, their seeds will not tolerate desiccation and are viable for only a short period, generally surviving for several weeks to several months. The time interval between large fruiting events is usually greater than three years. In the intervening periods, many individuals sporadically produce smaller quantities of fruit (Hopkins 1975).

The different successional plant groups are also characterised by differences in the size of their seeds. Rainforest species with larger seeds tend to become established in more stable, shady plant associations than those with smaller seeds (Foster & Janson 1985). Rainforest trees that require large light gaps for seedling establishment tend to have smaller seeds than those that become established beneath a closed forest canopy (Foster & Janson 1985).

Another distinguishing characteristic is that pioneers and early secondary species mostly form seed banks, whereas later successional rainforest species generally form seedling banks having no, or a very limited, seed-dormancy phase (Goosem 2003, 2008). In the majority of rainforest trees there is a comparatively short interval between seed-drop and germination. A very common regenerative strategy is that in which populations of tree seedlings and saplings persist for long periods. In the population dynamics of these trees, the reservoir of seedlings and saplings functions in a way which is in some respects analogous to that of a seed bank. The similarity extends even to the critical role of disturbance of the established vegetation and the creation of canopy gaps in releasing individuals from the bank. In many rainforest trees, seeds are not produced each year and the capacity of the seedlings to survive for long periods under sub-optimal conditions ensures that the potential for regeneration of the species is maintained. Regeneration involving a seedling bank is characteristic of plants adapted to circumstances in which the opportunities for recruitment from the seedling population occur infrequently and depend upon senescence, damage and mortality among the established plants to produce canopy light gaps.

SEED TRAITS

The morphological traits of young seedlings are important in the regeneration strategies of plants. Traits related to the function of cotyledons appear particularly important. These include whether the cotyledons remain enclosed within the testa (cryptocotylar) or emerge from it (phanerocotylar); and whether the cotyledons are reserve organs or photosynthetic organs.

Seeds from pioneer and early secondary species, almost without exception, have phanerocotylar germination (Clifford & Mott 1986). The proportion of cryptocotyly is much higher in the mature than in late secondary stages (Clifford & Mott 1986) (Table 5). Phanerocotylar germination is advantageous in early succession since the cotyledons become photosynthetic. However, it may have costs in both mechanical support and, more importantly, predation.

Conversely, suppressed late successional species should gain advantage from having their cotyledons enclosed within the testa. The cotyledons in such circumstances can act as food storage organs. This mode of germination confers persistence as it may defend the seedling from herbivores and pathogens - if the shoot is grazed or dies it can be replaced by expansion of the cotyledonary axillary buds. Functionally, this is equivalent to multiple germination events from a singe seed.

The tendency for cotyledon function to shift towards storage with increasing seed mass underpins the ‘reserve effect’ initially proposed by Westoby *et al* (1996) - the seedlings of larger seeded species perform better because they have more stored reserves available to them during times of carbon deficit resulting from deep shade, or for interim maintenance while replacing photosynthetic tissue lost through herbivory or other forms of damage. The key concept is that large seeds have absolutely more stored energy reserves than smaller seeds. A greater proportion of seed reserves in larger seeded species remains uncommitted during seedling deployment and is held in reserve to provision seedlings that germinate in hazardous environments (Kidson & Westoby 2000). Greater seedling survival is one mechanism which may compensate for lower seed production in larger seeded species. The reserve effect could have evolved as one of a suite of mechanisms promoting greater seedling survival in larger seeded species under conditions of deep shade.

The reserves contained in large seeds enable seedlings to persist for long periods in low light environments. For example, Connell and Green (2000) examined patterns of seedling recruitment, persistence and growth of *Chrysophyllum* sp. nov., a mature phase shade-tolerant Wet Tropics rainforest canopy species. They observed that the growth rate of seedlings of *Chrysophyllum* sp. nov. was extremely slow in the shaded understorey. During a 27 year data collecting period they recorded a doubling in height of the seedlings and confirmed that these mature phase species could persist in deep shade for long periods of time in a suppressed state. This strategy of persistence increases the possibility that light conditions will eventually become more favourable for growth before they die.

Phase	Phenerocotylar	Cryptocotylar
Pioneer	*Ageratum* *Physalis* *Rubus* *Senecio* *Solanum* *Urtica*	
Early secondary	*Macaranga* *Mallotus* *Homalanthus* *Solanum* *Trema*	
Late secondary	*Ailanthus* *Brachychiton* *Flindersia* *Halfordia* *Melia* *Synoum*	*Davidsonia* *Diploglottis* *Hernandia* *Microcitrus*
Mature	*Elaeocarpus* *Geissois* *Pseudoweinmannia* *Sloanea*	*Acmena* *Argyrodendron* *Beilschmiedia* *Cryptocarya* *Dysoxylum* *Endiandra* *Harpullia* *Idiospermum* *Pseudocarapa* *Syzygium*

(after Clifford & Mott 1986).

Table 5. *Examples of some characteristic genera of the four phases of rainforest regeneration grouped both according to their mode of regeneration and the stage of regeneration in which they commonly occur.*

9. MODELS OF DYNAMIC CHANGE

The classical concept of ecological succession involves two basic assumptions:

1. Species replacement during succession occurs because species tend to modify their environment as they grow, making conditions less favourable for their own persistence resulting in their progressive substitution; and

2. A stable self-perpetuating 'climax' system ultimately appears which is in balance with the physical and biological environment.

Egler (1954) suggested that the classical model of succession may not apply in all situations and proposed two alternative successional models:

i. 'relay floristics' model
ii. 'initial floristics' model

RELAY FLORISTICS

Relay floristics assumes that only pioneer species are able to colonise a site in the conditions that occur immediately following a large disturbance. Most, if not all, of the species which comprise the relatively stable mature stage were not present either as plants or propagules at the initiation of succession.
In the relay floristics model the early colonising species modify the environment so that it is more suitable for later successional species to invade and grow to maturity (facilitation).

INITIAL FLORISTICS

In the initial floristics model the modifications wrought on the environment by earlier colonists neither increases nor reduces the rates of recruitment and growth to maturity of later colonists - species which appear later are simply those that arrived later or else arrived at the beginning but grew slowly. Since early successional, transient species are short lived, they are replaced more often than are longer-lived persistent, late successional species. If propagules of these later species are available for invasion then, after a period of transition, the latter species will accumulate, resulting in the gradual decrease in relative abundance of the earlier species. The greater tolerance of late successional species is important in allowing the late species to survive long periods of suppression beneath the canopy. In effect this greater tolerance and persistence compensates for lower vagility of propagules, increasing the chances that a seedling of a late successional species will be on the site to replace a dying earlier individual, resulting in a succession of species leading from short-lived transient species to long-lived persistent species.

Connell and Slatyer (1977) proposed a broader system of successional processes which included the:

i. 'facilitation' model
ii. 'tolerance' model
iii. 'inhibition' model

FACILITATION MODEL

Their 'facilitation' model follows the classical replacement pattern whereby each successive suite of species which occupies a site makes the environment less favourable for their own persistence and more favourable for their successors.

TOLERANCE MODEL

In their 'tolerance' model, environmental modifications induced by earlier colonists may either increase or decrease the rates of recruitment and growth to maturity of later species. The latter appear later because they either arrived later or, if present directly after the disturbance, had their germination inhibited or their growth suppressed.

INHIBITION MODEL

In contrast, in their 'inhibition' model the early occupants, rather than facilitating the progressive occupancy by other species, inhibit the invasion of other species through physical occupancy, through physical competition, through the use of allelopathic chemicals, or through other effective means of inhibition. Later successional species may only be able to enter the site when the inhibiting species are damaged or die off. This represents a biotic mechanism for arrested succession discussed in Chapter 7.

FLUCTUATING RESOURCES

Chesson and Huntley (1997) showed that to maintain diversity there is a need for both the existence of flux or variability and populations capable of differentially exploiting this flux or variability. Davis *et al* (2000) developed this observation further and suggest that colonisation is influenced by three major factors:

1. propagule pressure (i.e. the number of seeds)
2. characteristics of the newly arriving species (i.e. traits)
3. the invasibility of the new (host) environment (i.e. vacant niches).

Davis *et al* (2000) argue that a plant community becomes more susceptible to colonisation by a new individual whenever there is an increase in the amount of unused resources. Their theory rests on the simple assumption that any incoming species must have access to resources such as light, nutrients and water. Species enjoy greater success establishing within a site if they do not encounter intense competition for these resources from the species already occupying the site.

An increase in resource availability can occur in one of two ways - either by a decline in the use of resources by the resident vegetation or, alternatively, by an increase in resource supply at a rate faster than the resident vegetation can sequester it. Resource use could decline due to a disturbance that damages or destroys an area of vegetation, reducing the uptake of light, water and nutrients. An increase in resource supply could arise in a particularly wet period (increased water supply) or a particularly dry period where drought conditions, if severe enough, cause a pulse of partial community leaf loss or patches of mortality, both of which create gaps in previously closed vegetation. The resulting increased light may increase colonisation and establishment, if not during the drought itself then once the drought is over. Newly restored sites have an abundance of available resources as much of the ground storey remains available and the resources within can be readily exploited. Whether resource uptake goes down, or supply goes up, there are more resources available and this is when a community is more susceptible to invasion or colonisation by new individuals.

This also means that successful species colonisation/establishment events are likely to occur episodically or irregularly. This is especially so when it coincides with availability of the colonising species' seed. Disturbance is a natural feature of all ecosystems and is the feature that facilitates the colonisation, establishment and subsequent growth process by reducing the cover or vigour of plant competitors and by increasing resource levels (such as light, nutrients or soil water). Consequently, the fluctuating resource availability hypothesis (Davis *et al* 2000) would predict that:

- Environments subject to pronounced fluctuations in resource supply are more susceptible to invasion by new individuals than comparable systems with more stable resource supplies. This emphasises the need to consider building small-scale temporal and spatial disturbance into a restoration plan.

- Environments are more susceptible to an influx of new individuals immediately following abrupt disturbances that cause either an increases or a decrease in resource availability (such as following restoration, a tree fall or cyclone damage).

- Invasibility will be greater when there is a prolonged interval between an increase in resource supply and its eventual recapture by a site's resident vegetation.

- A relationship between the species diversity of a plant community and its resilience to invasion by further species does not necessarily exist.

- Whether or not invasion by new individuals actually occurs in a particular environment also depends on the amount of incoming seed and the traits of these incoming species. Therefore it is important to consider the functional role of species selected for planting in a restoration project and their attractiveness to the animal seed dispersal guild.

These successional models show that the spatial and temporal pattern, frequency and intensity of disturbance within a rainforest restoration project are likely to affect the rate and nature of colonisation, establishment and growth of other individuals and species. This is discussed further in Chapter 6, 7 and 8.

Photo 13. *A 25 year old planting at Lake Barrine (Atherton Tablelands). Decomposing logs create habitat for many species including fungi and add nutrients to the soil. These logs are the remains of early successional species from the initial planting in 1988. Their demise has allowed space and light for new seedlings, and created suitable habitat for aroids such as the Alocasia brisbanensis in this image. Photo: © Biotropica Australia Pty Ltd.*

10. DISPERSAL

Scientists and artists have long pondered both the beauty and mystery of flowers. Charles Darwin was perplexed by the rapid evolution and dominance of flowering plants in the late Cretaceous and their role in recruiting animals to help distribute pollen and seeds, a phenomenon he called "the abominable mystery" (Friedman 2009). Maurice Maeterlinck, the Belgian playwright and poet who was awarded the 1911 Nobel Prize for Literature, considered the most striking feature of plants was the diversity of flowers that have evolved to enhance sexual reproduction (Maeterlinck 2008). Associated with the evolution of flowers came the need for plants to trigger flowering at the right time to ensure that flowering occurs at the time optimal for successful reproduction (see Chapter 11) and the co-evolution of pollinators to maximise pollination success and the survival of the species.

Dispersal refers to the movement of pollen or seed away from the parent plant. Unlike animals, plants are limited in their ability to seek out reproductive partners or to find favourable conditions for life and growth. While some plant species have pollen or seeds adapted for being carried by the wind, many others trick an animal into carrying their pollen or seeds, by wrapping the pollen or seed in an attractive flower or within a tasty fruit and advertising the flower or the fruit's ripeness by its colour or smell.

POLLEN DISPERSAL

Within rainforests there are very few wind pollinated species. These are mainly confined to emergent, gregarious, gymnosperm species such as the Kauri pines (*Agathis* spp.) and the Hoop and Bunya pines (*Araucaria* spp.) Genetic diversity in rainforest angiosperms is, therefore, closely linked to the diversity of flower-visiting animals (Waser 1983). In the tropics invertebrates represent the majority of flower visiting pollinators (Bawa 1990), and this trend is reflected in what we know of the Wet Tropics' flora where the main flower visitors are insects from the Coleoptera (beetles), Hymenoptera (bees, wasps, ants) and Diptera (flies) (Boulter *et al* 2008). Beetles are an important and diverse group of rainforest pollinators world-wide (Bawa 1990, Sakai *et al* 1999) and pollination by beetles is claimed to occur in up to one quarter of our rainforest flowering plants in Australia (Irvine & Armstrong 1990).

To ensure pollination success, plants have evolved flowers to entice and attract animals as well as mechanisms to encourage these animals to visit other plants of the same species. Flowers can offer rewards of nectar, pollen, fragrances and oils to attract and manipulate the behaviour of a wide variety of animals. In order to attract animal pollinators, flowers must:

1) advertise their presence (such as colour, nectar guides or scent);
2) entice by offering (or appearing to offer) a reward (such as pollen, nectar or breeding sites); and
3) be accessible (appropriate shape, position and a place to land).

Photo 14. *Xanthostemon formosus flowers are well adapted for pollination by blossom bats. Its robust flowers, which open in the evening, come equipped with a pollinator reward in the form of large purple nectaries which are clearly evident in this image. Ants also relish these nectaries, but are destructive of the flower and do not act as pollinators. Photo: © Wet Tropics Images.*

Pollination syndromes (**Table 6**) are suites of flower traits which consistently aid in targeting and attracting certain animal pollinators. Some of these traits include flower shape, size, colour, odour, reward type, nectar composition, and timing of flower opening (Howe & Westley 1986). Certain combinations of traits increase the likelihood of successful visitation and pollen transfer by particular pollinating animals. However, generally they do not exclude potential visitation by a wide range of other pollinating animal groups. There are two basic ways of attracting an animal pollinator - through the use of visual cues and olfactory cues. The main visual cue involves flower colour, with the following colours known to be especially attractive to particular groups of pollinators:

- Butterflies - bright red, yellow or blue
- Birds - vivid red or orange
- Flies - purple, brown, greenish
- Bees - variable, yellow or blue but not pure red
- Moths - white, pale green
- Bats - dull white, green
- Beetles - variable, usually dull greenish or off-white.

Photo 15. *The golden bouquet tree (Deplanchea tetraphylla), has a widespread distribution in the Wet Tropics, Cape York Peninsula and New Guinea. Its robust large golden-yellow inflorescence provides a platform for bird pollination. The cup shaped petals fill with nectar which is the inducement to attract and reward its pollinators. Photo: © D. Storch.*

An olfactory cue is essentially a smell emitted by a plant that is particularly appealing to certain animals. Smells known to be particularly alluring to certain groups of pollinators include:

- Butterflies - slight to moderately sweet
- Birds - no odour
- Flies - rotting flesh or dung
- Bees - sweet
- Moths - strongly sweet
- Bats - strong fruity, musky or fetid odour of fermentation
- Beetles - strong fruity, decaying fish or ammonia.

Boulter *et al* (2008) assigned a dominant colour to 1,533 Wet Tropics rainforest plant species' flowers and placed them into several pollination syndrome groups. Their flower colour groups included:

- white/green
- yellow/orange
- pink/red
- blue/purple
- brown
- no corolla.

The overwhelming majority of Wet Tropics rainforest flowers were found to be white/green (72 percent), with twelve percent yellow/orange, eight percent pink/red, six percent blue/purple, one percent brown and one percent having no corolla. They found that a greater proportion of vines have colourful flowers than trees or shrubs (Boulter *et al* 2008). Another interesting finding was that the proportion of white/green flowers appears to decrease with increasing flower size, so that small flowers are more often a dull white or green colour than are larger flowers. The flowers of the overwhelming majority of Wet Tropics rainforest species however, are small in size (i.e. less than ten millimetres in diameter) while large flowers are relatively rare (Boulter *et a*l 2008).

Irrespective of their pollination syndrome, it would appear that very few rainforest angiosperms are constrained by highly specialised pollination requirements. The vast majority of rainforest plants are capable of being pollinated by a diverse range of faunal species (Waser 1983, House 1989, 1993, Bronstein 1995, Waser *et al* 1996). The match between pollinator and syndrome is often relaxed, allowing many flowers to be visited by many kinds of pollinators. For example, Crome and Irvine (1986) demonstrated that in Bumpy satinash (*Syzygium cormiflorum*) which has a typical bat/bird pollination flower type, the low, steady occurrence of insect visitation to the flowers produced fertilisation results equal to that of bird visitation fertilisation. Irvine and Armstrong (1988) also observed that in Sarsaparilla (*Alphitonia petriei*) and Queensland maple (Flindersia brayleyana), beetles, flies and wasps act as pollinators at different times of the day, whereas Nutmeg (*Myristica insipida*) was exclusively beetle pollinated. In Bolwarra (*Eupomatia laurina*) the pollination system has become specialised to the extent that only one genus of weevil (*Elleschodes*) is known to visit its flowers throughout its geographic range, from east Victoria to north Queensland (Irvine & Armstrong 1988). The southern pollinating species of *Eupomatia laurina* is *Elleschodes hamiltonii*, but the weevils that pollinate the Wet Tropics populations are an as yet undescribed *Elleschodes* species (Williams & Adam 2010).

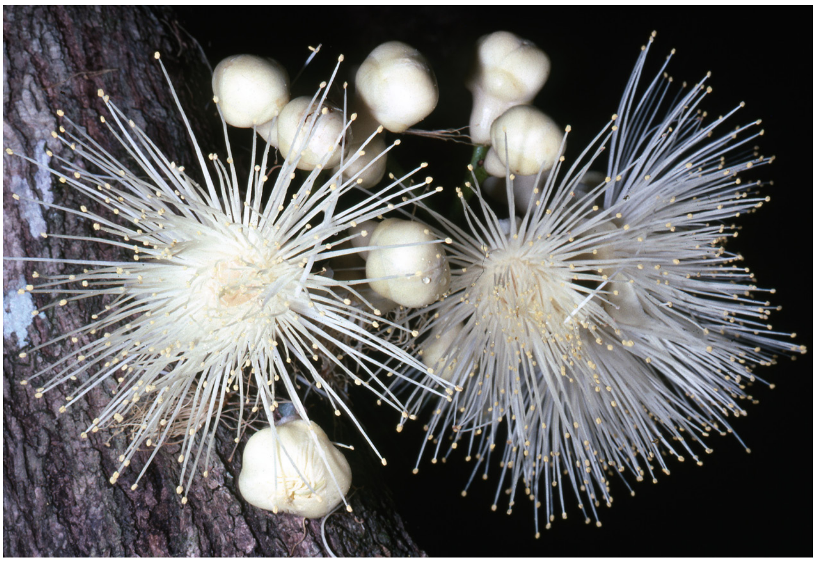


Photo 16. *Syzygium cormiflorum (bumpy satinash) produces masses of flowers (up to 50 mm diameter) on its trunk (described as cauliflorous), and sometimes its lower branches (described as ramiflorous). During the day, the flowers attract an array of birds while at night they attract numerous mammals, such as striped possums, long-tailed pygmy possums and Herbert River ringtail possums. The nectar is also an important food for the tiny rainforest blossom bat (Macroglossus minimus) which has a long, pointed nose and a thin tongue - perfect for licking nectar from the flowers. Photo: © Martin Cohen Wild about Australia.*

Table 6. *Pollination syndromes*

Agent	Time of floral opening	Colour	Odour	Flower size	Flower shape
Insect attracting traits					
Beetles (cantharophily)	Day and night	Variable but usually dull greenish or off-white	Strong, spicy, fruity, decaying fish or ammonia	Variable	Flattened or bowl-shaped
Carrion and dung flies (sapromyophily)	Day and night	Purple-brown or greenish	Strong, decaying meat or dung	Variable	Flat or deep; often traps
Hoverflies and bee flies (myophily)	Day and night	Variable	Variable	Small	Moderately deep
Bees (melittophily)	Day and night or diurnal	Variable but not pure red often yellow or blue. Often with ultraviolet nectar guides.	Usually sweet	Variable	Flat to broad tube
Hawkmoths (sphingophily)	Crepuscular or nocturnal	White, pale or green	Strong, sweet	Large	Deep, often with spur
Settling moths (phalaenophily)	Crepuscular or nocturnal	Variable, drab coloured, generally white, pale or green	Moderately strong, sweet	Small	Flat or moderately deep; sometimes aggregated in heads
Butterflies (psychophily)	Day and night or diurnal	Variable, but brightly coloured (e.g. bright pink, red, yellow, blue, orange)	Moderately strong, sweet	Large	Erect with a flattened rim; deep or with spur; often trumpet-shaped
Vertebrate attracting traits					
Bats (chiropterophily)	nocturnal	White, green or light coloured	Strong, musty; fetid odour of fermentation	Large	Flat 'shaving brush', bell-shaped or deep tube; often arranged on branches or trunk
Birds (ornithophily)	diurnal	Vivid, often red or orange	None	Large, sturdy	Tubular, sometimes curved; robust corolla; often hanging
Abiotic traits					
Wind (anemophily)	Day and night	Drab green	None	Small	Sepals and petals absent or much reduced; large stigmata; much pollen; often catkins

SEED DISPERSAL

Seed dispersal moves offspring away from the parent tree resulting in a lower density of individuals spread over a larger area and increasing chances of successful establishment (Connell 1975). This is important since germination and growth away from the parent plant increases the opportunities of a seed finding a suitable area to inhabit, avoids unfavourable conditions around the parent plant, reduces inbreeding, and reduces competition by siblings for identical resources (Willson & Traveset 2000).

Dispersal limitation is one of the key factors impeding recruitment of rainforest tree species to restoration sites (Tilman 1997, Hubbell *et al* 1999). Three features that strongly influence dispersal are seed size, abundance and dispersal mechanism. Seeds of rainforest trees range in size and abundance based on life history strategies that enhance survival and species coexistence (see Chapter 8). For example, the seeds of pioneer and early successional species are frequently small, abundant and widely dispersed, whereas late successional tree species often invest fewer, larger seeds with resources to recruit in the dim, competitive rainforest understorey (Dalling & Hubbell 2002).

A distinctive phenomenon of tropical and subtropical rainforest angiosperms is the production of fruits with a fleshy pulp which are consumed by a wide variety of animal species. Because the seed of the majority of tropical rainforest tree species are dispersed by animals rather than by other mechanism (Wunderle 1997), the interdependence of fruit-eating animals and the dispersal of seeds is of fundamental importance to the ecology and functioning of rainforests (Janzen 1975, Corlett 1998).

Photo 17. *Rainforest fruits come in many sizes, shapes, colours and aromas which attract a diverse range of animal seed dispersers. Photo: © M. Trenerry.*

Photo 18. *Large single seeded fruits can only be dispersed by a small specialised group of animals. In the Wet Tropics this role is largely confined to a group of large bodied birds with a wide gape such as the cassowary, several rainforest interior pigeons and the migratory pied imperial-pigeon. Photo: © Wet Tropics Images.*

In a rainforest, most trees arrive at their site of establishment via the gut of an animal. However, only animals which do not digest seed are effective dispersal agents (zoochory). To be an effective dispersal agent an animal must either:

- eat both the fruit and the seed but pass the seeds undam¬aged in its faeces;
- eat only the fruit discarding the seeds; or
- allow seeds to adhere or stick to its body.

The most common mode of animal seed dispersal is by passage of seed through the gut of a bird or mammal. One prerequisite for high-quality dispersal is that a frugivore should neither consume fruits before seed maturity nor destroy the seeds during fruit handling. With relatively few exceptions, animals that eat fruit pulp do not destroy the seeds it surrounds (Corlett 1998). As a result, for most frugivorous animals, seeds are unnecessary ballast, occupying valuable gut space and adding weight which most animals discard as soon as possible. Very large seeds that are easily separated from the fruit pulp tend to be dropped from the mouth (or discarded before they enter the mouth) by all but the very largest frugivores (such as cassowaries), while tiny seeds in a slippery fruit pulp are swallowed whole by all, including species that are usually considered seed predators (Shiels 2011).

Plant-frugivore interactions can be influenced by different fruit traits. Particular combinations of traits related to the consumption of fruits and dispersal of seeds by specific groups of frugivores have led to the inference of 'dispersal syndromes' (van der Pijl 1982, Charles-Dominique 1993) (Table7). The physical structure of seed dispersal devices (known as diaspores) is generally correlated with such variables as the dispersal agent, habitat, and successional stage. Fruit type (such as berry, drupe, nut) and the size of fruits and seeds may constrain fruit handling and seed dispersal by animals. Small fruit and large fruit with small seeds are consumed and dispersed by a greater number of frugivores than large fruit with large seeds (reviewed in Jordano 2000). Rainforest trees with diaspores adapted to dispersal by fruit eating fauna display a number of traits which encourage certain animals and discourage others. The quantity and nutritional quality of fruit pulp, the sizes of seeds, and the chemical composition of fruit pulp and seeds may determine attractiveness to different disperser groups (Howe 1989, Grubb 1998, Tewksbury & Nabhan 2001).

Table 7. *Seed (diaspore) dispersal syndromes*

Agent	Colour	Odour	Form	Reward
Primarily self-dispersed				
Gravity (barochory)	Various	None	Undistinguished	None
Explosive dehiscence (active ballistochory)	Various	None	Explosive capsules or pods	None
Bristle contraction (passive ballistochory)	Various	None	Hydroscopic bristles in varying humidity	None
Primarily abiotic dispersal				
Water (hydrochory)	Various, usually green or brown	None	Hairs, slime, small size, or corky tissue resists sinking or imparts low specific gravity	None
Wind (anemochory)	Various, usually green or brown	None	Minute size, wings, plumes, or balloons impart high surface to volume ratio	None
Primarily vertebrate dispersal (zoochory)				
Hoarding mammals (mammalochory)	Brown	Weak or aromatic	Tough thick-walled nuts; indehiscent	Seed itself
Hoarding birds (ornithochory)	Green or brown	None	Rounded wingless seeds or nuts	Seed itself
Arboreal frugivorous mammals (mammaliochory)	Brown, green, white, orange, yellow	Aromatic	Often arillate seed or drupes; often compound; often dehiscent	Aril or pulp rich in protein, sugar, or starch
Bats (mammaliochory)	Green, white or pale yellow	Aromatic or musty	Various; often pendant	Pulp rich in lipid or starch
Terrestrial frugivorous mammals (mammaliochory)	Often green or brown	None	Tough, indehiscent often >50 mm long	Pulp rich in lipid or protein
Highly frugivorous birds (ornithochory)	Black, blue, red, green or purple	None	Large arillate seeds or drupes; often dehiscent; seeds >10 mm long	Pulp rich in lipid or protein
Any frugivorous bird (ornithochory)	Black, blue, red, orange or white	None	Small or medium sized arillate seeds, berries or drupes; seeds <10 mm long	Various; often only sugar or starch
Animal fur or feathers	Undistinguished	None	Barbs, hooks, or sticky hairs	None
Primarily invertebrate dispersal				
Ants (myrmecochory)	Undistinguished	None to humans	Elaiosome attached to seed coat	Oil of starch body with chemical attractant
Trichoma bees (mellitochory)	Undistinguished	None to humans	Wax/resin found in seed capsules	Wax for hive construction

Dehiscent – fruits that splits open at maturity to release their seeds
Indehiscent – fruits that do not open to release their seeds
Arillate – seeds possessing a fleshy outgrowth providing food as an attractant and reward to the disperser.
Drupe – a fleshy fruit having a single hard stone that encloses a seed.
Berry – fleshy, indehiscent many-seeded fruit containing no hard parts except the seeds.
Elaiosome – fleshy structures attached to seeds rich in lipids that attract ants as dispersal agents

Photo 19. *The musky rat-kangaroo is a primitive rainforest marsupial which is an efficient seed disperser and hoarder. Photo: © M. Trenerry.*

Seed dispersal by birds (ornithochory)

A feature of the rainforests of the Wet Tropics is the very large number of frugivorous seed dispersing bird species. A very important trait of the bird seed dispersal syndrome is the observation that a seed passing through the digestive tract of a bird often improves seed germination success (Hollander & Vanden Wall 2009). Birds have heightened colour vision and a tendency to swallow seeds and fruits whole (Lomascolo *et al* 2008) so the general traits displayed by bird dispersed seed include small brightly coloured fleshy fruits (Armesto & Rozzi 1989, Fischer & Chapman 1993, Lomascolo *et al* 2008). There is great variation in both bird body size and the size of their gape. The larger the bird and the larger its gape the larger the size of the fruit it can process. This highlights the importance of the cassowary as the sole long distance animal dispersal agent for many of the largest seeded species in the rainforests of the Wet Tropics.

Photo 20. *The cassowary is the largest frugivore in the rainforests of the Wet Tropics and is the only long distance disperser for several very large seeded rainforest trees. Photo: © Wet Tropics Images.*

In fruit choice experiments, birds were found to generally prefer brightly coloured (red, orange, and black) and ultra-violet light reflecting fruit over white and dull (green and yellow) fruit. Red and black are globally the most common fruit colours of bird-dispersed plant species (Willson & Whelan 1990, Herrera 2002). Red and black exhibit stronger contrasts against foliage than other colours, making fruit more conspicuous for avian frugivores (Schmidt *et al* 2004). So, fruits with bird-dispersal traits are mostly vibrant black, blue, red, or orange in colour, such as members of the families Lauraceae, Sapindaceae, Elaeocarpaceae and Myrtaceae (Howe & Westley 1986).

SEED DISPERSAL BY MAMMALS (MAMMALOCHORY)

Unlike birds, mammals rely on smell more than vision for locating food. The general set of traits that characterise the mammal seed dispersal syndrome include large green or dull coloured fleshy fruit which are more fragrant compared to bird-dispersed seeds (Willson *et al* 1989, Fischer & Chapman 1993, Lomascolo *et al* 2008). The disadvantage of seed adapted to mammal dispersal is that most mammals destroy a large proportion of the seed they consume. Bat-dispersed fruits are usually dominated by duller colours such as browns, greens or yellows.

Photo 21. *The spectacled flying fox is an important rainforest pollinator and seed disperser which can travel many kilometres in a night and over many kilometres between camps. Photo: © M. Trenerry.*

PROTECTION OF SEED FROM PREDATION

Plants have also evolved character traits which protect immature fruits from predation, including camouflage (e.g. unripe fruits are often green), mechanical methods such as spines and an array of chemical defences which make the unripe fruits unpalatable, poisonous or uninviting to potential consumers.

SEED DISPERSAL BY WIND (ANEMOCHORY)

In stark contrast to the animal dispersed diaspores, wind dispersed seeds are usually grey or brown, mimicking the colour of dead plant tissue (Howe & Westley 1986). Seeds which glide in a still environment are well represented amongst late successional emergent rainforest trees and lianes (Harper 1977) where both wind and height enhance the potential dispersal distance. Traits include wing structures (Castro *et al* 2010) and a lack of obvious rewards (Du *et al* 2009). Anemochory is more commonly found in open habitats, and deciduous and semi-deciduous rainforests (Armesto & Rozzi 1989), and is more prevalent in sites exposed to persistent strong winds on summits and upper ridges in the Wet Tropics (Webb *et al* 1986). Wind dispersed seeds often mature in the dry season to optimise dispersal distance (Du *et al* 2009).

Seed dispersal by wind has generally been observed to be far less efficient than dispersal by animals. Under normal conditions the maximum distance travelled by wind dispersed rainforest seeds is less than 100 metres (Webb & Tracey 1981), but this distance may increase to up to one kilometre under exceptional windstorm conditions (Whitmore 1975). Wind dispersed trees with large winged seeds characteristically have a clumped distribution in the rainforest and unlike most rainforest trees are often found growing gregariously.

SEED DISPERSAL BY WATER (HYDROCHORY)

Dispersal of seed by water is basically confined to rainforest trees fringing watercourses. Seeds dispersed by water generally have the ability to float and resist water damage. The woody material enclosing the seed of the blue quandong (*Elaeocarpus angustifolius)*, the large seed of the black bean *(Castanospermum australe*) and the corky, irregularly shaped globular mass containing the numerous seeds of the Leichhardt tree (*Nauclea orientalis*) can float and remain viable in water for considerable periods. This is a necessary requirement for species often found in riparian rainforests.

Photo 22. *The spherical, fragrant flower heads of the Leichhardt tree (Nauclea orientalis) develop into buoyant golf ball-sized fruits. The Leichhardt tree is a characteristic tree of the gallery forests in northern Australia, and also grows in lowland rainforest, particularly in swampy and riparian areas in the Wet Tropics. Photo: © Campbell Clarke.*

SEED DISPERSAL BY GRAVITY (BAROCHORY)

While rolling down slopes may seem trivial, gravity dispersal is possibly the only means of dispersal for some large seeded species such as cycads (Cycadaceae) and Ribbonwood (*Idiospermum australe)* which are toxic and have no known animal disperser (however, Crome (1990) suggests that historically Ribbonwood's disperser may have been a now extinct dinosaur the size of a five tonne truck).

IMPORTANCE OF VERTEBRATE SEED DISPERSAL IN RAINFORESTS

Plant species adapted for dispersal by vertebrates generally represent between 75 percent and 90 percent of woody plants in tropical rainforests (Willson *et al* 1989, Jordano 1992). The rainforests of the Wet Tropics are typical in this respect, with as many as 95 percent of woody plants being adapted for vertebrate dispersal by some 65 vertebrate animal seed dispersers (Westcott *et al* 2008). These vertebrate seed dispersal vectors include 17 mammal species and 48 bird species which represent a roughly similar proportional breakdown to that of other tropical rainforests.

Both the bird and mammal seed disperser groups include species that process seeds gently and provide high quality dispersal, as well as species whose processing results in significant levels of seed damage or mortality. In the Wet Tropics it has been found that 64 percent of mammal seed dispersers also frequently damage or cause the death of seeds as compared with just 23 percent of bird seed disperser species (Westcott *et al* 2008). These results emphasise the important role of birds as the major long distance seed dispersal agent in the rainforests of the Wet Tropics.

About 1300 plant species with seeds adapted for dispersal by vertebrate animals have been recorded in the rainforests of the Wet Tropics (Westcott *et al* 2008). These 1300 species include members from 132 families and 469 genera. A summary of the most speciose animal dispersed Wet Tropics plant families are presented in Table 8; while Table 9 lists the most speciose rainforest plant genera dispersed by animal seed vectors (Westcott *et al* 2008). This sort of information should be used when planning rainforest restoration projects as it provides a logical basis for the selection and proportions of disperser attractive species; for identifying those species less likely to be moved across the landscape by natural dispersers; and for incorporating lean-time and keystone resources within a project.

Table 8. *Most speciose vertebrate dispersed plant families in the Wet Tropics*

Family	No of species
Myrtaceae	102
Lauraceae	100
Sapindaceae	78
Rubiaceae	68
Euphorbiaceae	50
Moraceae	43
Annonaceae	40
Rutaceae	38
Elaeocarpaceae	36
Meliaceae	31

Table 9. *Most speciose vertebrate dispersed plant genera in the Wet Tropics.*

Genus	No of species
Syzygium	46
Cryptocarya	37
Ficus	35
Endiandra	32

SEED SIZE

Fruit or diaspore size has been shown to be one of the most significant factors determining selection of fruits and dispersal of seeds by frugivores (Herrera 1985, Levey 1987, Jordano 1992, Wheelwright 1993, Peres & van Roosmalen 2002). In general, the larger the fruit the smaller the number of potential dispersal agents. In the rainforests of the Wet Tropics, for example, drupes and berries with a diameter of less than 11 millimetres are consumed by all animal seed dispersers; those with a diameter of between 11 millimetres and 24 millimetres are consumed by 84 percent of dispersers, while those with a diameter greater than 24 millimetres are consumed by only 27 percent of the animal seed disperser guild (Westcott *et al* 2008).

Fruit eating birds can be divided into opportunists and specialists. Fruits devoured by opportunist feeders are usually small (less than 11 millimetres diameter), many seeded, often showy and usually juicy. Large fruits attract specialist feeders, and contain few or single seeds. The opportunist feeder fruits typify pioneer/early successional phase rainforest plant species while the specialist feeder fruits are more typical of late and mature phase species.

Photo 23. *Pied imperial pigeons (Ducula bicolor) are summer breeding migrants to the Wet Tropics. They spend their non-breeding season in the forests of Papua New Guinea. They arrive in the Wet Tropics from late winter to mid spring. While the bulk of the migratory population nests on islands close to mainland, they travel between island nest sites and mainland rainforest feeding sites and are very efficient and important seed dispersers. Photo: © D. Pople.*

SEED-RAIN

Success of rainforest restoration over the longer term is greatly dependent on an influx of seed rain via effective seed dispersal mechanisms. The attractiveness of a restoration site to the local seed disperser fauna can have a major influence on which tree species arrive at the site and how quickly they arrive. The planting of rainforest trees may greatly speed the early stages of forest succession and the resulting enhancement of seed dispersal can lead to the progressive diversification of initially low-diversity plantings (Parrotta *et al* 1997). In theory, tree species that provide suitable fruits would be expected to attract more seed dispersal agents and more and a greater diversity of incoming seeds than tree species with unattractive, non-fleshy, fruits. Whether or not some trees are initially planted, large seeded tree species are unlikely to arrive at isolated sites of their own accord. Including some of these species in the planting mix will both ensure their survival in the landscape and provide food for their dispersal agents if these later re-invade or are reintroduced to the area (see also Chapter 12).

For animal-dispersed species, dispersal distances are expected to be longer in species that fruit in times of relative fruit scarcity. At these times, a larger proportion of a fruit crop is likely to be consumed and seeds may be taken farther by frugivores foraging over longer distances for food (van Schaik *et al* 1993). This is a very important consideration in restoration plantings. The incorporation of a range of 'lean time' fruiting species is more likely to make the planting an attractive target for frugivorous seed dispersers including the more long distance dispersers.

The quantity and quality of rainforest seeds dispersed into a restoration site is largely determined by how attractive the site is to rainforest seed dispersers (especially birds). Attributes that contribute to a site's attractiveness include the availability of perch sites, the diversity and availability of fleshy fruits, the structural complexity of the vegetation (Holl 1998, Stiles 1992, Wunderle 1997) and the availability of a source of drinking water nearby. Many studies have demonstrated that the seed rain beneath perches is significantly higher than in nearby sites without perches (Willson & Crome 1989, Nepstad *et al* 1991, Guevara *et al* 1992, McClanahan & Wolfe 1993, Debusche & Isenmann 1994). This is because most regurgitation and defecation of seeds by frugivorous birds occurs when they perch or immediately after they take off, rather than during flight (Guevara & Laborde 1993). Seed dispersal is often limited by the availability of perch trees rather than by the number of potential dispersers (Corlett 2002) and trees become more attractive or functional as perch trees once they exceed five metres in height (Toh *et al* 1999). The architecture of trees and their potential to provide perch sites are important considerations in the selection of species for planting in a restoration project.

Structurally complex vegetation has also been demonstrated to be more attractive to seed dispersing birds (Wunderle 1997). In addition to providing an array of perching sites and abundant and diverse fleshy fruits, structurally complex vegetation also provides more safe-sites, refuges from predators and alternative food resources for partial frugivores.

Photo 24. *The superb fruit-pigeon (Ptilinopus superbus) is a small colourful, arboreal (living entirely in trees) pigeon which feeds almost exclusively on fruit, mainly in large trees. They have a large gape which allows them to swallow large fruits. Photo: © M. Trenerry.*

Restoring multiple rainforest functions requires multiple rainforest species. Rather than focusing on taxonomic diversity *per se*, a focus on functional diversity would appear appropriate when selecting rainforest tree species for restoration (Aerts & Honnay 2011). Whereas general biodiversity measures are based on taxonomy (species presence or absence), functional diversity entails what organisms effectively do in an ecosystem (plant traits). The selection of relevant plant traits in the restoration of rainforest ecosystems should emphasise functional and successional traits. These include seed dispersal, pollination, tree architecture, light requirements, height, growth and vigour traits, for example.

11. PHENOLOGY

Seasonal rhythm is a basic characteristic of life. Phenology is concerned with the temporal pattern of recurring events such as flowering, fruiting and leaf flushing. The study of plant phenology provides knowledge about the patterns of plant growth and development as well as the effects of the environment on flowering and fruiting behaviour.

Flowering is often initiated in response to changes in photoperiod (the relative lengths of light and dark periods); however day length is only one of several cues affecting the regulation and timing of flowering. Other pathways may include temperature triggers or the internal production of plant substances, particularly sugars and the plant hormone gibberellin. Plant age, nutritional status and a range of environmental conditions also interact in the process. Therefore, the transition to flowering, at both the individual and forest community level, is complex and involves the convergence of multiple signals onto the plant's flowering gene circuitry. This complexity is probably fundamental to evolutionary bet hedging on the part of plants (Childs *et al* 2010).

The timing, intensity and duration of flowering dictate the success of a plant's reproductive cycle and, in turn, the success of those animals relying on the plant resources resulting from this process (such as pollen, nectar and fruit). Most tropical rainforests show marked seasonal rhythms of flowering and fruiting (Dew & Boubli 2005). The Wet Tropics enjoys distinct wet and dry season each year, a pattern that is reflected in the flowering (Boulter *et al* 2006) and fruiting (Westcott *et al* 2005) phenologies of the region' rainforests. This marked seasonal rhythm potentially results in a boom and bust, or feast and famine, environment for many rainforest consumer organisms.

Germination in rainforests shows a general community-wide peak at the onset of wet season. Although there is some level of continuous rainforest flowering and fruiting activity throughout the year, there are a greater number of species, and higher intensities of flower and fruit availability experienced at certain times of the year. Several predictable trends in peak times for flowering and fruiting are observable with a very general rule being that peak fruiting times precede the optimal time for germination (Janzen 1967, Frankie *et al* 1974, Primack 1987).

THE SEASONAL RHYTHM OF FLOWERING

The peak in rainforest flowering in the Wet Tropics generally occurs at the end of the dry season and the beginning of the wet season (October and November). This pattern is found for trees, shrubs and vines. Peak flowering near the beginning of the wet season is coincident with a peak of insect abundance, when pollinators are presumably most numerous. It is interesting to note that Boulter *et al* (2008) found that vines, in general, appear to have a very strong seasonal pattern, with low dry season flowering (May through to August). While greater numbers of species, and higher intensities of flowering, is experienced from the end of the dry season through the wet season across the Wet Tropics flora there is still lower intensity flowering activity occurring continuously throughout the year.

THE SEASONAL RHYTHM OF FRUIT RIPENING

The availability of ripe fruit also varies seasonally with peaks in fruit production tending to coincide with rainfall peaks. The more seasonal the rainfall, the larger the difference between the peaks and troughs of annual fruit production. Lean times for fruit consuming fauna tend to occur at the end of the wet season and the beginning of the dry season. During periods of scarcity certain plant products, referred to as keystone resources, act as disproportionally important mainstays of the primary consumer community.

On the upland tableland areas of the Wet Tropics the general seasonal rhythm of the rainforest is outlined in Table 10. The average number of species per hectare dropping significant amounts of fruit and seed peaks between October and January, while there is a severe depression in May through July. The forest's fruiting rhythm is dominated by canopy trees. Understorey trees and shrubs tend to fruit in May and June, when competition for animal dispersers is minimal. Wind-dispersed plants ripen fruit between September and December, possibly taking advantage of the season of partial leaflessness in some communities. Larger-seeded plants tend to drop fruit in March and April.

There is only one peak season of seed germination, at the beginning of the wet season in November through January. The seeds of most plants which drop fruit late in the wet season or in the dry season do not germinate until the beginning of the following wet season.

At lower elevations the patterns of fruiting are similar; however there is a shift in the timing of the peaks and troughs. Crome (1975) found that in the Mission Beach area, for example, the lean season extended through the January to May period, while fruit abundance increased from June/July to a peak between August and September and then declined to December. On the lowlands, the period of resource scarcity between April and July corresponds with the departure of migratory species such as the Pied imperial-pigeon (*Ducula bicolor*) and the Metallic starling (*Aplornis metallica*), and with reports of starving cassowaries and with reports of high levels of mortality or poor condition in other frugivores (Dennis & Marsh 1997).

Table 10. *The seasonal rhythm of rainforest fruit fall on the upland tablelands of the Wet Tropics*

Fruit and seed peaks
- October through January (mid-spring/mid-summer peak)

Severe depression in fruit and seed production
- May through July (late autumn mid-winter depression)

The forest's fruiting rhythm is dominated by canopy trees.

Understorey trees and shrubs
- May and June (end autumn/start winter)

Wind-dispersed plants ripen fruit
- September through December (spring/early summer)

Larger-seeded plants tend to drop fruit in
- March and April (autumn)

Peak season of seed germination
- November through January (late spring/mid-summer - (beginning of the wet season)

Flowering also peaks
- near the beginning of wet season, coincident with a peak of insect abundance, when pollinators are presumably most numerous.

Several other predictable trends occur regarding fruit and its seasonal availability. Canopy fruits tend to be produced in larger crops and are more seasonal than fruits in the rainforest understorey. Small seeded, early successional trees tend to have more extended fruiting periods but smaller daily fruit crops than later successional trees. In addition to this community or habitat level of variation, there are annual variations within species in the size of fruit crops and the timing of fruit production. Trees whose fruiting patterns have been observed over several years usually do not produce similar-sized crops every year, and individual plants often skip years between fruit crops (Crome 1975).

KEYSTONE PLANT RESOURCES

In many tropical rainforests there seem to be a few plants that regularly produce nectar, fruit, pollen, seeds, or flowers during the annual period of general food scarcity. The products of these plants have been termed keystone plant resources (Terborgh 1986a, 1986b). They are important mainstays for animals that consume them (Griffiths 1972, Howe 1977, 1984, Terborgh 1986a, 1986b) and their abundance largely determines the consumer community's carrying capacity at a site. Many fig species (*Ficus* spp.) and a number of early successional plants are major keystone plant resources in the Wet Tropics.

Photo 25 a.

Photo 25 b.

Cluster figs (Ficus variegata) are easily recognised by the large clusters of figs that are borne on short branches off the trunk (cauliflorous) and from their main branches (ramiflorous). These figs change from green to red as they mature. This tree is an important keystone food source for a variety of rainforest animals. Figs have an obligate, mutualistic relationship with their species-specific pollinating wasps. The fig fruit is an enclosed inflorescence, sometimes referred to as a syconium - an urn-like structure lined on the inside with the fig's tiny flowers. Photo: © Campbell Clarke.

Figs have been repeatedly identified as particularly important (Shanahan *et al* 2001, Westcott *et al* 2005), keystone (Terborgh 1986b), or attractive to a very wide array of dispersers (Coates-Estrada & Estrada 1986, Lambert 1989, Kitamura *et al* 2002). The importance of figs may be due to their spatial and temporal ubiquity as a fruit crop (Terborgh 1986b, Westcott *et al* 2005), and to their high nutritional value (O'Brien *et al* 1998). In the Wet Tropics, figs attract a much wider array of seed dispersing fauna than any other plant group and have particularly high visitation rates (Westcott *et al* 2008).

12. LANDSCAPE ECOLOGY

Landscape ecology is the study of spatial variation and pattern of distribution of communities and ecosystems, the ecological processes that affect those patterns and changes in these patterns, and processes over time.

The principles of landscape ecology are increasingly recognised as a means of improving nature conservation outcomes. Nature conservation has been gradually changing its focus from site protection towards conservation of ecological networks, including the wider landscape. The main functional aspect of landscape ecology is connectivity and its importance for both the dispersal and persistence of populations.

An ecological network can be considered to consist of three basic components:

1. Core areas - large expanses of rainforest where the habitat requirements of wildlife species are fulfilled and viable populations can be sustained in the long-term.
2. Corridors - functional ecological linkages or conduits which enable dispersal and smaller-scale movements of wildlife species.
3. Restoration areas – areas where ecological restoration will improve function and resilience of landscapes and connectivity.

LANDSCAPE RESILIENCE

Natural ecosystems have autopoietic (self-creative) capacities to organise, regenerate, reproduce, sustain, adapt, develop and evolve (Westra *et al* 2000). Disturbances whose extent, intensity or frequency is outside the natural historical range can undermine the autopoietic capacities of a system. 'Resilience' was defined by Holling (1973) as the capacity of a system to absorb the effects of disturbances by regaining or maintaining its characteristic structural, compositional and functional attributes, or in other words, without changing into a fundamentally different ecological system. Similarly, Walker *et al* (2004) have defined resilience as the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks.

A resilient ecological landscape is one that can withstand shocks and rebuild itself when necessary. Natural systems are characterised by environmental thresholds that, if crossed, may lead to large-scale and relatively abrupt shifts in state, including changes in ecosystem processes and structure (Knowlton 1992, Folke 2006). Once a threshold is crossed and a shift in state or a key process occurs, it may be difficult, or even impossible, to reverse the shift. Factors contributing to ecological resilience include:

- ***Biological diversity*** – Ecological systems with high biological diversity generally have greater inherent resilience, largely because they have more diverse responses and capacities available to them, which can provide the basis for adaptation (McClanahan *et al* 2002). Diversity of habitats also increases the likelihood of some habitats being more resilient to impacts from particular stresses or disturbances (McClanahan *et al* 2002).

- ***Connectivity*** – The capacity of natural systems to recover after a disturbance, or to reorganise in the face of new or intensified pressures, depends to a large extent on the ability of plant and animal populations and ecological processes to disperse or move across the landscape.

- ***Refugia*** – Areas within the landscape where ecosystems are buffered from pressures or disturbances that would otherwise result in reduced resilience. Refugia serve as secure source areas for the replenishment of disturbed populations and as stepping stones for maintaining population connectivity across larger scales. Important criteria for effective refugia include adequate extent to provide sufficient source populations and inclusion of a diverse and comprehensive sample of many different habitat types.

Conserving or creating greater landscape connectivity between areas rich in biodiversity, in conjunction with refugia, provides greater opportunities for species and ecological processes to recover, re-establish and relocate or to adapt and evolve.

Ecosystem resilience and stability in a developing and ever changing rainforest restoration site depends on the diversity of form and function of the constituent and colonising species. Since groups of closely related species tend to occupy similar niches (Futuyma 2010, Wiens *et al* 2010) it is possible that as environmental conditions and resource availability change, restoration plantings composed of species that encompass a broader range of niches (more distantly related species) may be better positioned to maintain ecosystem functioning because of the differential species responses to this variation (Yachi & Loreau 1999, Fox 2010).

LANDSCAPE CONNECTIVITY

The best response to the threats of habitat loss and degradation is to retain or restore strategic connections between habitat remnants. Elements of a landscape corridor include dispersal corridors (such as corridor networks and habitat corridors) and ecological corridors (which focus on landscape permeability for ecosystem processes).

In the late 1800s, scientists noted that islands contain fewer species than continental land areas of equal size. This observation eventually led to the formal development of the theory of island biogeography (MacArthur & Wilson 1967). Many of today's landscapes are divided into island-like patches that are decreasing in size and becoming more isolated in a sea of human development. Habitat patches display some similarities with islands and a number of spatial principles have been developed based on island biogeography theory:

- Large areas sustain more species than small areas
- Numerous small patches will help sustain regional diversity
- The shape of a patch can be as important as its size
- Fragmentation reduces diversity
- Isolated patches sustain fewer species than closely associated patches
- Species diversity in patches connected by corridors is greater than that of disconnected patches
- An increase in structural diversity increases species diversity
- A high diversity of plant species assures a greater diversity of wildlife.

The most important insight that followed from these theories was that habitat fragmentation increases the vulnerability of populations by reducing the area of available habitat and limiting opportunities for dispersal, migration and genetic exchange.

As originally defined, landscape connectivity is 'the degree to which the landscape facilitates or impedes movement among resource patches' (Taylor *et al* 1993). This definition emphasises that the types, amounts and arrangement of habitat or land use on the landscape influence movement and, ultimately, population dynamics and community structure.

Many remaining patches of rainforest now occur as fragments across landscapes dominated by agricultural and urban clearings. As a result, many species of native wildlife are unable to travel between remnant fragments. This is particularly the case for those rainforest fauna which are restricted to living under a closed canopy and are unable or unwilling to cross areas lacking a closed canopy.

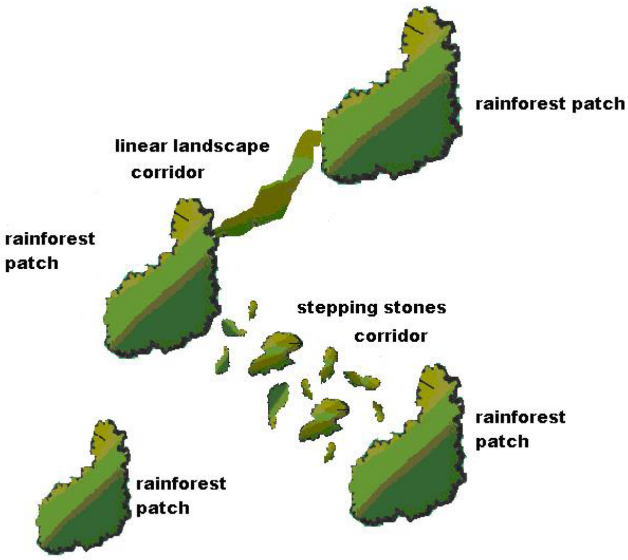
Broadly, there are two kinds of landscape connectivity - structural and functional.

Structural connectivity refers to the spatial arrangement of different types of habitat or habitat patches in the landscape. It ignores the behavioural response of organisms, the movement of organisms or the flux of processes. Structural connectivity is measured by analysing landscape pattern and describes only the patterns and physical relationships among habitat patches such as corridor or inter-patch distances. It is readily measured with a variety of landscape metrics devised to measure the degree to which a landscape is fragmented and to describe the spatial configuration of vegetation patches, their size, shape and isolation (e.g. Gustafson 1998, Moilanen & Nieminen 2002).

Functional connectivity refers to changes in spatially dependent biological, ecological and evolutionary processes. It increases when some change in the landscape structure increases the degree of movement or flow of organisms through the landscape.

This distinction between structural and functional connectivity is not a trivial one. First and foremost, habitat does not necessarily need to be structurally connected to be functionally connected. Some organisms, such as flying insects, bats and birds, are capable of linking resources across an uninhabitable or partially inhabitable matrix (Bélisle & Desrochers 2002). Ecological stepping stones provide resting and feeding stations that enable the safe passage of gap-crossing organisms across landscapes. Ecological stepping stones can be as simple as the preserving or creation of suitable roosting or watering places in deforested landscapes.

Figure 2: *Options for linking ecosystems*



RAINFOREST RESTORATION

Important aspects that need to be considered in a landscape-scale approach to rainforest restoration include (1) the size of restored rainforest patches, (2) the distance between rainforest patches, (3) any existing or potential connections linking patches, and (4) the absence of barriers to wildlife and especially seed disperser movement within these connections.

Some potential advantages for wildlife of restoring rainforest corridors and enhancing ecological connectivity are:

1. Higher immigration rates will maintain species number, increase population size, prevent inbreeding, and encourage the retention of genetic variation.
2. Foraging and habitat area will increase.
3. They provide escape routes from threats and cover for movement between habitat patches.
4. Access to a mix of habitats provides a greater range of resources over a greater period of time.
5. Animals have access to refugia from large disturbances.

6. Enhancing ecological connectivity:

- provides conduits through which wildlife can disperse from areas which have reached maximum carrying capacity and/or competition, and recolonise other favourable habitats, potentially improving the conservation status of the population;
- assists wildlife to escape local or longer-term seasonal changes in environmental conditions;
- allows wildlife access to previously separated populations with which breeding may take place, better maintaining and possibly improving genetic variability;
- allows other ecological processes (such as seed dispersal) to benefit from an increase in wildlife dispersal; and
- allows ecological processes to operate at a landscape scale.

Where restoration plantings are needed to re-establish habitat connectivity, emphasis should be placed on planting favoured wildlife food plants to provide a year-round food supply. A high proportion of the plantings should include those species that fruit outside normal periods of peak abundance. These 'lean time' species are those that fruit during the March to June period when low seasonal fruit production is most likely to induce greater animal movement and a need for expanded foraging ranges.

Relevant considerations in the design or planning of a corridor include:

- The physical structure of the corridor should be designed to minimise ecological edge effects
- Corridors should be established to minimise competition with exotic and native invasive species
- Corridors should not allow local populations to be overwhelmed by immigrants, especially in areas with high levels of local endemism
- Where populations are small and lack immunity, corridors should not allow for the spread of infectious diseases
- The usefulness of establishing and maintaining a corridor should be assessed against other options. For example, would it be more effective and achieve greater biodiversity outcomes to enlarge an existing rainforest patch?

RIPARIAN CORRIDORS AND CONNECTIVITY

It is well documented how forested riparian areas perform many important land management functions, such as their ability to trap nutrients, sediment, or pesticides transported from upslope areas. In addition, riparian buffers provide multiple benefits in terms of biodiversity and water regulation. Although narrow riparian strips perform some ecological functions, the range of environmental benefits increases with the width of the vegetated streambank buffer (Figure 3). Wider riparian corridors provide greater habitat area with reduced edge effects, while generally promoting more opportunities for species movement. Wider riparian corridors can facilitate stream meandering, providing overall higher habitat quality and diversity. Different ecological processes and ecosystem functions occur at different spatial (Figure 3) and temporal scales. Some general relationships with respect to corridor width can be inferred:

- The larger the species, the wider the corridor will need to be to facilitate movement and to provide potential habitat, this is particularly the case for 'deep forest' or rainforest specialist species.
- As the length of the corridor increases, so should the width. Shorter wider corridors are more likely to provide increased connectivity than long narrow corridors.
- A corridor will generally need to be wider in landscapes that otherwise provide limited habitat or that are dominated by clearing and human use.
- Corridors that need to function for decades or centuries should be wider. Some functions that require significant time include dispersal for slow-moving organisms, gene flow, and changes to range distribution due to environmental changes such as climate change.

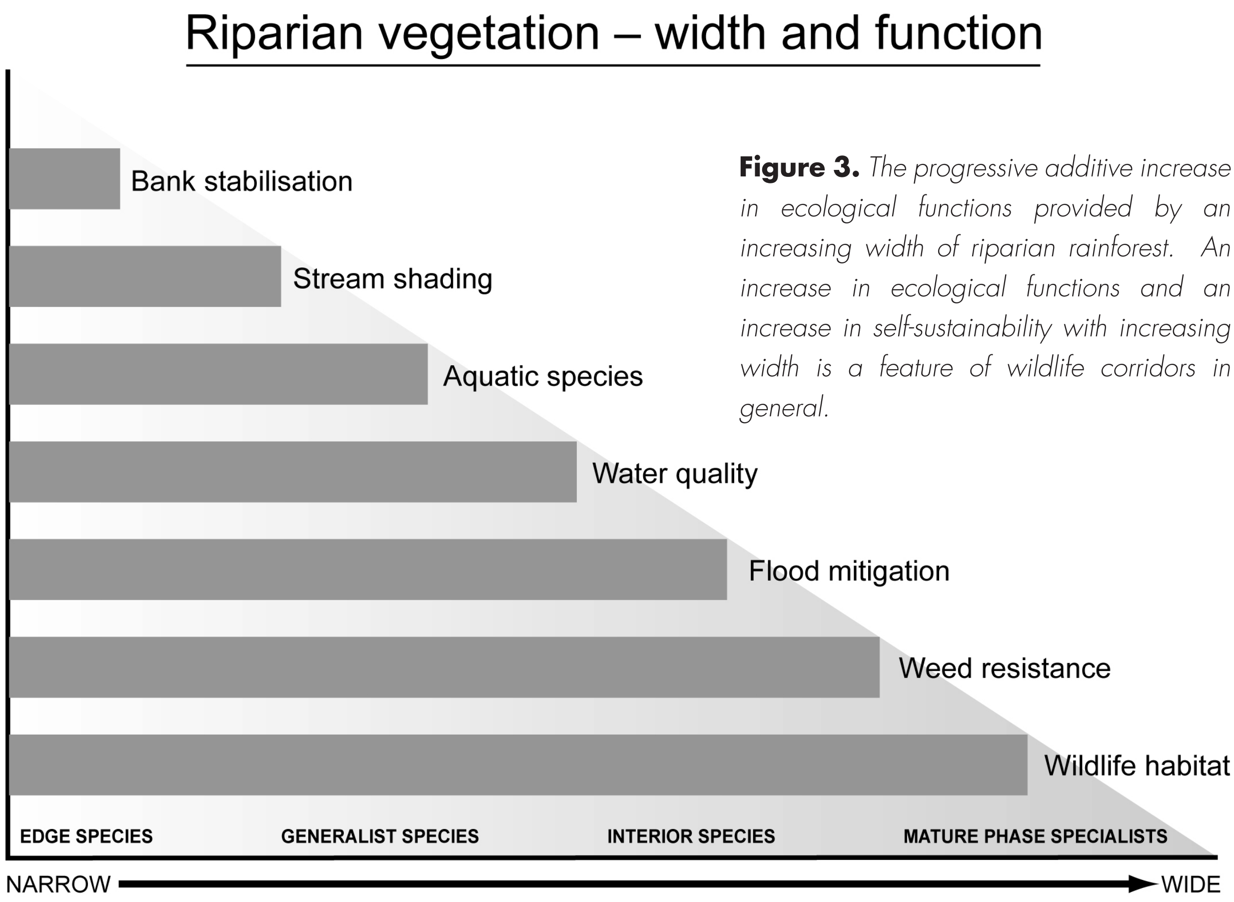


Figure 3. *The progressive additive increase in ecological functions provided by an increasing width of riparian rainforest. An increase in ecological functions and an increase in self-sustainability with increasing width is a feature of wildlife corridors in general.*

In summary, rainforest connectivity refers among other things to:

- the structural configuration of rainforested habitats or habitat patches in a landscape mosaic
- the permeability of a landscape mosaic for dispersal and movement of specific rainforest species
- the presence or absence of barriers or impediments to the natural flux of water or nutrients in a landscape
- landscape permeability with respect to meta-population dynamics of rainforest species
- gene flows amongst species of rainforest plants and animals.

Landscape connectivity and biological permeability can be increased throughout the landscape matrix, and at different spatial scales, through the promotion of:

- linear wildlife corridors linking existing rainforest patches
- larger, more extensive (e.g. whole-of-catchment scale) rainforested corridors
- establishing, maintaining or expanding rainforest patches to serve as 'stepping stones' for particular mobile species such as birds
- special habitat locations that function as refugia
- networks of rainforested corridors throughout the landscape along the riparian zone of watercourses
- inter-connecting areas of high conservation value and strategic conservation importance.

FRAGMENTATION AND EDGE EFFECTS

Forest fragmentation occurs when an expanse of forest is broken and subdivided into smaller, more isolated areas of forest. Fragmentation of a forest is bad for many reasons. Fragmentation:

- reduces the total area of forest
- increases isolation among populations associated with the forest fragments
- creates artificial 'edges' where unmodified habitat abuts disturbed habitat

- increases vulnerability to invasion by non-native species resulting in an increase in new habitat (Andren 1994, Paton 1994, Laurance & Bierregaard 1997)
- decreases habitat value along forest edges well beyond the actual loss of area (edge effects)
- fundamentally alters the community and population dynamics for surviving species (Laurance 2002).

Each of these changes affects habitat suitability. The smaller an area, the fewer individuals and species it can contain. The more isolated a population, the less chance that immigrants will rescue it from catastrophes. Abrupt forest edges allow the invasion of non-native alien species and alters microclimatic conditions. Forest fragmentation, therefore, exerts its effects through both habitat loss and habitat isolation while the edge effects associated with forest fragmentation can modify the environmental conditions of a forest fragment for substantial distances from the edge itself.

Edge effects are major drivers of change in many fragmented landscapes. However the strength of edge effects diminishes as one moves deeper inside forests. Three factors affecting artificial forest edges have been summarised by Murcia (1995) as abiotic effects, direct biological effects and indirect biological effects.

ABIOTIC EDGE EFFECTS

Abiotic edge effects involve changes in the environmental conditions that result from proximity to a structurally dissimilar habitat matrix. In human-fragmented rainforests, the fragments are usually surrounded by a matrix of low biomass and low structural complexity, such as pastures or croplands or a road pavement or a housing estate. Differences in structural complexity and biomass also result in differences in microclimate. Compared to a rainforest, crops, pastures and infrastructure clearings allow more solar radiation to reach the ground during the day and higher re-radiation to the atmosphere at night. Consequently, temperatures in pasture, crops and other types of clearings are generally substantially higher than in an adjoining rainforest fragment, and daily temperatures fluctuate much more widely. The environment under the rainforest canopy, in contrast, is cooler, moister and more uniform. The difference in microclimate between the two sides of an edge is likely to create a gradient of temperature and moisture from the forest edge to the interior of the fragment. Light intensity, light wavelengths, air temperature, air moisture, soil moisture and air movement can vary greatly between the edge zone and the interior of a rainforest fragment.

DIRECT BIOLOGICAL EDGE EFFECTS

Direct biological effects involve changes in the abundance and distribution of species caused directly by the physical conditions near a forest edge. For example, desiccation, wind-throw and plant growth and are determined by the physiological tolerances of species to the conditions on and near the edge. Changes in the physical environment caused by edges may thereby directly affect rainforest structure. The creation of an edge increases incident light which, in turn, promotes the growth of certain species resulting in some rainforest species having lower densities or being absent near the edge while others, which are favoured by these modified edge conditions, show higher densities. The physical environment can also affect rainforest structure in a zone near the edge by causing an increase in tree mortality as a result of wind throw or from the growth of dense, smothering, vine climber towers (Laurance & Bierregaard 1997).

INDIRECT BIOLOGICAL EDGE EFFECTS

Indirect biological effects involve changes in species interactions, such as predation, parasitism, competition, herbivory, pollination and seed dispersal. Edge-driven changes in the forest environment and in forest structure may affect the dynamics of species interactions near the edge. For example, the edge effect on light availability, and on the abundance of herbivorous insects, may initiate a series of cascading effects that can spread across the ecosystem through species interactions (Mucia 1995).

Photo 26. *An example of rainforest fragmentation on the Atherton Tableland. Some of the larger blocks of rainforest are linked by linear wildlife corridors and many fragments are small and isolated. In a few locations, fragments are clustered and have the potential to act as functional connectivity 'stepping stones'. Photo: © K. Kupsch.*

Predictions taken from the study of island biogeography have been extrapolated to predict how numbers of species within habitat fragments will decrease with increasing isolation and decreasing fragment size. However, rainforest fragments are different from true islands in several ways. Rainforest fragmentation also leads to an increase in new habitat which causes changes to the old, particularly on the boundary between the two habitats (Andren 1994). Therefore, there is a decrease in core habitat beyond the actual loss of area (Yahner 1988). The boundary or edge in a habitat fragment is windier, sunnier and drier than the interior, and has a greater variety of microhabitats (Bierregard *et al* 1992). Studies suggest that edge effects for many vertebrate species usually occur within a zone extending up to 50 metres from an edge (Paton 1994), but edge effects, and their zones of influence, are different for different species (Yahner 1988, Laurance & Bierregaard 1997, Neville & Black 1997). Generalist species that thrive on edges and disperse well at the scale of fragmentation may become excessively abundant at the expense of other species in a fragmented landscape. The length of the edge relative to the size of the interior may therefore have a large effect on the species richness of a habitat fragment.

The magnitude of edge effects in a rainforest restoration project can be moderated to some extent by the appropriate selection of tree species with edge sealing characteristics. Edge sealing plant species have characteristics such as an architecture consisting of an overhanging canopy of branches that grow towards open space, or species that maintain leafy branches down their trunks when exposed to full light. Edge sealing plants also include low growing species with a dense shrubby habit. In some circumstances planting a simple, dense, fast growing, tall windbreak adjacent to a rainforest restoration planting may also help ameliorate many of the adverse ecological edge effect impacts. Overhanging canopies not only offer a more aerodynamic profile that can reduce wind damage, but they also act as an umbrella that shadows the edge understorey, buffering it from the conditions exerted by the non-rainforest matrix. Edge sealing can reduce the adverse effects of open edges by reducing fluctuations in temperature, moisture, wind and other microclimate attributes while also reducing the ability of weed species to germinate and spread (see also Chapter 16).

13. GENERAL RESTORATION PRINCIPLES DERIVED FROM THE THEORY

This chapter attempts to synthesise and simplify many of the key points and concepts discussed in the previous chapters. The next part of this book will then describe the practical on-ground application of these general ecological concepts and principles in designing and undertaking rainforest restoration projects.

Although every site is different, and every site has its own unique array of constraints, the adoption of the following principles, which are derived from the concepts described in the previous chapters, should not only increase the biological diversity of an area but also help to restore its ecological functions.

1. Preserve and protect existing patches of rainforest.

Existing, relatively intact rainforest ecosystems are the keystone for conserving regional biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems. Rainforest restoration is a complementary activity that, when combined with protection and conservation, can help achieve overall improvements in landscape health.

2. The defining characteristic of a rainforest, apart from its biological complexity, is its closed canopy.

The establishment of a closed canopy not only shades out most unwanted invasive weed species, but importantly, it creates the moist, buffered microclimate which enables the establishment and growth of a huge diversity of life forms apart from trees. The sooner a closed canopy can be reinstated the sooner many of the functions of a rainforest can begin to take shape and the sooner costly and time consuming weed maintenance can be avoided.

3. There are many different rainforest types. This variability is explained to a large extent by the state factor controls of climate, soil parent material and topographic position.

Within combinations of these state factor controls there are pools of species with a high likelihood of being found together because they share similar environmental requirements and tolerances. These pools of potential biota form the basis of the broad species selection lists provided in Part 3 of this book (Chapters 21, 22).

Other potential species selection considerations might also include:

- To encourage seed dispersal select species attractive to frugivores.
- To encourage development of wildlife populations select species which form mutualistic relationships with animals.
- To facilitate colonisation of dispersal limited species plant poorly dispersed species.
- Introduce rare, threatened and locally endemic species to increase their populations.
- To capture a site quickly and suppress invasive weeds include fast growing species.
- To restore very degraded sites consider species tolerant of poor soils or species capable of site remediation.

4. Mature rainforest ecosystems comprise a mosaic of patches in different successional stages, with the fraction of the landscape in any particular state relatively constant over large temporal and spatial scales.

The size, distribution and return frequency of disturbance events, and subsequent recovery processes, determine to a large extent the spatial scale over which a mature rainforest develops in different locations.

5. Any remnant patches of rainforest still remaining in the landscape provide an ideal starting point from which to strategically design rainforest restoration projects.

Pre-existing rainforest remnants provide a blueprint of what it is that should be restored, an ideal source of propagating material, help in the selection of species adapted to a particular site and provide a source of seed for eventual dispersal to the restoration site.

6. The identification of reference sites are important benchmarks for restoration efforts.

Reference sites are areas that are comparable in structure and function to the proposed restoration site before it was degraded. As such, reference sites may be used as models for restoration projects, as well as a yardstick for measuring the progress of the project.

7. Seed mass is a trait that occupies a pivotal position in the ecology of a rainforest species as it links the ecology of reproduction and seedling establishment with the ecology of vegetative growth and with the ecology of dispersal and succession.

The size of a seed represents the amount of maternal investment in an individual offspring or how much 'packed lunch' an embryo is provided with by its parent when it is sent off to fend for itself and start its perilous journey in life. Small seeds are quicker to ripen and can be dispersed in a shorter period of time while larger seeds have more energy reserves for germination and seedling growth and produce larger, more established seedlings after germination. In general, larger seeded rainforest species perform better under a diversity of adverse establishment conditions including deep shade, competition, low soil moisture and nutrients, burial and herbivory.

8. Since animals are important rainforest seed dispersers and play an important role in rainforest restoration ecology it is important to consider the fruit traits of species chosen for planting that make them attractive to animal dispersers. In addition a proportion of plant species that are unlikely to be dispersed by wildlife also need to be considered, including species with propagules lacking animal-attracting features, wind-dispersed species which are unlikely to reach a site, species with large fruit as well as rare/uncommon species.

The rate at which additional plant species enter a restoration planting site is very dependant on the distance to available reliable seed sources, such as a sizable intact rainforest patch, and on the extent to which populations of seed dispersing wildlife are present in the landscape and capable of travelling to the restoration site. Lower rates of colonisation are expected the more isolated the site or where only small rainforest fragments remain in the landscape.

9. The attractiveness of a site to seed dispersing wildlife will be an important determinant of the rate at which they bring seeds of new species to a restoration site. Structurally complex plantings and sites with a closed canopy are likely to be more attractive to a wider range of wildlife.

Sites with tall trees are likely to be more attractive than those with only short stature trees and the larger the size of the restoration project the more attractive the site is likely to be.

10. The mature canopy trees that create the framework of a well developed rainforest generally have seeds which have a short viability and most have poor long-distance dispersal abilities.

Reserves of mature phase species do not build-up in the soil seed bank as do short-lived early successional species. Most also have either large fleshy fruits or large wind dispersed winged seeds (helicopter-like seeds) designed for short distance dispersal. From a practical perspective this means that the further a restoration site is from a large patch of intact rainforest, the greater the need to incorporate the poorly dispersed late secondary and mature phase component of the local flora into the planting design.

11. The more isolated a rainforest patch the less the chance for recolonisation of the patch from outside seed sources.

Isolated patches of rainforest generally support fewer species than closely associated patches. Restoring landscape structures such as corridors and 'stepping stones' can reduce isolation. Corridors also increase the chances of colonisation of a restoration site by providing a defined path to re-establish populations. Species diversity in rainforest patches connected by corridors tends to be greater than in disconnected patches. Corridors may also act as conduits for genetic exchange among small populations, helping to maintain their viability, adaptability and resilience.

12. In areas where natural recolonisation is slow because of isolation from other large rainforest remnants, restoration methods which bypass the normal successional sequence may be required.

In such circumstances the species used should come mostly from late and mature successional stages, rather than early successional stage species. The more isolated a site from intact rainforest, the more likely the dispersal and colonisation process will be dominated by small seeded readily dispersed early successional generalist species and the more likely the system may be locked into an arrested early succession.

13. Because most rainforest plant species have very short-distance dispersal abilities, it is recommended that as a general rule that only local seed sources are employed in any rainforest restoration planting.

The use of locally sourced seed is important to conserve local adaptations (i.e. characteristics that make individuals suited to their local environment).

14. Rather than focussing on species per se, focussing on functional (trait) diversity of tree species assemblages may be more appropriate when selecting tree species for rainforest restoration projects.

A strong emphasis on functional rather than taxonomic diversity should provide a better kick-start to accelerating natural successional processes and providing a greater array of wildlife resources earlier. It is also valuable to focus particular effort on including strongly interactive species that play a disproportionate role in maintaining ecosystem function.

15. Consideration of successional processes, system development and the role of gap dynamics in fostering a progressive successional sequence and a progressive build-up of biodiversity and structural and functional complexity is important.

In a natural rainforest, disturbance and succession are constantly modifying the environment and all plants are at different stages of growth and maturity. This is different to restoration sites where most stems are initially even aged and similar in size. An initial low disturbance establishment period is highly desirable however, since a major initial aim is for the planted trees to 'capture' the site, shade-out competitive weed species, create a closed canopy and modify and moderate microclimatic conditions. One way to promote controlled small scale, spot-wise natural disturbance is to incorporate a percentage of early successional species into a rainforest restoration planting. By incorporating these species spot-wise disturbances become integrated as a natural event following an initial establishment lag period.

Photo 27. *After 25 years, this restoration planting at Lake Barrine has developed a forest floor with large amounts of small woody debris and a thick leaf litter layer. Evidence of dynamic change can be gauged from the different sized light gaps and obvious bright sunflecks, lichen encrusted tree trunks, the range of different life forms, shade-pruning of lower branches, development of forest layering and the mixed trunk diameter sizes. However, even after 25 years this site still allows greater light penetration to forest floor than would be experienced in a mature rainforest, has still not developed any very large trees, no plank buttressing or woody lianes are evident, no trunk or branch hollows have formed, epiphytes are not yet conspicuous and there is no evidence of development of thick large branches – all these features take a long time to develop. Photo: © Biotropica Australia Pty Ltd.*

16. A forest is more than the sum of its component trees. Faunal species vary considerably in their habitat needs, but in general the older the regrowth vegetation, the more species for which it can provide habitat. Diversity and heterogeneity are the keys to ensuring a range of animals can be accommodated.

This principle is based on the observation that it takes many decades for important habitat features like fallen timber, tree hollows and leaf litter to develop. Similarly, the structural complexity of a restoration planting should also develop and improve with age. The retention of as much standing and fallen dead wood as feasible when preparing a rainforest restoration site can help by-pass this lag-phase as it provides ready-made micro-habitats for birds, insects, reptiles and fungi. This woody material, in addition to acting as an initial mulch layer, can also accelerate the re-establishment of nutrient cycling and other processes important for the ecology and development of soil. It may be beneficial to consider using artificial habitats if key natural habitats are absent or will take a long time to restore; for example artificial nesting sites or boxes, and tunnels and bridges to assist the movement of wildlife across roads or other barriers.

17. Trees serve as important recruitment foci for seed deposition because they provide perching and roosting sites for seed-dispersing birds, bats and other animals.

Understanding how the presence of planted trees influences seed deposition is a critical first step toward understanding the effectiveness of planted areas as catalysts of succession, because the patterns of seed dissemination into a rainforest restoration site ultimately forms the basis for the distribution and abundance of plant recruitment and succession.

18. Connectivity is important as it increases the functional size of ecosystems, improves genetic interchange and, under climate change, allows species to move to find suitable habitat conditions as conditions change.

Restoration projects can provide multiple functional benefits by:

- maximising ecosystem mosaics and connectivity
- increasing patch size
- reducing habitat fragmentation
- providing migration corridors
- conserving sources of plant material for propagation and colonists
- conserving refugia for sedentary species
- reducing edge effects
- increasing opportunities for adaptation to disturbances.

19. Improved connectivity cannot make up for less overall habitat.

Patches of all sizes contribute to habitat for wildlife, but larger patches can also support some species that don't like small patches. Although connectivity among patches is important for many reasons, including animal dispersal and access to resources and is particularly important in landscapes with little vegetation cover and many small isolated patches; improved connectivity cannot make up for less habitat overall. The single most important thing that can be done for wildlife in cleared landscapes is to increase the amount of native vegetation they can use as habitat.

20. Riparian vegetation is ideally suited as the basis for a wildlife corridor system.

There are many benefits from re-establishing rainforest along watercourses including:

- Gullies, drainage lines, streams and rivers form a hierarchy of natural corridors through the landscape
- Riparian habitats support rich biological communities and usually have a high level of structural habitat diversity
- Most forest-dependent species use riparian vegetation, and most animals require water to drink on a regular basis
- Vegetated strips are presently retained along streams to protect water quality and for erosion control. Using the same area as a wildlife corridor minimises the loss of productive rural land.

Photo 28. *An example of a lowland rainforest riparian corridor. Photo: © Campbell Clarke.*

Photo 29. *An intact rainforest bordering an upland stream. Photo: © Tourism Queensland.*

21. Although bigger is not always better, within similar environments, and consistent with the fundamentals of island biogeography, larger areas of rainforest generally sustain more species than smaller areas.

Very large areas are also important as they are more likely to preserve rare species, large predators and forest interior species. Larger area have a greater chance of having a higher diversity of habitat types and, in general, tend to be more stable and self-buffered. The resilience or natural recovery ability of an ecological system also tends to be greater as its size increases.

22. The shape of a rainforest patch is important. Although the ideal shape depends on the surrounding landscape, it is generally accepted that the shape of a rainforest restoration patch should be designed to maximise interior habitat and minimise edge.

The larger the proportion of edge the more pervasive the adverse array of edge effects. Long thin corridors are good at catching immigrants and directing them to larger habitat blocks but they do not allow distinct interior habitats to develop. Many species of wildlife are rainforest interior species which avoid forest edges. To maintain these species, patches need to be both large and have a high area to perimeter ratio.

23. Even though it is desirable to preserve or restore large areas of rainforest, fragmentation of natural forests, expanding human populations and costs preclude this in many areas. The next best option is to preserve or restore many smaller areas.

Because of subtle habitat differences, each small area will contain different combinations of species. By restoring and maintaining several patches, the likelihood of a species becoming extinct is reduced. Many small patches of rainforest in an otherwise heavily impacted landscape will help sustain regional diversity.

24. The aim of a rainforest restoration project should be to re-establish ecological integrity to a degraded site by restoring natural processes and resiliency.

Ecological integrity refers to the condition or health of an ecosystem - particularly the structure, composition, and natural processes of its biotic communities and physical environment. An ecosystem with integrity is a resilient system able to accommodate stress and change.

25. Restoration efforts are likely to fail if the sources of degradation persist. To restore natural processes and initiate progressive succession there is a need to identify and remove the causes that impede natural recovery processes.

It is essential to identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible. Halting activities that cause degradation or prevent ecosystem or species recovery should be considered the first and most critical step in restoration.

26. Invasive weed species can directly threaten biodiversity through competition, or indirectly through introducing diseases, or cause other ecological problems. Invasive weed species also incur economic costs and their management is the major site preparation and on-going maintenance costs in most restoration projects.

Weeds are particularly influential in the early stages of a rainforest restoration project and can prevent arrest or divert the development of the desired or anticipated successional trajectory at a site. The success of any tree planting is largely dependent upon controlling weeds. Site preparation is a crucial stage in the control process as is a regular ongoing maintenance regime for successful rainforest re-establishment.

27. Rainforest structure and function are closely linked and efforts to re-establish the appropriate natural structure can bring back beneficial functions.
Verifying whether desired functions have been re-established can be a good way to determine whether the restoration project has succeeded.

28. Use passive restoration techniques wherever possible and appropriate.
For many sites the saying "time heals all wounds" applies. In many instances simply reducing or eliminating the sources of degradation and allowing sufficient recovery time will be enough to allow the site to naturally repair itself. It is important to note that, while passive restoration relies on natural processes, it is still necessary to assess the site's recovery needs and determine whether time and natural processes can meet them.

29. Monitor and adapt where changes are necessary.
There are many reasons why restoration efforts may not proceed as anticipated. Some level of monitoring of the restoration site is important for finding out whether goals are being achieved. If they are not, remedial actions or adjustments need to be undertaken. This process of monitoring and adjustment is known as adaptive management.

PART 2. PRACTICE

14. ECOLOGICAL RESTORATION

The loss of forest in the past half-century is one of the most profound and rapid environmental changes in the history of the planet. Its impact on biodiversity is automatic and severe… Such is likely to be the world of 2100 - if present trends continue. The most memorable heritage of the twenty-first century will be the Age of Loneliness that lies before humanity. E.O Wilson (The Future of Life)

As any gardener knows, there is a sustained sense of satisfaction when you 'create' with living plants. When you undertake ecological restoration, it is gardening on a grand scale – grand in terms of space and time and endless in terms of the palette of permutations you might create. The garden may be hundreds of hectares and some individuals of the myriad of species you could plant may conceivably live for a thousand years. Moreover, your handiwork will provide homes for millions of creatures, unwittingly going about their daily existence unaware of the creative hands responsible for initiating the complex web of which they are now a part.

Ecological restoration is as much a creative art as a science. But in another way, it is more than both. When you restore an ecosystem you tend to observe, interpret and utilise natural ecological processes such as disturbance, succession, dispersal and pollination. Through this bond, the tree planter develops a deeper understanding of ecological processes and a greater insight into the Wet Tropics environment.

WHY RESTORE?

Ecosystem restoration can benefit everyone and can be managed for a range of land-use, including the two seemingly opposed uses of agriculture and biodiversity conservation. This section explains these benefits in the context of where we live and what we do.

MAINTAINING BIODIVERSITY

Biodiversity occurs at different scales and restoration can improve biodiversity at these multiple scales (Noss 1990). Because restoration involves creating new habitat it helps to ensure that local and regional populations of plants and animals remain stable or increase. It also reduces climatic variation by moderating the temperature and reducing evaporation. This enables species to utilise restored areas as refugia during periods of environmental stress stemming from both natural and man-made disturbances (see also Chapter 12).

PROTECTING ECOSYSTEM SERVICES AND ECOLOGICAL COMMUNITIES

Many ecosystems, and the ecological communities within them, provide essential services such as clean air and water, and regulate ecological interactions such as pollination and dispersal. These ecosystem services are provided free of charge and are of immense importance (TEEB 2010).

PROTECTING RARE AND THREATENED SPECIES AND COMMUNITIES

Humans preferentially clear forests which are accessible and grow on fertile soils in areas with an amenable climate - so-called non-random deforestation (Laurance & Laurance 1999). Unfortunately, these communities also tend to have very high biodiversity values, so clearing results in a disproportionate loss of species. Restoring plant species and communities that are now rare or threatened is one way to immediately improve their conservation status, in addition to providing habitat for animals that may also be threatened.

RE-BUILDING ECOLOGICAL CONNECTIVITY

A well connected landscape is more resilient to all forms of disturbance because animals and plants have the ability to move through the landscape instead of being restricted to one area/fragment. Continuous forests and watercourses allow pollen, seeds and genes to be dispersed more freely across the landscape with less chance of encountering a dispersal barrier.

PROTECTING CATCHMENTS

Watercourses are landscape lifelines. They provide water not only for ecological processes but also for domestic, agricultural and recreational needs. A well-vegetated catchment in the Wet Tropics protects soil and improves the quality of water throughout the landscape, and contributes to the health of the Great Barrier Reef (Devlin & Brodie 2005, Hutchings *et al* 2005, Brodie *et al* 2012).

AGRICULTURAL PRODUCTION

Rainforest restoration can provide a range of benefits to tropical agriculture. Windbreaks, shade and shelter-belts can improve production in both cropping and grazing systems. Restoring riparian forests has been shown to reduce rodent damage in sugarcane (Wilson & Whisson 1993) and macadamia crops (Ward *et al* 2003). Weeds and soil erosion are reduced where there is appropriate native forest cover and many local tree species are highly suited to small-scale farm forestry.

VISUAL AMENITY

Landscapes which feature well-vegetated streams and rivers and patches of native vegetation are more visually appealing than eroded and poorly managed lands with rank weeds and grasses. This is a key consideration in an area where tourism is an important component of the regional economy.

ACHIEVING ECOLOGICAL FUNCTION

Our rainforests have a complexity of structure, species and ecological interactions that is simply not possible to re-build in a short space of time. In a small area there may be many hundreds of plant species, and only a sub-set of these can be established in a restoration plot. Nest hollows may take over 200 years to form (Gibbons & Lindenmayer 2002) so permanent habitation by animals requiring these features cannot take place until these are created. Large hollow logs on the ground may conceivably take many centuries more than nest hollows. Orchids and epiphytes require a stable microclimate as do most shade-tolerant species. Interactions between plants and animals can be complex and require a combination of factors which are also time dependent.

It is not possible to restore these components rapidly - they take a long time. It is, however, possible to harness natural forces and assist nature to speed the process of succession and recovery.

Photo 30. *Donaghy's Corridor is a rainforest restoration site on the Atherton Tableland. It links Lake Barrine (498ha) to the main rainforest massif of Wooroonooran (80,000ha) after over 60 years of isolation. Within three years of planting this corridor 119 species of plants had been naturally dispersed and established, with over 40 percent of these being dispersed from the rainforested areas at either end of the corridor planting. An analysis of dispersal mode showed that over 80 percent of the colonists were primarily bird dispersed and comprised species whose fruits were between 10-30mm in diameter. Large fruited species (>30mm) were rare colonists and almost exclusively species that are primarily dispersed by spectacled flying-foxes (Pteropus conspicillatus) (Tucker & Simmons 2009).*

Prior to the restoration, the only mammals detected at the site were grassland rodents and mice. Within three years these rodents were displaced by rainforest species as grass and weeds became shaded out within the corridor area and a rainforest structure began to develop (Tucker & Simmons 2009; Paetkau et al 2009). After being isolated for over 60 years from neighbouring populations, two species of rodents from Lake Barrine already had sufficient genetic variation to distinguish them from the Wooroonooran population. Based on this genetic data the study definitively showed that animals from one population had joined the other. This occurred when hybrids were identified whose parents had originated at either end of the restored corridor (Paetkau et al 2009).
Photo: © L. Kazmeier.

15. PLANNING

This section focuses on the integration of the theoretical components described in **Part 1 (Chapters 1 – 13)**. These chapters provided a brief overview of the theory of rainforest restoration. They provide the basis for designing and implementing restoration projects in the Wet Tropics. Just as much of the theory applies broadly across tropical environments, the practice outlined here also applies broadly to tropical rainforest restoration.

SITE ANALYSIS

The hallmark of a good project is a commitment to planning. The first stage in the planning process involves an analysis of the site. This is important to understand the limitations inherent to a site. The key information that needs to be considered includes:

a. What have been the agents, frequency, and intensity of disturbances on the site?

Plants and ecosystems have learned to constantly adapt to disturbances (**Chapter 6**). In all natural ecosystems disturbance is a regular and necessary feature. However, in the context of restoration, most disturbance results from human activities and the resulting disturbance, and the type of intervention required, does not occur in nature.

Different disturbance histories will all affect the type and magnitude of appropriate site preparation. Sites which have been subjected to a history of intense and regular disturbance will require significantly more preparation than sites which have only been moderately disturbed. For instance, cattle may have grazed a site for many years, vehicles may have regularly travelled over the site, a significant weed may have covered the site for a period of time, or inappropriate fire may have killed native vegetation.

Identifying weeds on the site and in the surrounding area provides clues to the intensity and nature of past disturbances. For example, sites which have been heavily grazed are often colonised by Snake weed (*Stachytarpheta* spp), Sensitive weed (*Mimosa pudica*) and Rats tail grasses (*Sporobolus* spp). If there are weeds with long-lived seeds such as Sickle-pod (*Senna obtusifolia*), this will influence the approach to site preparation, because sites may need multiple weed treatments before they are ready for planting. Soil compaction resulting from stock or vehicles can be overcome by deep ripping soils to improve porosity. Weed invasion can be remediated by repeated spraying prior to planting to exhaust the weeds in the soil seed bank. Finally, if fire scars are present there is a chance the site may burn again and some form of protection from future burns would be prudent.

b. What has been the level of disturbance to soil (physical, chemical and biological)?

Restoration plantings are challenging and plant growth poor where soils are compacted or eroded, or on soils with limited nutrients which have lost the beneficial micro-organisms which aid in nutrient breakdown and uptake. A simple method to determine the level of soil compaction is to use some form of garden implement to gauge how difficult it is to penetrate the soil. If compaction is obvious then it may be necessary to use machinery to overcome the problem by deep ripping to a depth of 300 millimetres. This greatly improves soil porosity and enhances root development.

Most rainforest restoration sites in the Wet Tropics are not devoid of nutrients, and fertiliser is usually only used to boost the early growth of individual plants, rather than as a broad-acre agricultural application. Provided individual seedlings are supplied with regular fertiliser for 12 months after planting there is no requirement to provide nutrients elsewhere. Excessive fertiliser application to these sites is often counter-productive as it tends to promote weed invasion and vigorous weed growth.

c. What is the distance to the nearest source of propagules and their dispersers?

It is not possible to rebuild the complexity of rainforest life form and structure by restoration planting alone. To rebuild the complexity of a rainforest we rely almost completely on the natural mechanism of dispersal (see Chapter 10). Our decisions regarding the most efficient method to restore a particular site depend mainly on recognising other limitations to dispersal and distance from a source of rainforest seeds.

Open pasture, linear infrastructure (such as roads, powerlines and railway lines), human settlements and dams all present man-made barriers to seed-dispersing wildlife, and impose limitations on the likelihood of successful dispersal (Goosem 2000, 2002).

d. Which ecosystem was formerly present on the site?

In Chapter 4 the differences in rainforest types was discussed, and in Chapter 5 the influence of state factors on regulating the type of ecosystem which is present at a site was explained. Together, these factors will dictate the type of forest which should be the aim of restoration in any particular area.

The Wet Tropics region is fortunate in that patches of forest remain in most parts of the landscape and this allows inferences to be made about the composition of the ecosystem that was present prior to clearing. A visual survey of the vegetation in the area immediately surrounding the site will provide a good indication of those species which grow well in the immediate locality. In Part 3 of this book is a map of the Wet Tropics and lists of species which should be suitable for planting in a particular locality. This takes the guesswork out of selecting species. However it is still useful to look around your local area and observe which species are prominent and which might provide a potential source of propagating material. This local knowledge will enable the refinement of the general species listed in Part 3 for your specific area and specific sets of circumstances.

e. What are the natural disturbances or perturbations that need to be considered?

Newly established plantings have little resistance to flooding, drought, fire or frost. Flooding resilience can be improved by choosing appropriate species from the list of riparian species provided (Part 3), and by planting seasonally inundated sites immediately after the flood season to ensure plants are well established and capable of withstanding inundation in succeeding wet seasons. Conversely, the site should always be accessible so that supplementary watering is possible if a drought period occurs during the first year following planting. If the site has been subject to fire in the past some form of fire break should be considered to protect the site from a possible recurrence of such an event. During cold seasons on the Atherton Tablelands, frost can kill small seedlings, particularly in riparian areas in the lowest parts of the landscape. If the site is likely to suffer frost damage consult with local specialists to determine which species are appropriate for that site. Frost tolerance is discussed further in Chapter 16 in the riparian restoration section.

f. What is the site's ecological relationship to the surrounding landscape?

Chapter 12 dealt with the concepts of core areas, corridors and restoration areas and the role of each in an ecological network. Connectivity and permeability were discussed, as was the importance of restoration in enhancing the viability and persistence of species across the landscape.

A restoration site's spatial relationship to its surrounding landscape influences the decision to choose a particular site in preference to other sites. Locally, sites may contribute to conservation of a particular species such as the cassowary or an ecological community such as Mabi forest or littoral vine-forest.

At a district scale sites may be selected to enhance connectivity between large rainforested fragments in the landscape. Regionally, the site may contribute to enhancing the quality of water discharged onto the Great Barrier Reef. Sites which can provide multiple benefits should be preferred over those which offer fewer advantages.

g. What is the target of the restoration?

The Wet Tropics is renowned for its diversity of species and communities, many of which are restricted by state factors, some to particular parts of the landscape or by particular habitat requirements. Restoration can focus on improving the long-term conservation of certain threatened species and communities.

If a project aims to increase the area of a threatened community then it is necessary to identify the dominant species characteristic of the various strata of that forest type. Some species may only establish after there is a shade producing canopy in place, if so, this needs to be factored into project planning, planting and logistics. Such projects may need to be actively managed for a much longer period than for restoration projects with more modest targets. If the project is designed to promote the conservation of a particular plant or animal then the specific needs of that species need to be addressed. For animals this means establishing favoured food plants and the particular habitat features required to ensure a species has access to all its essential resources to enable it to persist at the site.

h. What resources are required (physical, biotic and abiotic, intellectual, financial, community)?

The hallmark of a good project is a commitment to planning. It is vital to understand all the resources that will be required, and to ensure these resources are in place at the time they are required. Some resources such as funding and a supply of the correct plants require long lead times.

Physical resources include the personnel, equipment and consumables that will be required to complete all the tasks required to establish and maintain a restoration site.

Biotic and abiotic resources are the plants and ecological furniture that will be needed to complete a restoration project.

Intellectual resources are the knowledge and expertise that underpin the design, implementation and monitoring components of a successful project.

Financial resources are those required for labour associated with establishment and maintenance, fencing and other preparation costs such as, plants, fertiliser, mulch and herbicide.

Community resources may include volunteer labour, the provision of land for restoration and a commitment to protect such projects into the future, both from landholders and community groups.

i. Which restoration method will be the most appropriate?

There is a range of approaches available to restore rainforest to a site. The following chapter discusses the rationale behind the selection of an appropriate technique and the methodology involved in the application of each different approach. All of the methods described in the following chapter are underpinned by the theoretical concepts outlined in Chapters 1-13.

16. RESTORATION METHODS

There are two basic approaches to restoring rainforests to areas they once inhabited. Passive restoration largely relies on nature's recuperative abilities. It involves minimal intervention and relies almost entirely on natural mechanisms to progressively restore the plant community. Active restoration, on the other hand, involves active intervention to change the nature and rate of succession. The methods described below represent both active and passive approaches.

Rainforest restoration is now a well advanced practice in north Queensland. The community tree planting group TREAT (Trees for the Evelyn and Atherton Tablelands) was established in 1982 and the group's activities have allowed members throughout north Queensland to develop and refine restoration approaches based on their successes and failures over thirty years. The emergence of other tree planting groups, the Landcare movement, Catchment Management groups, and other community organisations has added immeasurably to rainforest restoration knowledge and capability across the region. The choice of which species to plant, as well as propagation, planting and maintenance techniques, have all been trialled over many years and provides a solid information base.

The combined experience of all these individuals and groups led to the development of the restoration techniques which were originally described in the first edition of this publication (Goosem & Tucker 1995) and which have proved to be still relevant today.

There are three main methods that can be used to restore rainforest ecosystems:

1. Natural regeneration (a passive approach)
2. Framework species method (an active approach)
3. Maximum diversity method (an active approach)

The use of each depends on a variety of factors, but the most critical is the distance of the restoration site to the nearest patch of native rainforest vegetation and the nature of the vegetation between them.

NATURAL REGENERATION

As the name suggests, the natural regeneration method relies solely on dispersal to restore native plants and ecological processes to a site. Although no planting is involved, other interventions may be required to manipulate, assist or accelerate the successional process. These other interventions are also termed 'assisted natural regeneration', 'facilitation' and 'spray and release'.

This method is often appropriate for locations adjacent to an expanse of established rainforest vegetation. The first step is to manage any factors limiting natural regeneration such as stock grazing, fire and weeds. Excluding stock and fire is relatively straightforward, but controlling weeds is a more complex problem and requires an appropriately designed strategy.

Some weed species are able to assist the natural regeneration process because they offer an attractive food resource to rainforest seed-dispersing wildlife such as birds (Aide *et al* 2000, Neilan *et al* 2006, White *et al* 2009). These birds may also feed on fruits found on rainforest margins and in small rainforest fragments. As they visit patches of fleshy-fruited weeds such as lantana or tobacco bush (*Solanum mauritianum*), they defecate seeds eaten at other sites (Parrotta *et al* 1997, Holl *et al* 2000, Meiners *et al* 2002). In abandoned areas, woody weeds often grow taller than most grasses, progressively shading out the grasses and creating the microclimate conditions more suitable for forest plants to establish beneath them (Meiners *et al* 2002, White *et al* 2009). However, both tobacco bush and lantana are 'Declared' weeds in Queensland (Land Protection (Pest and Stock Route Management Act 2002) so it is neither sensible nor lawful to propagate them. However, once the recovery process is underway these weeds can be manually controlled when required, leaving the developing rainforest seedlings to continue to capture the site. Tall, dense grass cover is more likely to halt natural regeneration than other forms of non-allelopathic weed infestation (see also Chapter 7).

It is possible to assist natural regeneration through selective weed control (Woodford *et al* 2000). This is especially the case along rainforest margins where seed rain and natural regeneration will be most productive (White *et al* 2009, Dennis & Westcott 2006). By controlling weeds along rainforest margins, native seed rain is more likely to germinate and establish, allowing the rainforest margin to advance into areas previously dominated by weeds. When treating rainforest margins with herbicide, the objective is to carefully eradicate only the weeds, and to avoid over-spraying onto desirable native plants.

Although weed control can be done at any time, natural regeneration is more prolific if weed control is undertaken in late spring. The majority of local rainforest plants produce fruits between October and February. By spraying weeds in spring, the extensive seed falls of the wet summer season are not competing with weeds. Weeds are also likely to germinate from the soil seed bank. However, most of the germinating weeds will be members of Asteraceae (the daisy family), and with some exceptions these plants are generally unable to compete with rainforest trees.

Natural regeneration can also be assisted by erecting perches where birds typically rest between flights (Holl *et al* 2000, Toh *et al* 1999, Harvey *et al* 2004). Fence-lines are a good example of the interaction between birds and perches. Most cattle tend to avoid barbed wire, but birds regularly use fences as perches, so many seeds are dispersed into sites where cattle don't trample and germination can occur. The result over time is a fence-line which often resembles an unmanaged hedge (Harvey *et al* 2004).

A tree is the best perch because it offers a safer place to forage, to hide or to breed, and a single tree or a small clump can be a focal point for regeneration as visiting birds deposit seeds beneath. If weeds are controlled beneath the tree and/or it is fenced off from stock, the seeds which fall have a much better chance of establishing and regeneration is more likely (Harvey *et al* 2004). This is one way to overcome the problem of aging shade trees on dairy and cattle properties. Many such shade trees are now moribund and have been damaged by cyclones. Fencing these trees and allowing natural regeneration to occur beneath them is an effective strategy to rejuvenate paddock shade trees.

This technique depends on an adjacent seed source to provide the necessary inputs of seed (Parrotta *et al* 1997, Wunderle 1997). If there are no native trees in the vicinity of the site, then it is likely that regeneration will be dominated by weeds. However, amongst the weeds there will also be some native plant species, and by specifically controlling the weeds more desirable species will survive and succession can commence (Woodford 2000).

Facilitation techniques are well suited to the small gullies and streams which occur across agricultural areas in the Wet Tropics. All that is required to start the succession towards a woody plant community is to release the site from grazing or cultivation pressure. The fencing of watercourses is an important first step in reducing erosion and hastening succession and is a good interim measure until more active restoration approaches can be used.

FRAMEWORK SPECIES METHOD

The framework species method is perhaps the most common rainforest restoration technique used in north Queensland. Since it was developed in the Wet Tropics (Goosem & Tucker 1995), this technique has been copied in other parts of Australia (Peel 2010) and has also spread to India (Mudappa and Raman 2010) and many parts of South-east Asia (Elliott et al 2006, Neidel *et a*l 2012). The basis of the technique is to establish particular mixtures of species which act as ecosystem building blocks and attract seed dispersing wildlife. It is this process of natural dispersal that is relied upon to progressively add diversity of life-form and species (Goosem & Tucker 1995).

Because this method relies on both a source of seeds and the animals which disperse them, it is only useful where there is a source of rainforest seeds close by and suites of vertebrates capable of dispersing them (Tucker and Murphy 1997, Moran *et al* 2009). In a study of seedling regeneration in restoration plantings in north Queensland, White *et al* (2004) recorded between 20 and 50 colonising species in ten year old restoration plantings which were between 600 metres and two kilometres from the nearest patch of rainforest. Exotic species were the dominant colonisers. By comparison, restoration plots situated adjacent to rainforest had been colonised by up to 120 new species over the same period, and exotic species were no longer present. Similar studies, emphasise the importance of rainforest seed dispersers and the diminishing dispersal of rainforest seeds as restoration plantings become more ecologically isolated.

Where plantings are close to a standing rainforest the effects of seed dispersal are rapid and sustained. As a planting develops food and foraging resources, bird and other animal visitation increases and the number and diversity of seeds brought in from adjacent rainforests also increases (Tucker & Murphy 1997, Elliot *et al* 2008). In a study at Donaghy's Corridor, a restoration site near Lake Barrine, Tucker and Simmons (2009) recorded 109 new plant species colonising the site three years after planting. Considering 101 species were planted in the corridor, this effectively doubled the total species complement. Some lowland framework species restoration sites have shown even faster rates of native species colonisation (Tucker & Murphy 1997).

Photo 31. *A 22 year old rainforest restoration planting located at Eubenangee Swamp National Park. All the pioneer plants at this site have now been replaced through processes of natural dispersal and colonisation of later successional plant species. The forest has developed a complex multi-layered appearance, and colonising epiphytes are conspicuous. Eubenangee Swamp National Park is one of north Queensland's most diverse environments and the Alice River planting is an example of the rapid recovery which typifies framework species plantings on the coastal lowlands. Photo: © Biotropica Australia Pty Ltd.*

Around 30-40 framework species are generally planted when using this technique, a very small proportion of the total number of species that might occur in a particular area. All plants are established at the same time and there are no follow-up plantings. The framework species method results in canopy closure in around two years and maintenance is reduced to occasional weed control only. It is important to remember that plants selected in the framework species method have the capacity to attract many seed dispersing wildlife. It is the responsibility of these species to add the extra diversity of life form and species typical of a particular area. The objective is not to re-create a rainforest, but to put in place conditions that foster the natural regeneration of a diverse, resilient and self-sustaining ecosystem (see also Chapter 9).

In order of importance, the principal features of framework species include:

a. Tolerance of open conditions
Many rainforest plants are able to cope with being established in open areas, and many canopy species in particular tolerate exposure to full sun. Framework species should also have some drought tolerance and be able to grow in degraded soils. Many Wet Tropics framework species have broad distributions, often extending to other parts of Queensland and Australia. This suggests that they are adapted to a wide range of climatic conditions and are attractive to a wide range of dispersal vectors. They do not rely on specialist dispersal relationships.

b. Attractiveness to seed dispersing wildlife
All vascular plants produce seeds, but careful observation has shown that some species produce fruits which are particularly attractive to frugivorous birds and mammals. The fruits of these species have a number of common characteristics:

- convenient size (e.g. three to ten millimetres) allows them to be swallowed by most rainforest birds
- produced annually (rather than every two years or irregularly)
- provide nutritious fruits which offer a significant dietary reward (Crome 1975, Goosem and Tucker 1995)
- produced in abundant crops.

c. Early production of wildlife resources
Earlier production of resources leads to increased frugivore interaction and the potential for enhanced vertebrate dispersal of seeds. Framework species typically begin producing flowers and fruits from between three and eight years after planting, although this is dependent on a range of factors including light availability, root competition and the successional stage in which a species typically occurs (Tucker & Simmons 2004). Individuals on the margins of a planting and those at canopy level will generally fruit more quickly than other species. Some rainforest species can take many years to produce flowers and fruit and offer only a perch site until this time.

d. Keystone species
In rainforests, resources tend to occur in annual cycles of feast followed by famine. Consequently, resources available for wildlife are intermittent in both space and time. For frugivorous wildlife in the Wet Tropics the months between March and July are especially difficult with fewer fruits available. Plants which produce fruits at all times do not exist, but the figs (*Ficus* spp.) are one plant group which usually has at least one species fruiting at any time of the year (Shanahan *et al* 2001). For this reason figs are an important component of the framework species method. Some figs will also produce fruit from an early age. Species in the Lauraceae (laurel) family are also keystone species, providing a wide variation of different sized seeds, often with a nutritious, oily flesh. Other families are seasonally important (Crome 1975).

Some plants can also be considered keystone species because they produce fruits which ripen outside periods of peak abundance (the lean-time species discussed in Chapter 11). For vertebrates with a mainly fruit diet, these plants supply bridging resources until more varied choices are available. The celery wood group *(Polyscias* spp.) are a good example of a genus which feeds many fruit eating birds in the late autumn – mid winter period. *Polyscias elegans* is especially desirable as its regular and abundant fruit crops often attract large groups of fruit pigeons and the plant is both widespread and very hardy.

Some plants are important in the life cycle of many local animals, both vertebrates and invertebrates. This may be because the plant is a specialised host such as the ant plant (*Myrmecodia beccarii*) and its attendant ant colonies, or the plant relies on a particular disperser such as the relationship between mistletoes and the mistletoe bird (*Dicaeum hirundinaceum*), or the animal's young feed on the plant's foliage, such as the larvae of the hercules moth's (*Coscinocera hercules*) preference for the bleeding heart (*Homalanthus novoguinensis*). These mutualist relationships should be accommodated in planting designs where they exist in a particular locality.

Finally, certain species are dominant components of a particular plant community, yet they are not well represented in natural regeneration. For instance, the tulip oaks (*Argyrodendron* spp.) are a conspicuous component of the canopy in many forest types in the Wet Tropics. This genus typically occupies the upper canopy, and its gyroscopic, wind dispersed seeds are conspicuous during 'mast' seasons (van Schaik *et al* 1993) when mature tulip oak trees fruit simultaneously with a subsequent pulse of seedling establishment (Nadolny 1999). Observations in the Wet Tropics suggest dispersal and regeneration of tulip oaks, and other wind dispersed canopy species, does not extend into restoration plots, even those over 20 years old and adjacent to intact forest. When planted however, tulip oak seedlings generally perform well in restoration plantings, as do many late successional canopy trees with wind dispersed seeds.

e. Ability to create new habitat away from planting sites

Many framework species have the ability to germinate in sub-optimal conditions, which is why many of these species are frequently seen beneath fence-lines and amongst patches of young regrowth across the landscape (Harvey *et al* 2004). Planting framework species can promote rapid regeneration of habitat away from the planting site, again through the activity of wide-ranging seed dispersing wildlife, as seeds from framework species plantings are dispersed to other parts of the landscape.

f. Rapid or persistent growth

Plants which are able to quickly gain a height advantage over weeds are preferred over other slower-growing species. The microclimate created by woody plants provides a better growing site for vertebrate dispersed rainforest plants and their height attracts seed-dispersing vertebrates (Davis *et al* 1998, Toh *et al* 1999, Holl *et al* 2000). Some plants are not known for rapid growth, but are very persistent, even when conditions are not ideal. These species tend to cope well with competition and many only occur in mature rainforests. Shrubs are also important because of their persistence and bushy habitat which casts shade at levels closer to the ground.

g. Ease of germination

Plants with seeds which are easy to collect and germinate are preferred over species which are erratic or difficult to germinate. A plant which produces abundant seed crops and is also easy to grow makes such species an ideal choice for restoration purposes. Plants which have become rare through habitat loss may also germinate readily and, where possible, these should be included in the planting.

Why are earlier successional species important?

While framework species encompass plants from across the successional gradient, pioneer and early successional species comprise 30 percent of the total; with the remaining 70 percent derived from later successional stages (refer to Table 3). Plants from earlier successional stages are important for their:

1. rapid growth and relatively short life span
2. ability to produce flowers and fruits from a young age (Goosem & Tucker 1995, Erskine *et al* 2007).

For example, bleeding heart (*Homalanthus novoguineensis)*, a common north Queensland species, can produce two prolific seed crops in one year, increasing its wildlife resource value.

Because early successional species grow very quickly, they can rapidly create a more structurally complex environment (Swaine & Whitmore 1988, Seimann & Rodgers 2003). Because they grow taller more quickly, they are also more likely to attract birds seeking a safe vantage point and attract more seeds in their vicinity. Their rapid development means they tend to shed branches and leaves quickly. This increased leaf, twig and branch litter provides better conditions for seed germination and seedling growth (Benitez-Malvido 1999, Seimann & Rodgers 2003, Celentano *et al* 2011).

As the early successional species die (generally after 15-50 years) they fall and create disturbance. This results in reduced root competition, extra light penetration to the forest floor, and increased structural complexity at ground level as a result of fallen trunks and branches (Erskine *et al* 2007, Celentano *et al* 2011). Extra light is available to seedlings which germinate beneath early successional species, speeding their growth and creating even more structural complexity. Fallen trunks provide dead wood, a feature which provides habitat for many forms of life. For instance, wood-boring beetles depend on a supply of dead wood for food and habitat. These beetles are the creatures responsible for burrowing into the dead wood within live trees and creating tree hollows – a critical resource for many species which are dependent on hollows for breeding and den sites.

Early successional species also produce flowers and fruits early in life, generally from 3-4 years onwards. These resources attract a variety of wildlife, including those wildlife species which play important roles in pollination and seed dispersal. Species with fleshy fruits are the most useful of this group. Species such as bleeding heart (*H. novoguineensis*), celery wood (*Polyscias elegan*s), coffee bush (*Breynia cernua*) and glossy tamarind (*Guioa acutifolia*) are good examples, as they attract frugivorous birds. Conversely, wattles (*Acacia* spp.) and sarsaparilla *(Alphitonia* spp.) have hard seeds which tend to attract more seed eating birds with cracking beaks (such as cockatoos and parrots).

However, hard seeded species should not be ignored. Acacias create dense shade and out-compete weeds very effectively, providing good sites for seedling regeneration. Sarsaparilla attracts small seed-eating birds, which also feed on the fruits of other plants. The horizontal branching architecture of sarsaparilla trees also provides ideal perching sites for birds. Other hard-seeded species such as *Macaranga* spp. also have many similar, useful attributes.
Intense tropical cyclones are events which create major disturbance and changes to forest structure and microclimate (Catterall *et al* 2008, Kanowski *et al* 2008, Bellingham 2008). In mature forests, the

Photo 32. *An 11 year old planting at Tarzali (Atherton Tablelands). Taller stems attract higher numbers of frugivore visits and are a focal point for natural regeneration. This Alphitonia has accumulated many species and life forms including the vine (Piper sp.) using the trunk to climb upwards to the developing canopy. Photo: © Biotropica Australia Pty Ltd*

extra light penetrating to the forest floor after a cyclone stimulates the growth of established seedlings and new seedlings from the soil seed bank. They thrive in the extra light and grow to occupy new spaces (Connell & Green 2000, Pohlman *et al* 2008, Turton & Siegenthaler 2004). In rainforest restoration plots, because of age and other factors the number of established seedlings, and native seeds in the soil seed bank is much lower. Seeds and seedlings will feature more weeds, so that after disturbance these are likely to be the plants which germinate (Bellingham *et al* 2005, Murphy *et al* 2008). Weed invasion can rapidly diminish habitat values and may overwhelm the restoration plot to the point where a complete re-planting is required. Restored systems do not have the same resilience to disturbance as an established forest. Planting a component of early successional species is an important way in which to build resilience.

Shorter-lived species produce seeds from a young age, and many seeds are incorporated into the soil seed bank. In restored areas after Tropical Cyclone Larry, early successional species rapidly occupied the space left after canopies were damaged, an effect more noticeable in older restoration plots, and plots where early successional plants comprised 25 percent of the initial planting mix. Without fast growing earlier successional species being incorporated within restoration plots, large scale disturbances such as those caused by cyclones are more likely to be colonised by weeds. If the surrounding canopy is able to recover, these plants may not survive for more than one or two years, but if the canopy is largely destroyed then the early successional plants are more likely to provide some long term resilience to weed invasion.

Photo 33 a.

Photo 33 b.

A 20 month old framework species planting in Wooroonooran National Park. Weeds are no longer present but the site has yet to begin recruiting new species. Note the developing litter layer and the shedding of lower branches under the influence of shading by the upper canopy. Only 12 species were used to plant this site because the site has intact forest on both sides and dispersal will rapidly add new species. This plot is now self-maintaining and no further maintenance is required. Photo: © Biotropica Australia Pty Ltd.

MAXIMUM DIVERSITY METHOD

Rainforest animals are remarkably intolerant of cleared land and most will avoid these areas (Laurance 1997, Goosem 2000, 2002, Laurance *et al* 2009). The strength of the isolation effect varies significantly, depending on an individual species' tolerance and the distance between fragments (Goosem 2002). Rainforest dependant frugivores such as the cat bird (*Ailuroedus* spp.) avoid the pastures, crops and settlements which surround and isolate rainforest fragments, whereas cassowaries commonly travel across such areas in their wide-ranging search for food, water and mates (Crome & Moore 1990, Moore 2001). Mammals such as the lemuroid ringtail possum (*Hemibelideus lemuroides*) avoid clearings (Laurance 1997, Goosem 2002) whereas Lumholtz's tree-kangaroo (*Dendrolagus lumholtzi*) appears less constrained (Kanowski *et al* 2003).

Isolation greatly reduces the chance of seed dispersers visiting a site and naturally increasing rainforest species diversity (Tucker & Murphy 1997, White *et al* 2004, Moran *et al* 2009). Instead, isolated plots tend to be visited by birds that are characteristic of open areas - birds such as the pied currawong *(Strepera graculina*) and the brown wood pigeon *(Macropygia amboinensis*) (Crome 1990, Jones & Crome 1990, Westcott *et al* 2008). The vegetation surrounding isolated rainforest restoration sites is usually weed dominated, and it is these weeds that are the source of seeds dispersed by open area birds (White *et al* 2004, 2009). As a result, rainforest plantings distant from native rainforest vegetation, or within areas with highly invasive weeds, are very susceptible to invasion by exotic plants. Isolation therefore means few native seed inputs and potentially high rates of weed invasion.

Because of rainforest seed dispersal limitation to isolated rainforest restoration sites, species and life form diversity will not increase naturally. Maximum diversity plantings aim to overcome some of this dispersal limitation problem by re-planting as much as possible of the pre-clearing diversity. In addition to establishing a wider variety of species and life forms, these plantings also differ from framework species plantings in other respects, including:

- Early successional species are avoided, or restricted to less than ten percent of the individuals planted
- Sequential plantings may be necessary over several years to cater for shade dependant rainforest species that are intolerant of open conditions
- Longer maintenance periods are required because weed inputs are more persistent.

There are many areas in north Queensland which have experienced widespread habitat loss where extra species diversity is required. Large parts of the coastal lowlands between Cairns and Ingham have been extensively deforested and small fragments have been badly disturbed by cyclonic activity (Bruce *et al* 2008). Small rainforest fragments are generally isolated in a sea of sugar cane. Herbaceous and woody weeds are diverse and abundant in the landscape surrounding rainforest fragments. Streams and rivers flanked by narrow bands of native vegetation are similarly susceptible to weed invasion. These sites also need plantings which are multi-layered because of the regular flooding disturbance which occurs on the lowlands.

Maximum diversity plantings are well suited to the re-establishment of Mabi forest - Regional Ecosystem 7.8.2 or Type 5b (Tracey 1982). This endangered semi-deciduous rainforest community is restricted to very small and isolated fragments on the upland tablelands between Atherton and Malanda and most fragments are heavily infested by weeds (Mabi Forest Working Group 2000).

Unlike all other Wet Tropics rainforest community types, Mabi forest is characterised by a high proportion of deciduous or semi-deciduous canopy trees and a dense shrub layer which is dominated by two or three species. This shrub layer is only present in the largest fragments such as at Curtain Fig, Wongabel State Forest and Tolga Scrub Reserve. The dominant shrubs are not tolerant of open conditions and are only encountered in well-developed forest. Where they remain, plants such as turkey bush (*Hodgkinsonia frutescens*), *Codiaeum variegatum* and *Dichapetalum papuanum* are a prominent layer. Elsewhere the shrub layer has been largely replaced by exotic shrubs and vines.

Photo 34. *Mabi forest is a semi-deciduous complex notophyll vine forest which is confined to areas of young stony basalt on the drier western margins of the Atherton Tablelands. The fertile substrate compensates for the high rainfall normally associated with a complex rainforest. The semi-deciduous nature of the canopy is a response to seasonal water stress. It allows a seasonal abundance of light to reach the forest floor and enables the development of a shrubby understorey. Photo: © Campbell Clarke.*

Photo 35. *Mabi forest is characterised by a high proportion of deciduous or semi-deciduous canopy trees and a dense shrub layer which is dominated by turkey bush (Hodgkinsonia frutescens), Codiaeum variegatum and Dichapetalum papuanum. These shrubs are not tolerant of open conditions and, in a restoration planting, are very slow to colonise naturally. These shrubs can be introduced into a planting two to three years after the initial planting when conditions are more suitable for their survival. Photo: © Campbell Clarke.*

In a restoration planting, these shrubby plants are very slow to colonise naturally and intervention is required to manually establish them when the microclimate becomes suitable. Generally, it may take two to three years after the initial planting for sufficient shade and leaf litter to develop. However once a microclimate has established, the process of introducing shade-tolerant plants can commence. Naturally, these shrubs occur in dense aggregations and they can be planted at a close spacing of 300 millimetres. Mabi forest also contains a number of understorey plants that occur only in this forest type and, because only two percent of this type of forest remains, the total population of some of these plants is very low (Mabi Forest Working Group 2000).

As forest fragmentation continues to increase, it may be inevitable that greater initial and subsequent species diversity will need to be incorporated into restoration plantings. Each site is different and the decision to include more species diversity should be made after three years. By this time, weed diversity and abundance begins to decrease and native species colonisation is more common. If a plot has failed to recruit many new species after three to five years, then extra diversity will be required to build resilience.

The timing of follow-up plantings is important. Once plantings become established, competition for light and from the roots of existing plants can create difficulties for establishing additional plants. New individuals planted into an existing established planting tend to grow quite slowly unless they are planted into natural gaps which provide both extra light and less root competition. This effect becomes more severe if tall, lanky plants are used in follow-up plantings. Improved growth rates are achieved by planting smaller seedlings, e.g. no taller than 200-300 millimetres, which tend to grow more vigorously than larger more advanced plants. Satisfactory results may sometimes be achieved by direct seeding into established plantings (Doust 2004, Cole *et al* 2011). Hand dispersal of seeds is a cheap and effective way to increase diversity. Care is required if plantings are adjacent to existing forests where rodents are present and may consume a large proportion of introduced seeds (Pena-claros & de Boo 2002, Elmouttie 2009).

Photo 36 a.

Photo 36 b.

A 17 year old planting at Donaghy's Corridor. A naturally recruited understorey almost completely obscures the people in the left image. Note the over-storey comprising the originally planted trees, now clothed in lichens. Studies showed that within five years, bush rats (Rattus fuscipes) from the previously isolated Lake Barrine patch (498ha) had acquired new genes from the intact population at Wooroonooran (80,000ha). Photo: © Campbell Clarke.

SEALING MARGINS

Regardless of the methodology employed, protecting the edges of a planting from weed invasion is an essential task. One way to limit weeds invading a restoration site is to use a suite of so-called 'edge sealing species' which have common architectural features, and are highly attractive to seed dispersing wildlife.

Bushy species which retain foliage from ground level to their tops cast significant shade and can physically block weeds from penetrating into a plot. When planted within a plot, these species will grow tall and straight with a typical crown, but when planted on the edge where they receive high levels of side light they adopt a bushy habit with branching down the trunk. Even as they age, they typically retain this feature, possibly a response to strigolactone levels (Gomez-Roldan *et al* 2008).

Photo 37. *A 12 year old planting at Tarzali (Atherton Tablelands). The margin has been sealed using a variety of species to block weed movement into the plot. Note the taller stems of pioneer plants just inside the outer row. Their sparse canopy is not suited to margins, but their height attracts perching birds which accelerates dispersal and colonisation. Photo: © Biotropica Australia Pty Ltd.*

As seedlings develop their density also tends to exclude weed growth and prevent weed seed dispersal into the edge. This strategy has been adopted at Donaghy's Corridor – the wildlife corridor linking Lake Barrine to Wooroonooran National Park. At this site many different figs (*Ficus* spp.) were established along the planting margin, and inter-planted with brown salwood (*Acacia celsa*). As discussed previously, fig fruits are a keystone resource, being consumed by most frugivorous birds at some point, but particularly when there are few other resources available. Brown salwood forms a very dense canopy which resists weed invasion. Together, these species form an effective barrier to weed invasion.

Other framework species can fulfil a similar role. Species with good edge sealing features are identified in the species lists provided in Part 3.

Photo 38. *A 15 year old planting at Donaghy's Corridor. At this site, wattle and fig are alternately planted along the margin. Wattles grow quickly and suppress weeds whilst the dense fig canopy will grow outwards into the paddock, providing shade to cattle, buffering the edge, and attracting the attention of passing frugivores. Fig leaves also provide food to a number of possum species which require more or less continuous canopies for ease of movement. Photo: © Campbell Clarke.*

Another more labour intensive method of edge-sealing a planting is to hedge-prune the branches on the periphery of the site which stimulates the dense growth of lateral branches. This technique is useful in some farm situations to maintain vehicle access and to maintain safe working conditions for farm equipment such as harvesters. The example in the photograph is of a sealed edge of a planting adjoining a sugar cane farm.

Photo 39. *Hedge pruning of plants on the edge of a planting will stimulate the dense growth of lateral branches and seals the edge very thoroughly. This labour intensive technique is useful in some farm situations to maintain vehicle access and to maintain safe working conditions for farm equipment such as harvesters. Photo: © Campbell Clarke.*

RIPARIAN RESTORATION

All the major rivers of the Wet Tropics, and many of the minor watercourses which feed them, pass through disturbed lands. This affects the quality of riparian ecosystems. Even the region's least disturbed catchments suffer from weed invasion. For example, the riparian zone along the Russell River around the base of Mount Bartle Frere is lined by guinea grass and garden escapees from the pastures and settlements originating in the river's headwaters. Rivers also carry large quantities of sediment and nutrients lost from adjacent agricultural development and human settlement.

Pure and abundant water is important to the function of rainforest ecosystems, in-stream freshwater aquatic ecosystems and ultimately to coastal marine ecosystems, and the organisms which inhabit them. Restoration of degraded riparian rainforest recognises the importance of maintaining the quality and quantity of our water resources. The restoration of stream bank or riparian vegetation has been a focus of much rainforest restoration effort in north Queensland for decades. Over this period, many kilometres of riparian vegetation has been replanted and there are many reasons why this should continue.

The riparian zone of tropical watercourses is biologically rich because of the abundant soil moisture for plants and surface water vital for animal survival. Watercourses, of whatever size, are sometimes referred to as 'nature's lifelines' in recognition of their importance in sustaining life. Restoring riparian rainforest benefits a wide range of different wildlife and ecosystems, and provides new habitat where it is most needed (Jansen 2005, Lawson et al 2008a, 2008b, Lees & Peres 2008, Seaman & Schulze 2010). These benefits extend from the rainforests all the way to coastal and marine ecosystems.

Water quality is highest along well vegetated watercourses (Burcher *et al* 2008, Arnaiz *et al* 2011). Overhanging vegetation reduces water temperature resulting in higher levels of dissolved oxygen and improved habitat for cold-blooded aquatic species (Heartstill-Scalley & Aide 2003, Burcher *et al* 2008). Overhanging vegetation also contributes leaf litter and organic detritus which forms the basis of many aquatic food chains (Bunn *et al* 1999, Lorion & Kennedy 2009). The woody debris which falls into streams (twigs, branches, logs etc.) also provides important habitat for aquatic organisms (Lorion & Kennedy 2009, Arnaiz *et al* 2011).

Species which are adapted to the rapid rises and falls in water levels so common in the tropics are adept at binding and covering soil, and reducing the scouring effects of flood waters. Riparian vegetation also reduces the velocity of floodwaters thereby reducing the potential erosion and transport of sediments and the pollutants that are bound to sediment particles (Lowrance *et al* 1984, Dosskey 2001).

Vegetated streams are important sites for recreation. Swimming, fishing, bird watching, bush walking and sight seeing are common pastimes in the Wet Tropics and these activities are dependant in some way on the quality of our waterways and their associated riparian rainforest vegetation. Well developed riparian rainforest is also more visually appealing than bare, eroding banks, and shows a responsible and more sustainable approach to land use.

SPECIES SELECTION

Riparian areas are unlike other parts of the forest because disturbance in the form of high velocity floodwaters is a regular occurrence, and most of the plants growing beside streams and rivers are adapted to this regular high intensity disturbance. This creates zones of vegetation where a small group of more specialised species inhabit the area where land and water meet. Small streams which rise and fall quickly do not generally support specialist riparian flora, whereas larger streams and rivers always support species which are often restricted to the vicinity of stream banks. This means that restoring riparian rainforests in the uplands and highlands will utilise a different suite of species to riparian restoration plantings on the lowlands. In many upland/highland plantings there will be fewer species which are found only near watercourses.

Whilst there are fewer specialist riparian species in the uplands/highlands, this area can also be prone to frosts between June and September. Frosts have always occurred at higher altitudes, but frosts only affect open areas. Mature forests are able to create their own microclimate and buffer themselves from frost damage. Frosts now extend into cleared areas formerly supporting rainforest. The area between Tolga and Ravenshoe is most susceptible to frosts.

Because streams are the lowest point in the landscape and many streams now lack the microclimate buffering of intact forest along their margins, frosts can be a regular and destructive occurrence. Few rainforest plants are adapted to frosts. Species displaying frost tolerance tend to be those with a wide distributional range, often extending to the sub-tropics.

Although there are a number of frost tolerant north Queensland riparian rainforest species, many do not necessarily occur naturally in all frost prone areas. In this case the need to establish a native rainforest cover overrides the choice of 'local' plants only. Local species such as creek cherry (*Syzygium australe*), creek lillypilly (*Acmena smithii*), black wattle (*Acacia melanoxylon*) and river oak (*Casuarina cunninghamiana*) do not occur in all upland areas, but all are tolerant to frosts of medium to heavy intensity. If these and other tolerant species are not planted in frost-prone riparian sites, then widespread plant losses should be expected. Once these species have established they provide frost protection by modifying the microclimate. This permits the successful subsequent growth and development of local, frost-sensitive native species.

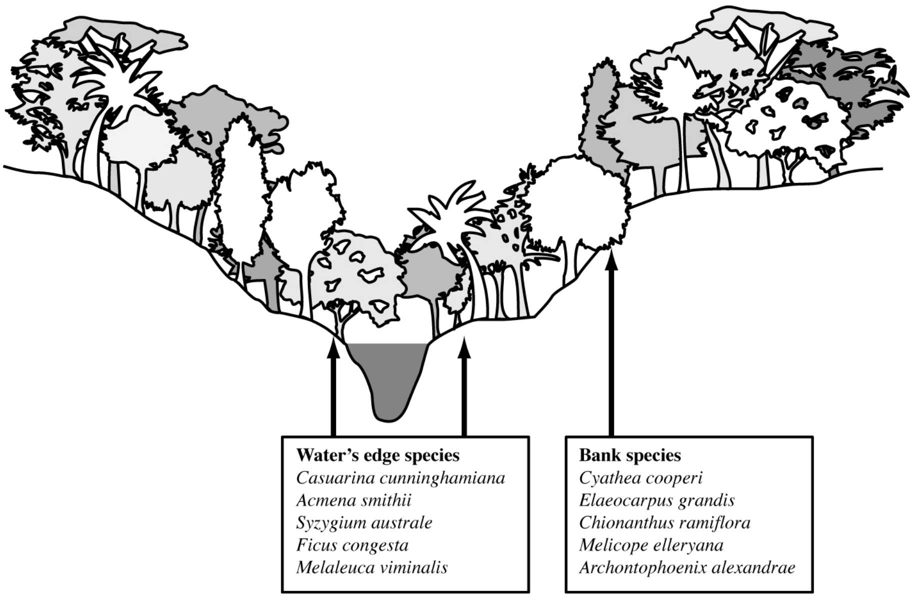


Figure 4. *Typical profile of a riparian rainforest planting on the Atherton Tablelands. Steep, incised streams such as this are common on the Tablelands and the coastal foothills. There is little zonation of vegetation and fewer plants which are solely restricted to riparian zones. Water's edge species in this diagram are more common in wet sclerophyll forests, but are very frost tolerant so are suggested for any area where frost is likely. Bank species are often associated with moist sites away from riparian zones. In the longer term, these bank species will replace most of the suggested water's edge species.*

On the lowlands, larger rivers have riparian zones that are subject to periods of inundation as well as rapid rises and falls in water levels and flow rates. Many lowland rainforest species are adapted to intermittent inundation and lowland river systems feature a number of species which are primarily found in such situations. In planning lowland rainforest riparian restoration plantings it is important to be aware of the length and depth of inundation which occurs at the site in a typical wet season. Stream flow rates are higher in the foothills than on the lowlands and species such as golden penda (*Xanthostemon chrysanthus)*, river cherry (*Syzygium tierneyanum*) and kanuka box (*Tristaniopsis exiliflora*) dominate. As flow rates decrease and rivers widen, these species are generally replaced by Leichhardt pine *(Nauclea orientalis*) and narrow-leaf paperbark (*Melaleuca leucadendra*). Combinations of all these species occur in many sites, depending on local factors. As the period of inundation increases, species such as Leichhardt pine and narrow-leaf paperbark become more dominant, until the watercourse becomes influenced by saline tidal processes where they are replaced by mangroves.

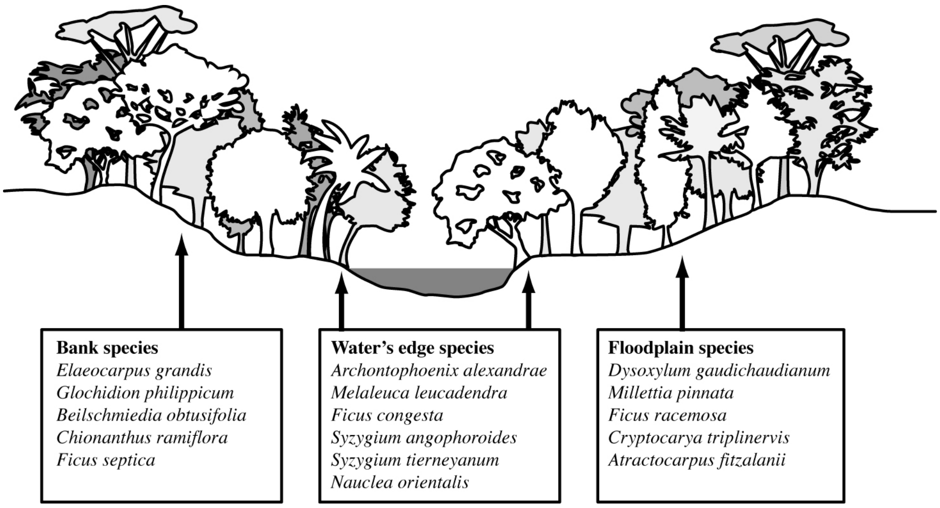


Figure 5. *Typical profile of a riparian rainforest planting on the coastal lowlands. Wider watercourses reflect differences in water volume and surrounding topography, and result in stronger patterns of vegetation zonation. The floodplain is prominent and hosts species that are generally restricted to this position in the landscape. Bank species are more typical of this position, although they also occur in other parts of the forest. Channel width means canopies may not close over the stream, so dense plantings at the water's edge are needed to resist weed invasion.*

WIDTH

Stream bank stability and erosion control depend largely on the quantity and width of riparian vegetation (Tabacchi *et a*l 1998). In a study of the Wet Tropics lowlands near Mossman, Lawson *et al* (2008a,b) found rainforest dependant birds were absent from riparian rainforests of less than 200 metres in width. Whilst many rainforest species will use vegetated strips that are narrower, these studies show that strips of rainforest that are wider than the strictly 'riparian zone' of a watercourse are far more likely to protect soil resources and support the total complement of biodiversity (see Figure 4; Chapter 13). Economically it may not be possible to restore wide swathes of rainforest along watercourses, but planting very narrow strips is unlikely to provide any real wildlife benefit. In essence, wider is better.

One of the problems inherent in restoring the banks of watercourses is the long, narrow, linear nature of these plantings and the susceptibility of this shape to edge effects (see Chapter 12). Weeds can invade both sides of these plantings – at the water's edge and along the side of the top bank - and weed control is difficult and may be required for many years. Along the water's edge more sunlight penetrates and weeds such as guinea grass and Singapore daisy (*Sphagneticola trilobata*) are common and aggressive invaders. Both can establish at the edge and persist for many years or at least until shaded-out by the development of a continuous canopy extending over the land-water interface area and the restored vegetation is sufficiently thick to resist weed establishment.

The long edge along the top bank of a watercourse is also very susceptible to weed invasion. The edge effects associated with narrow plantings allow these weeds to extend throughout the planted area. Edge sealing species should always be established to limit weed ingress along the margins of these plantings. A row of tall trees also provides a useful additional buffer when planted alongside riparian restoration plantings. This further reduces edge effects by buffering the new margin from wind damage. This has been done at the Tableland restoration sites shown in the photograph below - in this case using local native conifers – hoop pine (*Araucaria cunninghamiana*) and bunya pine (*Araucaria bidwillii*). On the coastal lowlands, kauri pine (*Agathis robusta*) and milky pine (*Alstonia scholaris*) can perform the same function.

A list of species for planting in riparian zone plantings is provided in Part 3. This list also indicates the position of each species in relation to the stream profile (water's edge, upper and lower banks, floodplains) and species distribution (lowlands, foothills, uplands and highlands). Some of these species are entirely restricted to riparian habitats, others occur in a broader range of forest settings, but all are commonly associated with wetter areas.

Photo 40. *A 15 year old planting at Donaghy's Corridor. Hoop pine has been row-planted adjacent to the corridor planting to lessen edge effects in the corridor planting, provide shade and shelter to stock, and be a future source of timber and farm income. The foliage of hoop pine also provides nesting habitat for granivorous birds which inhabit adjacent grassland paddock environments. Photo: © Campbell Clarke.*

Photo 41. *An 18 – 22 year old riparian restoration planting along the Alice River at Eubenangee Swamp National Park. Photo: © Biotropica Australia Pty Ltd.*

Because disturbance in the riparian zone is regular and intense it is important to build resilience at the outset. This is done by paying careful attention to the position of plants. It is important to establish water's edge plants as close to the normal water level as possible. This zone is where weed germination and growth is most likely because of the extra light and disturbance along this area. Avoid using pioneer species close to the flow path. They have minimal resistance to floodwaters and are only suitable above the normal flood level. As the planting reaches the upper banks, plant selection should be based on the species suggested in the appropriate lists provided in Part 3.

17. WEEDS

Probably the most significant obstacle to ecological restoration is weeds. Weed control is a major part of successful site preparation and on-going maintenance. A weed, also known as an exotic or invasive species, can be defined as a plant which does not naturally occur in a particular area. Some species may be native plants which have become 'weedy' but the vast majority are plants which have been introduced to Australia from other continents. It is estimated there are around 2700 introduced plant species in Australia which can be classified as weeds (NRM Ministerial Council 2007). Many weed species are highly aggressive and capable of invading both agricultural and natural areas. Weed control costs Australian agriculture around four billion dollars annually and costs to the natural environment are thought to be similar (NRM Ministerial Council 2007).

Many weeds are plants which have been deliberately introduced but have subsequently escaped from horticulture e.g., lantana (*Lantana camara*) and agriculture e.g., Guinea grass (*Megathyrsus maximus*).

Ecological weeds have two main effects. Firstly, they are able to invade and establish in or adjacent to natural areas and, secondly, they are able to stop or reverse the process of natural succession and regeneration within restored areas. Some weeds may completely stop succession, whilst others may temporarily deflect succession away from a recovery pathway (Erskine *et al* 2007, Goosem 2008). Both these effects will compromise the value of a restoration project.

In the context of rainforest restoration, weeds are a problem in two distinct phases. The first phase relates to weeds which are present at the restoration site prior to planting and require control as an important part of the site preparation process. Before any restoration plantings are undertaken the existing weed cover should be eliminated as thoroughly as is practicable to ensure planted seedlings are established free of weed competition. The second phase relates to weeds which colonise the site after a site has been planted. Because the environmental conditions on the site change from full-sun to semi-shaded, the second phase weeds are invariably different to those present on the site prior to the restoration planting. Grasses will not be as dominant, although they will persist in those areas receiving more sunlight. Forbs, herbs and fleshy-fruited vines become more common because of the modified microclimate and the dispersal of these plants into the site, as birds begin to make use of the new opportunities presented by the developing habitat.

When undertaking restoration in the Wet Tropics the most troublesome weeds tend to be the grasses, and the scrambling vines. Each of these groups has different effects on the growth and development of native rainforest species.

GRASSES

Grasses are often a major problem to be overcome in restoration projects. There are a number of reasons for this. Firstly, exotic grasses are extremely competitive and are able to efficiently capture nutrients and moisture (Sun and Dickinson 1996, Davis *et al* 1998, Hooper *et al* 2005). Their ability to successfully outcompete tree seedlings for resources may result in tree growth being stunted or young seedlings dying from being completely smothered. The taller growing grasses are the most competitive. Terrestrial species such as Guinea grass, elephant grass (*Cenchrus purpurea*) and giant cane (A*rundo donax*) are especially competitive. Semi-aquatic grasses such as para grass (*Urochloa mutica*) and olive hymenachne (*Hymenachne amplexicaulis*) are also very efficient at stopping regeneration of native riparian species. Secondly grasses are fire-tolerant and promote their domination by producing a highly combustible fuel load (Hooper *et al* 2005). Rainforest seedlings are killed by fire and fire damage to edges allows the grasses to expand further into fire damaged sites. Finally, grasses maintain a dense groundcover which stops many seeds from reaching the ground surface and germinating successfully (Sun and Dickinson 1996).

Most grass weeds are escapees from cultivated pasture. They are primarily dispersed by machinery, birds and water, and are moved long distances by these vectors.

VINES

Many exotic vines are efficient at climbing onto young seedlings and smothering their growth. In restoration sites the group of vines which cause the most problems are the improved pasture legumes. Their vigorous twining stems can quickly overwhelm planted seedlings and removal is difficult because the plants cannot be sprayed and the twining stems need to be cut from each seedling. All pasture legumes cause these problems, although glycine (*Neonotonia wightii*), calopo (*Calopogonium mucunoides*) and centro (*Centrosema pubescens*) are the most widespread and problematic.

There are also horticultural vines which have escaped from garden cultivation and are significant invaders of small forest fragments. These vines also threaten restoration plantings adjacent to fragments. Siam weed (*Chromolaena odorata*) Madeira vine (*Anredera cordifolia*), blue thunbergia (*Thunbergia grandiflora*), and turbine vine (*Turbina corymbosa*) are very vigorous vines which can rapidly overwhelm plantings.

Exotic vines are found in most parts of the landscape because they are derived from both agriculture and horticulture. The seeds of exotic vines are moved by many dispersers and may also be spread vegetatively by division.

USEFUL WEEDS

From a restoration perspective not all weeds are ruinous. Some can be exploited because they attract seed dispersing vertebrates and are able to shade out grasses and other light-demanding weeds. Camphor laurel (*Cinnamomum camphora*) is one example of a woody weed which performs both these roles. The fruits of camphor laurel are eagerly sought by flocks of white-headed pigeons (*Columba leucomela*) during the months of March and April when there are few other rainforest fruits available. The trees cast deep shade which provides an ideal germination niche for native rainforest plants.

In northern New South Wales, these attributes have been strategically exploited by restoration practitioners who are using existing camphor laurel trees to increase the amount of woody plant cover and hasten the process of succession (Neilan *et al* 2006, Moran *et al* 2009). In north Queensland there are other weeds which can also promote succession. For example, tobacco bush (*Solanum mauritianum*) provides a regular supply of fruits to many birds, and casts sufficient shade to encourage the germination of rainforest plants.

It is not legal or advisable to cultivate some of these species, but in many areas they are an important existing component of a woody succession and arguably there are situations where there is merit in allowing them to continue to function in this way.

18. PREPARING THE SITE

One of the main lessons learnt from 30 years of tree planting is that inadequate site preparation is a key reason behind subsequent failure. Early rainforest plantings were established in areas where grasses and broad-leaf weeds dominated. Initially, no pre-planting control was undertaken, and grasses and weeds were manually cut around seedlings after planting. Failures inevitably ensued until the process of eliminating weeds prior to planting became a standard part of site preparation.

It is important that seedlings are established free of competition. This is best achieved by broad-scale application of herbicide or mulch. Non-residual herbicide application is the most effective technique for large sites. When preparing a site, remember that spraying may be required more than once. The soil seed bank at sites which have supported exotic vegetation for a long period will contain a large store of weeds (Paul *et al* 2012). Killing ground cover weeds, especially if accompanied by soil disturbance, often stimulates the germination of further weed seeds from the soil seed bank. These will usually begin to germinate within 14-21 days after the initial herbicide treatment. For this reason, it is advisable to spray a site at least two or three times prior to commencing tree planting. Blanket spraying the site is the easiest and most effective way to remove potential weed growth prior to planting. However, once seedlings have been planted, the job of weed control using herbicides requires great care.

Photo 42. *A well prepared site. Note the absence of weeds, the use of slashed grass as an initial mulch layer and the close spaced planting of tree seedlings. This community planting was designed to widen and extend an upland wildlife corridor on the Atherton Tableland. Photo: © Campbell Clarke.*

If the weed seed reserves of a site are exhausted as much as possible there will be fewer weeds to control post-planting, and less likelihood of accidental overspray onto planted stock. A final herbicide application a day or two before planting ensures there will be no requirement for maintenance for some weeks after planting.

Dead weed material should always be left on site to add organic matter to the topsoil and to act as a soil cover. Mulching is highly recommended for small sites where hay, cardboard, newspaper and other material can be used to rid the site of weed competition prior to planting. Mulch should be sufficiently thick to stop weed growth, and be re-applied as weeds appear.

ECOLOGICAL FURNITURE

The process of land clearing and subsequent grazing and cropping leads to the loss of ground-storey habitats. Logs, branches and rocks of all sizes and different physical arrangements are part of the forest's ground-storey furniture. They are used by a wide variety of animals for feeding, breeding, resting and hiding from predators. Different portions of fallen logs are used by a wide assortment of animals. Peeling bark is used for foraging and shelter by invertebrates. Decaying wood provides foraging sites for the striped possum (*Dactylopsila trivirgata*), and specialised dead wood feeding beetles. Beneath the log is a habitat for small mammals, skinks, lizards, snakes and frogs. When semi-submerged in water, logs are essential habitat for turtles, water dragons and fish, and favoured basking sites for pythons.

In the process of decay, logs return valuable nutrients and organic matter to the soil and aid in moisture retention. This improves the quality of habitat available for plants which germinate adjacent to these features.

Large logs (fresh and/or decaying) are not always available where and when they are needed. However, there are many landholders whose properties contain exotic species such as camphor laurel, rain tree (*Samanea saman*) and African tulip (*Spathodea campanulata*). These species are quite suitable as dead wood habitat and are readily available. Large branches are also valuable and, when stacked in piles, can form complex microhabitats. As the restoration site matures and natural regeneration commences, early successional plants and/or late secondary species can also be thinned to provide dead wood and under-bark habitat. Ringbarking can speed their demise, but their long term contribution as dead wood will depend on the species. Wattles have much harder wood and will provide longer lasting habitat when compared to species such as sarsaparilla.

Agricultural ploughing and slashing has removed most of the original rocks and boulders once found in potential restoration sites. One rock may provide only minor value but piles of rocks with crevices of different sizes provide a significant and varied habitat. Snakes, lizards and skinks are especially attracted to rocks, and many ferns and orchids are commonly found on rocks and boulders. Rocks are easily found – most farmers have large piles adjacent to paddocks where they have been pushed after clearing for cultivation.

Once a site is planted it is not as easy to place these features. It is a site preparation task which should be completed beforehand. Once they are placed, it is possible to more carefully select plants to establish adjacent to the feature. Planting gingers, scramblers and vines nearby will increase the value of ground-storey habitat by integrating features into the surrounding vegetation.

Artificial nest boxes are one way to circumvent the absence of nest hollows. Because nest hollows are slow to form naturally but are an important habitat resource, they are worth erecting if there are wildlife species present which require hollows. There is considerable variability in the dimensions and shape of nest hollows utilised by birds and mammals. Owls generally require much larger boxes than gliders, for instance.

Once the site has been prepared and the required furnishings are in place, planting can commence.

PLANTING

'Tree planting is an act of faith in our collective future' J. Peter Stanton 1991.

Planting is perhaps the easiest part of rainforest restoration and also the most enjoyable. There are however, a number of steps which need to be taken prior to the commencement of planting. It is important to ensure plants are sun hardened prior to planting. Plants purchased from nurseries are often grown and displayed in shady conditions. When these plants go from a shady environment where they are watered twice daily to an open site, the effects of full sun and wind can cause transplant shock. In some cases the plant may shed all of its leaves and then re-shoot, or the plant may die.

If purchasing soft nursery plants which have come from a greenhouse, place them in a sunny position where they can be regularly watered. When new leaves appear, they will be adapted to stronger sunlight and the plant is then ready for planting out. Sun hardening will generally require two to four weeks. Always ensure planting stock is watered before being taken to the site. It may be some hours before plants go in the ground and a pre-planting soaking will ensure the plant is in good condition at planting and can be removed from its pot with minimal root disturbance.

At planting, ensure that the faster growing early successional species are well spaced and interspersed amongst other species and avoid having the same species side by side. Ensure that margin-sealing species are placed along edges. Pay particular attention to species that will be established adjacent to a site's ecological furniture.

Holes should be dug twice the size of the pot containing the plant. At the base of the hole put a small amount of general fertiliser and cover this lightly with soil. As the roots establish they will grow into the fertilised soil and growth will be boosted. Fertiliser can also be applied as a top dressing around the base of the stem. If you place the fertiliser on the surface ensure there are no weeds present - fast growing weeds are more efficient at capturing nutrients and will rapidly overwhelm planted rainforest seedlings. Although slow-release manure based fertilisers are recommended, as these are less likely to cause root burn, any general purpose fertiliser is an acceptable alternative.

Roots are able to rapidly regrow if they are moist and in direct soil contact, so at the completion of planting, each rainforest seedling should receive sufficient water to ensure the roots and soil are bound. Creating a saucer-shaped soil mound around the base of the plant is a good way to increase the amount of water which flows to the root system.

Dead stems should be replaced as quickly as possible after the main planting unless they are in a patch. After six months, neighbouring plants will begin to exert competition for light and root space and some newly established plants will be unlikely to grow satisfactorily.

Generally plants are spaced at distances of 1.5 metres to 1.8 metres. The difference can be significant in that a 1.5 metre spacing requires 4400 stems per hectare whilst a wider 1.8 metre spacing requires only 3700 stems per hectare. When using the framework species method a 1.5 metre spacing promotes very rapid canopy closure and the creation of a microclimate that allows regeneration of native species within twelve to eighteen months. In the maximum diversity method planting at a spacing of 1.8 metres allows more room for follow-up plantings. Spacing distances of two metres or more results in light levels which favour weeds and a requirement for their on-going maintenance for a much longer period of time and should be avoided.

MAINTENANCE

The maintenance of a restoration site predominantly entails weed control. The highly competitive nature of weeds is the main reason why tropical rainforest restoration plantings may fail. Once rainforest seedlings and saplings are embedded in a matrix of tall grasses and broad-leaf weeds, they will cease growing or exhibit very slow growth. Grasses and broad-leaf weeds are better adapted at capturing moisture and nutrients in high light environments and must be continuously controlled until the planting has developed a canopy which can effectively shade-out the light-demanding weeds.

Herbicide is the more commonly used site maintenance option, although there is an inherent risk of overspray onto planted trees which are equally susceptible to the effects of herbicide. If weeds have colonised the site, it will be necessary to clear around planted stems prior to spraying. This is to reduce the risk of overspray onto planted stems. Herbicides are a fast and reliable way to eradicate weeds over large areas and can be applied at any time when weather conditions permit. Generally, broad-spectrum herbicides are more useful because sites will contain a mixture of grasses and broad-leaf species. Glyphosate preparations are most commonly used.

Maintenance weed control can be done either by heavy mulching or by herbicide application, or a combination of both. There are a wide variety of materials that can be used as mulch including cardboard, newspaper, hay, woodchip or any other vegetative material. In addition to stopping weed germination mulch assists with moisture retention and adds nutrients through decomposition. Some types of mulch such as shredded bark and wood chip will render some nutrients unavailable and supplementary applications of nitrogen fertiliser may be required, along with liming to reduce soil acidity.

Mulching is best suited to small sites because of the large volume of material required to cover large areas. Depending on the material used, mulch should be at least 150 millimetres deep. Some woody weeds are able to grow through mulch of this depth and may require manual control if this occurs. There are variations in the rate of decomposition between various mulch products. Some products will require supplementary applications to maintain effective soil cover and resistance against weed germination.

19. GROWING YOUR OWN PLANTS

Most rainforest plants are easily propagated and growing your own seedlings is a way of reducing costs and ensuring the quality and provenance of seedlings. Many species listed in **Part 3** occur across a wide range of ecological gradients. By collecting seeds from the area surrounding the restoration site you are more likely to capture the genetic variation which occurs in populations which are adapted to local environmental condition. If you collect and then plant the progeny of only one tree, there is a risk of plantings comprising a narrow gene pool. Collecting from a number of individual trees will maximise the genetic variability of a planted site, so always attempt to collect from at least five individuals of the same species.

Seed treatment is required to enhance germination and reduce the likelihood of seed predation by invertebrates. However, some fruits are quickly attacked and fleshy fruits harvested from the ground should be soaked in water for 12-24 hours prior to sowing to kill any insects which may have already begun to attack the seed. **Table 11** summarises the most common techniques used to propagate rainforest seed. Community nurseries across the Wet Tropics are ideal places to learn more about native plant propagation and maintenance.

Table 11. *Seed treatments to enhance germination success of rainforest species*

Fruit type	Species (examples)	Treatment
Seed surrounded by a hard nut/shell, usually with a fleshy covering	*Elaeocarpus bancroftii* *Athertonia diversifolia* *Aleurites rockinghamensis*	Remove flesh, place the nut 'end to end' in a vice and turn slowly until cracked. Seed can be removed from the shell, and sown fresh.
Single seed surrounded by a fleshy covering	*Syzygium spp.* *Endiandra spp.* *Arecaceae (Palms)*	Soak in water for 12-24 hours to destroy insects/larvae. Remove flesh and sow immediately.
Fleshy fruit enclosing many seeds (except figs)	*Acronychia spp.* *Atractocarpus spp.*	Allow the outer flesh to soften, hasten this by soaking in water. Remove seeds and sow fresh
Fleshy fruit enclosing many small seeds (including figs)	*Ficus spp.* *Nauclea orientalis*	Allow the fruit to dry, hasten this by breaking the fruit into fragments. Crumble the dried material and sow.
Seeds surrounded by an aril, and enclosed in a leathery capsule	*Myristica globosa ssp. muelleri* *Diploglottis spp.* *Mischocarpus spp.*	Remove capsule and aril, sow fresh. Species with very fleshy arils may require soaking to kill off insects/larvae.
Conifers	*Araucaria cunninghamii* *Agathis spp.*	Collect whole cones beneath the parent tree. Allow the cones to split and winged seeds to separate from the cone scales. Sow fresh
Paper-like seeds enclosed in a dry capsule	*Buckinghamia spp.* *Flindersia spp.* *Cardwellia sublimis*	Pick capsules slightly green and allow them to split in a warm, dry place. Remove seeds and sow fresh.
Pioneer species with enforced dormancy	*Acacia spp.* *Alphitonia spp.*	Place seeds in boiling water. Soak Acacia spp 1hr, Alphitonia spp 24 hours then sow. Can be stored.
Large seeds (>60mm)	*Castanospermum australe* *Beilschmiedia bancroftii*	Remove any fleshy covering. Sow one seed directly into an individual pot.
Grasses and grass-like plants	*Lomandra spp.* *Oplismenus spp.*	Pick as seed heads begin to brown and allow them to split in a warm, dry place. Can be stored.

20. WHERE TO FROM HERE

This book provides the basis for understanding the ecological restoration process, but there are many other resources available to anyone interested in delving more deeply. In north Queensland there are community groups and government agencies which assist in a variety of ways including designing and implementing restoration projects, helping with tree supply and practical advice, as well as providing funds and assistance preparing grant funding applications.

Some organisations operate nursery facilities specialising in the production of plants for restoration works, and many offer valuable opportunities to participate in the restoration process. Seed collection, propagation, tree planting and public education are all skills which can be acquired at locations across the Wet Tropics region, as well as access to expertise in convenient locations.

The table below provides a list of regional groups and organisations involved in restoration and/or environmental protection and the range of services they provide. Anyone involved in ecological restoration in the Wet Tropics will need the advice and assistance of these organisations at some point, and making contact is an ideal first step.

Group	Contact
Barron River Catchment Group	www.barronriver.org.au
Cairns and Far North Environment Centre (CAFNEC)	www.cafnec.org.au
Cairns Regional Council Nursery (Mossman)	07 4044 3044
Cairns Regional Council Nursery (Stratford)	07 4099 9444
Cassowary Coast Regional Council Nursery (Tully)	07 4068 0055
Community for Coastal and Cassowary Conservation (C4) – Mission Beach	www.cassowaryconservation.asn.au
Daintree Region Cassowary Group Inc	www.daintreecassowary.org.au
Tablelands Regional Council Community Revegetation Unit	07 4096 5354
Girringun Aboriginal Corporation (Cardwell)	www.girringun.com.au
Malanda Landcare Group	www.terrain.org.au
Mitchell River Watershed Management Group Inc	www.mitchell-river.com.au
QPWS Restoration Services (Lake Eacham)	07 4095 3406
Society for Growing Australian Plants	www.sgapqld.org.au
Terrain NRM	www.terrain.org.au
Tree Kangaroo and Mammal Group Inc	www.tree-kangaroo.net
Trees for the Evelyn and Atherton Tablelands Inc (TREAT)	www.treat.net.au
Wet Tropics Management Authority	www.wettropics.gov.au
Yungaburra Landcare Group	www.terrain.org.au

There are a range of publications that offer additional information on ecological restoration, rainforest ecology and plant identification. The texts listed below are both broad general publications and more specialised reference material on the Wet Tropics region.

Beasley, J. *2006. Plants of Tropical North Queensland: the compact guide.* Footloose Publications, Kuranda, Australia

Calvert, G., Lokkers, C. and Cumming, R. 2005. *Rare and Threatened Plants of the Townsville – Thuringowa Region.* Coastal Dry Tropics Landcare Inc, Townsville.

Cramer, V.A. and Hobbs, R.J. 2007 *Old fields: Dynamics and restoration of abandoned farmland.* Island Press, Washington

Cooper, W. and Cooper W.T. 2013. *Australian Rainforest Fruits: a field guide*. CSIRO Publishing

Erskine, P.D., Lamb, D. and Bristow, M. (eds) 2005. *Reforestation in the Tropics and Subtropics Using Rainforest Tree Species*. RIRDC Publication No 05/087, Rural Industries Research and Development Corporation, Canberra.

Jackes, B.R. 2001. *Plants of the Tropics - Rainforest to Heath an Identification Guide*. James Cook University, Townsville.

Lottermoser, B.G. and Willmott, W. (Eds) 2008. R*ocks, Landscapes & Resources of the Wet Tropics* Geological Society of Australia Inc, Brisbane.

Nicholson, N. and Nicholson, H. (1985-2004) Australian Rainforest Plants Vols 1-6 Terania Creek Publishing, The Channon, NSW.

Queensland Museum 2000. *Wildlife of Tropical North Queensland.* Queensland Museum, Brisbane.

The journal *Ecological Management and Restoration* is a quarterly publication aimed at researchers and practitioners engaged in ecological restoration. The journal produces a variety of material accessible to professionals and the layman, and is highly recommended.

Flecker Botanical Gardens in Cairns offer the opportunity to see living specimens with names. Around the Parks and Wildlife Office on McLeish Road at Lake Eacham are extensive plantings of north Queensland Lauraceae, Proteaceae, Moraceae and Myrtaceae. A collection of north Queensland Araucariaceae can be seen at Hallorans Hill Conservation Park in Atherton, and there are named botanical walks at James Cook University, Lake Eacham, and at Malanda Falls Conservation Park. Such resources provide an ideal way to learn more about local plants and the habitats in which they occur.

There are also professional bodies which offer a range of services and more specialised resources. The Society for Ecological Restoration Australasia is the local chapter of a world-wide organisation which offers a wide range of benefits to members, including regular publications and a wide range of reference material. Visit SERA at www.seraustralasia.com. Other national professional bodies exist that provide similar specialist services to members. These organisations are shown in the table below.

Organisation	Contact
Australian Association of Bush Regenerators	www.aabr.org.au
Australian Network for Plant Conservation	www.anbg.gov.au/anpc
Wetland Care Australia	www.wetlandcare.com.au
Greening Australia	www.greeningaustralia.org.au

Finally there are many well established ecological restoration projects across the Wet Tropics region, some over 30 years old. Such plantings are valuable sources of information on species performance and the re-establishment of ecological processes. One of the oldest and largest restoration projects follows the course of the walking track along the Alice River at Eubenangee Swamp National Park, near Miriwinni. Your local restoration group can advise on other projects in your local area.

PART 3. WHAT TO PLANT WHERE

It is not possible to offer detailed prescriptions of what to plant at every type of site. However, the species lists which follow will assist in species selection.

The nomenclature for all species listed in the following chapters follows Bostock and Holland (2010).

21. SPECIES SUITABLE FOR RIPARIAN PLANTINGS

The species listed in this chapter are suitable for riparian rainforest restoration in the Wet Tropics of Queensland. The location column in the list provides guidance as to the altitude zone for which the species is most suited and the stream bank position where it should be planted.

Species	Common name	Location
Acmena hemilampra ssp. hemilampra *	Blush satinash	Upper and lower banks Lowlands and foothills
Acmena smithii *	Lillypilly	Water's edge Uplands to highlands. Suited to open degraded sites, frost tolerant
Alstonia scholaris	Milky pine	Upper and lower banks Lowlands and uplands
Archontophoenix alexandrae	Alexander palm	Water's edge More common on lowland sites but extends to 800m asl, frost sensitive
Atractocarpus fitzalanii ssp. fitzalanii *	Native gardenia	Upper and lower banks, floodplains Lowlands and foothills
Beilschmiedia obtusifolia	Blush walnut	Upper and lower banks Lowlands only
Carallia brachiata	Corkwood	Upper and lower banks Lowlands and foothills
Castanospermum australe	Black bean	Upper and lower banks, and floodplains Lowlands only
Casuarina cunninghamiana	River oak	Water's edge Uplands and highlands Suited to open degraded sites, frost tolerant
Chionanthus ramiflora	Native olive	Upper and lower banks Lowlands and uplands
Cryptocarya triplinervis *	Brown laurel	Upper and lower banks Lowlands and uplands
Cyathea cooperi	Coopers tree fern	Any moist site. Uplands to highlands. Frost tolerant
Dillenia alata	Red beech	Upper and lower banks Lowlands only
Dysoxylum gaudichaudianum	Ivory mahogany	Upper, lower banks and floodplains Lowlands only
Elaeocarpus grandis	Blue quandong	Lower banks Lowlands and uplands, frost sensitive
Ficus congesta *	Water fig	Water's edge Lowlands, uplands & highlands
Ficus racemosa	Cluster fig	Upper banks and floodplains Lowlands and foothills
Ficus septica *	Septic fig	Upper and lower banks Uplands and highlands
Ficus variegata	Green fruited fig	Upper and lower banks Lowlands and uplands
Ganophyllum falcatum	Scaly ash	Upper, lower banks and floodplains Lowlands only

Glochidion philippicum *	Buttonwood	Upper banks, suited to open degraded sites Lowlands and uplands
Melaleuca leucadendra	Narrow-leaf paperbark	Water's edge Lowlands and foothills
Melaleuca viminalis *	Weeping bottlebrush	Water's edge Uplands to highlands. Suited to open degraded sites, frost tolerant
Melicope elleryana	Butterfly tree	Upper and lower banks Lowlands and uplands, frost sensitive
Millettia pinnata	Indian beech	Upper banks and floodplains Lowlands only
Nauclea orientalis	Leichhardt pine	Water's edge, floodplains Lowlands
Pandanus solmslaubachii	Pandanus	Any moist site Lowlands and foothills
Syzygium angophoroides *	Lost dog	Water's edge Lowlands
Syzygium australe *	Creek cherry	Water's edge Uplands to highlands. Suited to open degraded sites, frost tolerant
Syzygium tierneyanum *	River cherry	Water's edge Lowlands, foothills and uplands, frost sensitive
Tristaniopsis exiliflora	Kanuka box	Water's edge Lowlands and foothills

* *denotes edge-sealing species*

22. SPECIES SUITABLE FOR DIFFERENT ENVIRONMENTAL CONDITIONS

The lists of species which follow contain species recommended for a particular ecological zone, based on the state factors of soil, climate and altitude. Many species occur across a number of ecological zones, but there are no species which occur in every zone. Each zone contains lists appropriate for either Framework Species or Maximum Diversity planting approaches. There are, of course, many more species than these within each zone that could potentially be planted. However, the species in these lists have been selected on the basis of their known field performance within the nominated ecological zone. Whilst all these species are known to survive in a one-off planting, some Maximum Diversity method species prefer semi-shade and may establish better if under-planted into a two or three year old plot. By this time, larger stems are able to provide protection to these softer species.

TYPES OF PLANTS LISTED

These lists contain mainly trees and shrubs, and some palms. Vines, lianas and rattans are not included, for three main reasons. Firstly, they are not easy to maintain in a nursery, and require cutting back regularly until planting time. Secondly, most of these plants require a trunk or foliage to climb and this will not be available until planted trees are two to three years old. Thirdly, research has shown that these life forms are well represented in the natural regeneration within framework species plots (Tucker & Murphy 1997, Tucker & Simmons 2009), often arriving in the first wave of natural regeneration. If using the Maximum Diversity method, collect and germinate local vines and plant them as small seedlings at the base of growing stems.

Indicative fruiting times are provided for each species. In a small number of species, fruiting is not highly synchronised and different individuals in a local population may produce fruit throughout the year. Where there is a significant difference in ripening times between zones, this difference is reflected in the recommended harvest period. Typically, these are species with a wide distribution which often present ripe fruits on the coastal lowlands two or three months earlier than the uplands or highlands. Generally, the middle of the nominated fruiting period is the most likely time to find fruits, but the best way is to find the desired species and observe the development and ripening process until fruits are ready to harvest. Careful attention to fruiting periods can ensure the planting will eventually provide a year round supply of fruit resources. Fruiting times nominated have been gleaned from author records, the Queensland Parks and Wildlife Service's Lake Eacham Nursery, and Cooper and Cooper (2004).

Species which are more adept at 'sealing' the margins of plantings are marked with an asterisk *. These species should preferentially be established on the margin. Both Framework species and Maximum Diversity species marked with an asterisk are suitable for this portion of a site. However, they can also be planted at other locations within the site.

Determining climatic zone (after Tracey 1982)

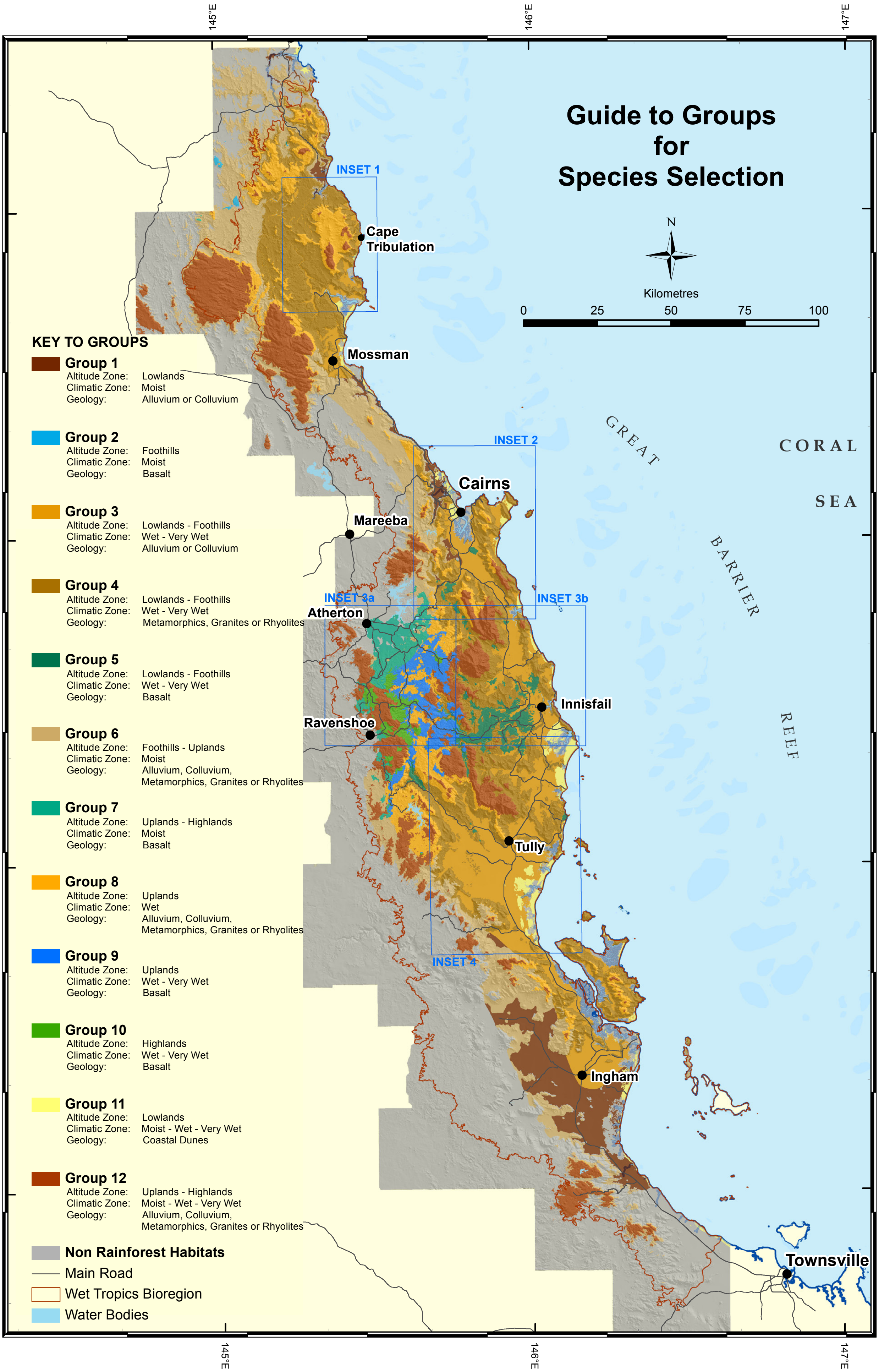
Zone	Mean Annual Rainfall	Rainfall Driest 6 Months
Very wet	>3000 mm	>750 mm
Wet	2000 - 3000 mm	500 - 750 mm
Moist	1600 - 2000 mm	300 - 500 mm
Dry	1300 - 1600 mm	200 - 300 mm

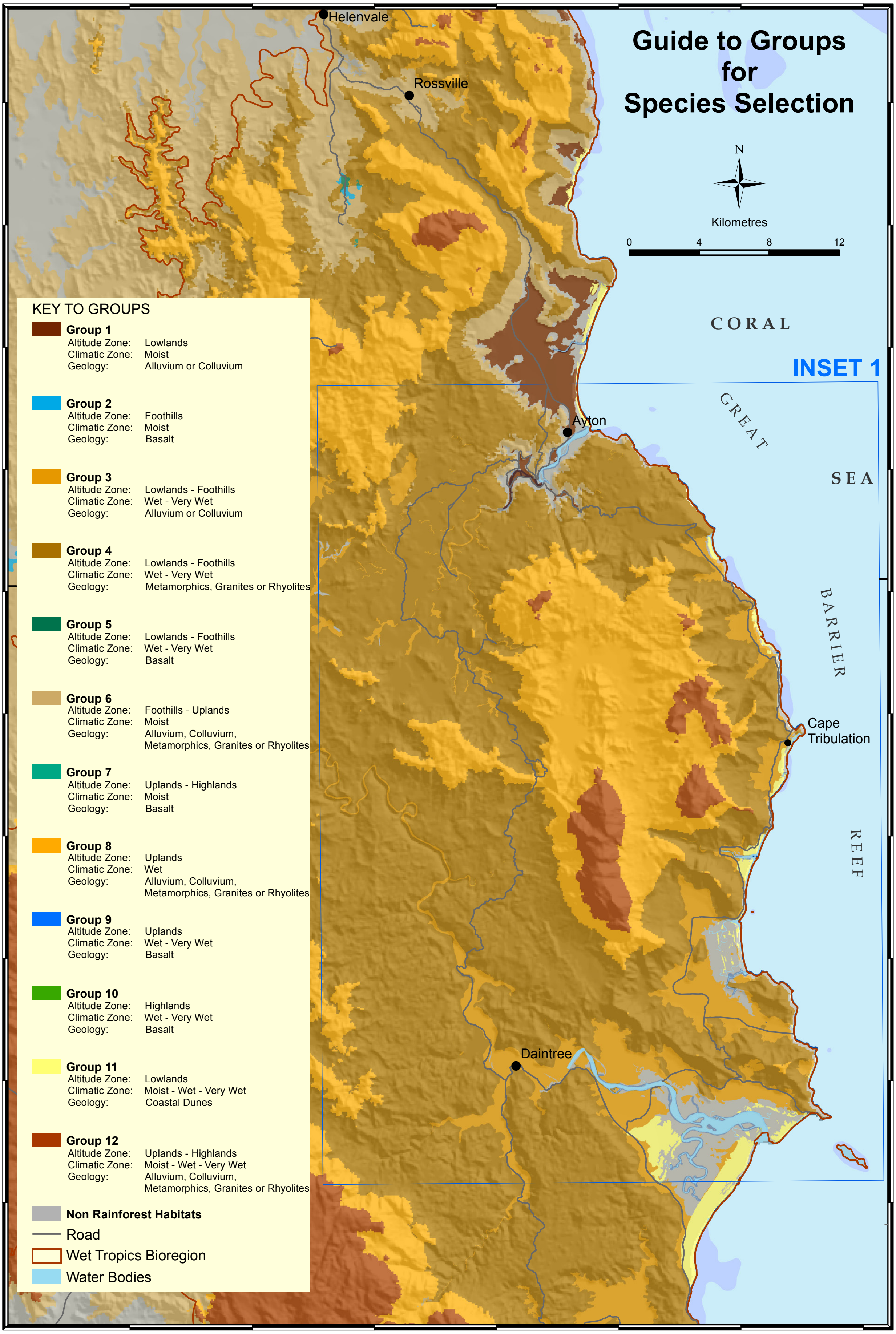
Determining altitudinal zone (after Tracey 1982)

Zone	Altitude (metres)
Highlands	>800
Uplands	400 - 800
Foothills	40 – 400
Lowland	0 – 40

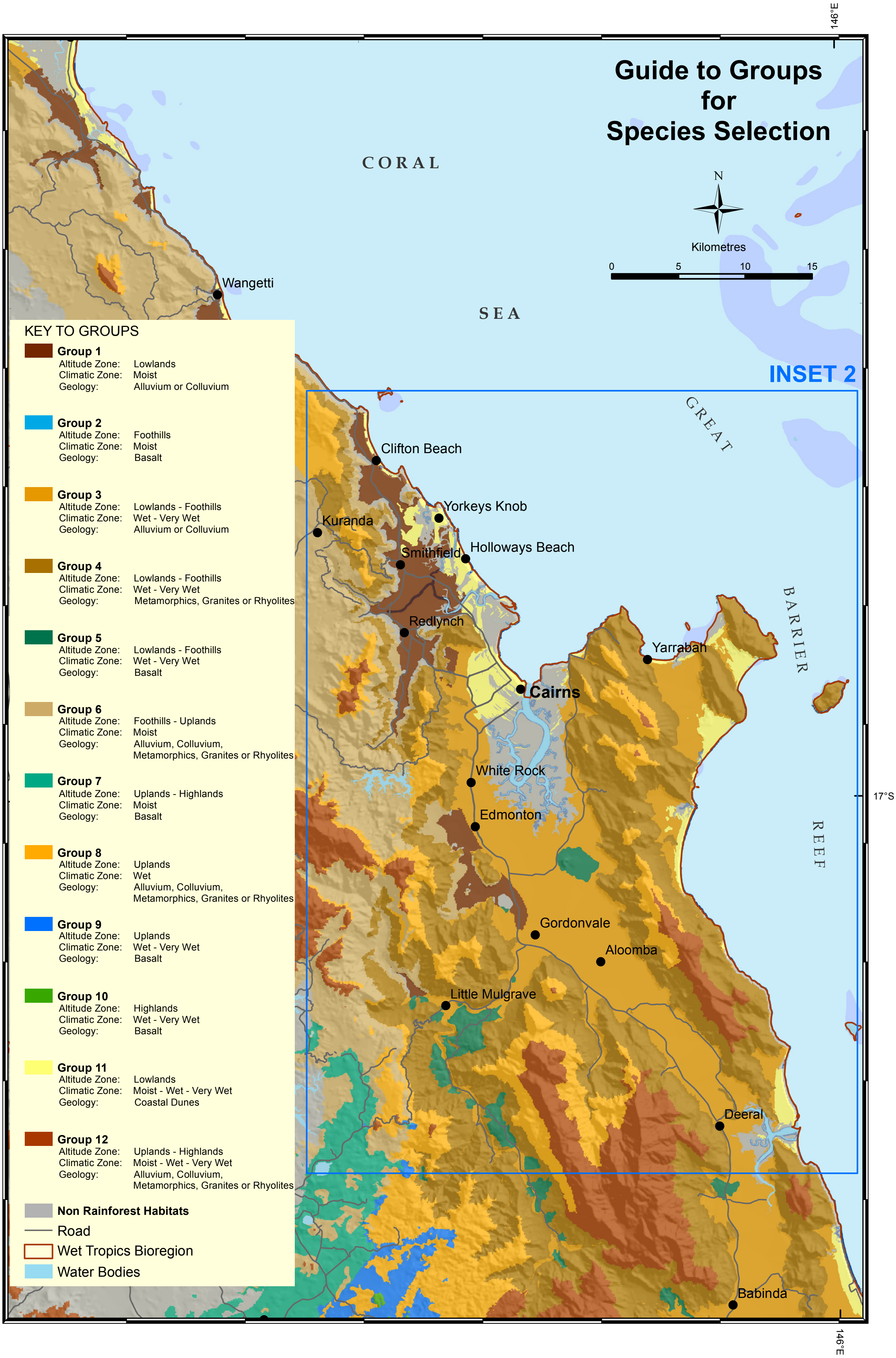
Key to determining the environmental site groups

Altitudinal zone	Climatic zone	Parent material	Group
<40 metres Lowlands	1600 - 2000mm Moist	Alluvium or colluvium Coastal dunes (beach sands)	1 11
<40 metres Lowlands	2000 – 3000mm Wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites Coastal dunes (beach sands)	3 5 4 4 11
<40 metres Lowlands	>3000mm Very wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites Coastal dunes (beach sands)	3 5 4 4 11
40-400 metres Foothills	1600 - 2000mm Moist	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	6 2 6 6
40-400 metres Foothills	2000 – 3000mm Wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	3 5 4 4
40-400 metres Foothills	>3000mm Very wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	3 5 4 4
400 – 800 metres Uplands	1600 - 2000mm Moist	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	6 7 6 6
400 – 800 metres Uplands	2000 – 3000mm Wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	8 9 8 8
400 – 800 metres Uplands	>3000mm Very wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	12 9 12 12
>800 metres Highlands	1600 - 2000mm Moist	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	12 7 12 12
>800 metres Highlands	2000 – 3000mm Wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	12 10 12 12
>800 metres Highlands	>3000mm Very wet	Alluvium or colluvium Basalt Metamorphics Granites and rhyolites	12 10 12 12

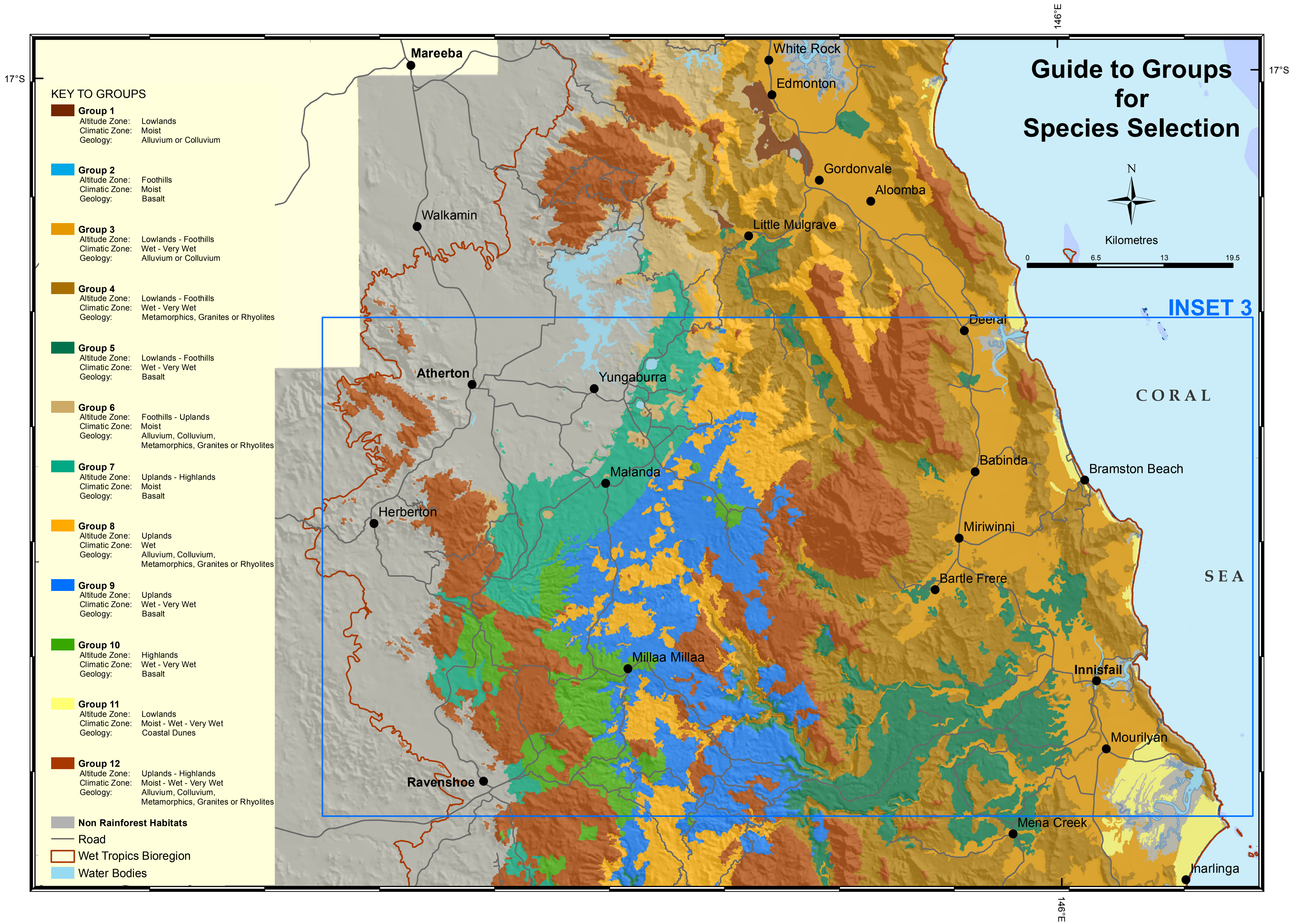

Guide to Groups for Species Selection
N
Kilometres
0 25 50 75 100
KEY TO GROUPS
Group 1
Altitude Zone: Lowlands
Climatic Zone: Moist
Geology: Alluvium or Colluvium
Group 2
Altitude Zone: Foothills
Climatic Zone: Moist
Geology: Basalt
Group 3
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Alluvium or Colluvium
Group 4
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Metamorphics, Granites or Rhyolites
Group 5
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 6
Altitude Zone: Foothills - Uplands
Climatic Zone: Moist
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 7
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist
Geology: Basalt
Group 8
Altitude Zone: Uplands
Climatic Zone: Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 9
Altitude Zone: Uplands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 10
Altitude Zone: Highlands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 11
Altitude Zone: Lowlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Coastal Dunes
Group 12
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Non Rainforest Habitats
Main Road
Wet Tropics Bioregion
Water Bodies
145°E
146°E
147°E
16°S
17°S
18°S
19°S
INSET 1
INSET 2
INSET 3a
INSET 3b
INSET 4
Cape Tribulation
Mossman
Cairns
Mareeba
Atherton
Innisfail
Ravenshoe
Tully
Ingham
Townsville
GREAT BARRIER REEF
CORAL SEA



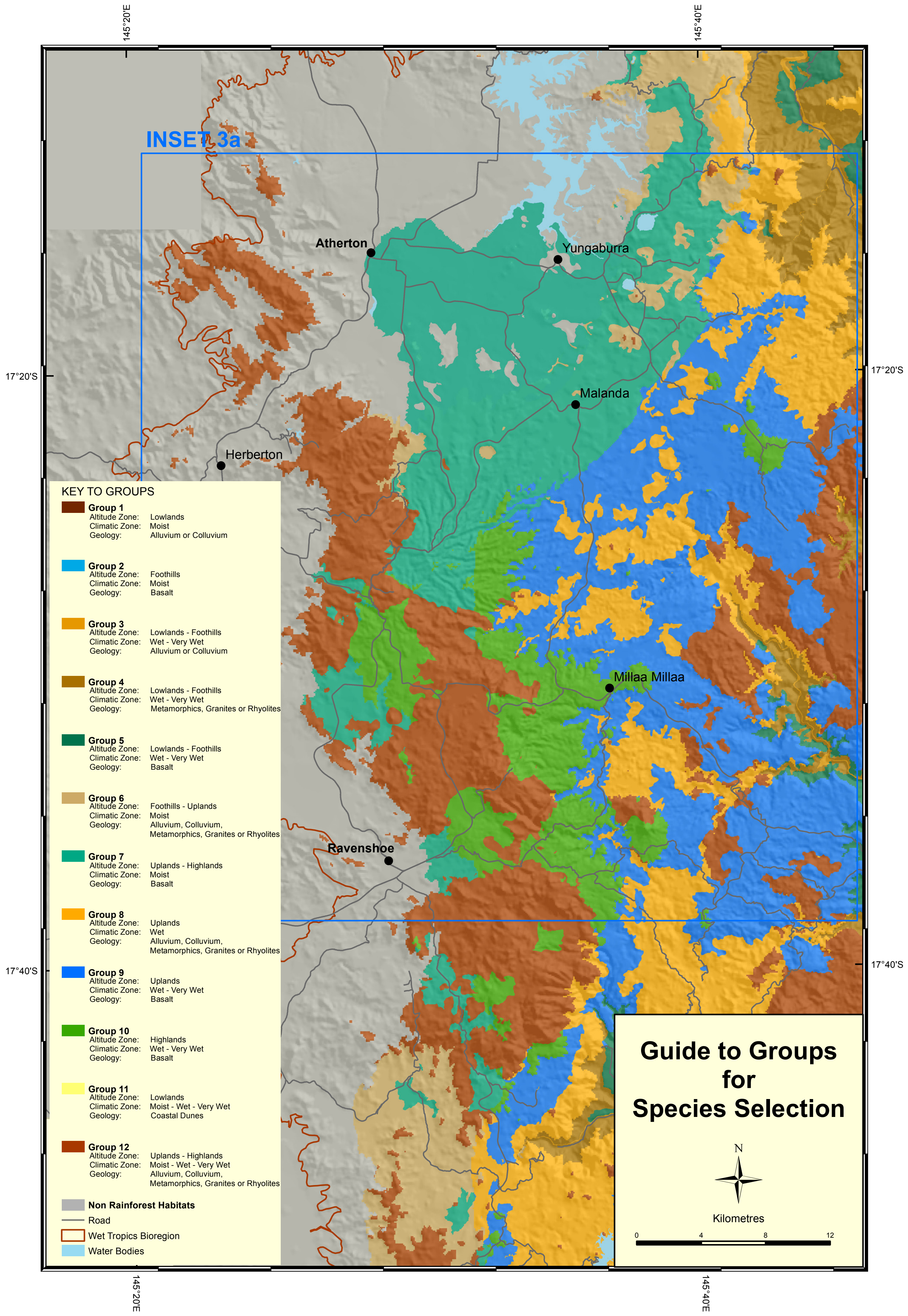
Guide to Groups for Species Selection
N
Kilometres
0 4 8 12
Helenvale
Rossville
Ayton
Cape Tribulation
Daintree
CORAL
SEA
GREAT
BARRIER
REEF
INSET 1
16°S
16°S
KEY TO GROUPS
Group 1
Altitude Zone: Lowlands
Climatic Zone: Moist
Geology: Alluvium or Colluvium
Group 2
Altitude Zone: Foothills
Climatic Zone: Moist
Geology: Basalt
Group 3
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Alluvium or Colluvium
Group 4
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Metamorphics, Granites or Rhyolites
Group 5
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 6
Altitude Zone: Foothills - Uplands
Climatic Zone: Moist
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 7
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist
Geology: Basalt
Group 8
Altitude Zone: Uplands
Climatic Zone: Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 9
Altitude Zone: Uplands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 10
Altitude Zone: Highlands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 11
Altitude Zone: Lowlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Coastal Dunes
Group 12
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Non Rainforest Habitats
Road
Wet Tropics Bioregion
Water Bodies



Guide to Groups for Species Selection
CORAL
SEA
GREAT
BARRIER
REEF
INSET 2
N
Kilometres
0 5 10 15
146°E
17°S
Wangetti
Clifton Beach
Yorkeys Knob
Kuranda
Smithfield
Holloways Beach
Redlynch
Yarrabah
Cairns
White Rock
Edmonton
Gordonvale
Aloomba
Little Mulgrave
Deeral
Babinda
KEY TO GROUPS
Group 1
Altitude Zone: Lowlands
Climatic Zone: Moist
Geology: Alluvium or Colluvium
Group 2
Altitude Zone: Foothills
Climatic Zone: Moist
Geology: Basalt
Group 3
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Alluvium or Colluvium
Group 4
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Metamorphics, Granites or Rhyolites
Group 5
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 6
Altitude Zone: Foothills - Uplands
Climatic Zone: Moist
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 7
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist
Geology: Basalt
Group 8
Altitude Zone: Uplands
Climatic Zone: Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 9
Altitude Zone: Uplands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 10
Altitude Zone: Highlands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 11
Altitude Zone: Lowlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Coastal Dunes
Group 12
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Non Rainforest Habitats
Road
Wet Tropics Bioregion
Water Bodies



Guide to Groups for Species Selection
KEY TO GROUPS
Group 1
Altitude Zone: Lowlands
Climatic Zone: Moist
Geology: Alluvium or Colluvium
Group 2
Altitude Zone: Foothills
Climatic Zone: Moist
Geology: Basalt
Group 3
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Alluvium or Colluvium
Group 4
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Metamorphics, Granites or Rhyolites
Group 5
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 6
Altitude Zone: Foothills - Uplands
Climatic Zone: Moist
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 7
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist
Geology: Basalt
Group 8
Altitude Zone: Uplands
Climatic Zone: Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 9
Altitude Zone: Uplands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 10
Altitude Zone: Highlands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 11
Altitude Zone: Lowlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Coastal Dunes
Group 12
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Non Rainforest Habitats
Road
Wet Tropics Bioregion
Water Bodies
17°S
146°E
N
Kilometres
0 6.5 13 19.5
INSET 3
CORAL
SEA
Mareeba
Walkamin
Atherton
Yungaburra
Herberton
Malanda
Millaa Millaa
Ravenshoe
White Rock
Edmonton
Gordonvale
Aloomba
Little Mulgrave
Deeral
Babinda
Bramston Beach
Miriwinni
Bartle Frere
Innisfail
Mourilyan
Mena Creek
Inarlinga



145°20'E
145°40'E
17°20'S
17°40'S
INSET 3a
Atherton
Yungaburra
Malanda
Herberton
Millaa Millaa
Ravenshoe
KEY TO GROUPS
Group 1
Altitude Zone: Lowlands
Climatic Zone: Moist
Geology: Alluvium or Colluvium
Group 2
Altitude Zone: Foothills
Climatic Zone: Moist
Geology: Basalt
Group 3
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Alluvium or Colluvium
Group 4
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Metamorphics, Granites or Rhyolites
Group 5
Altitude Zone: Lowlands - Foothills
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 6
Altitude Zone: Foothills - Uplands
Climatic Zone: Moist
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 7
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist
Geology: Basalt
Group 8
Altitude Zone: Uplands
Climatic Zone: Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Group 9
Altitude Zone: Uplands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 10
Altitude Zone: Highlands
Climatic Zone: Wet - Very Wet
Geology: Basalt
Group 11
Altitude Zone: Lowlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Coastal Dunes
Group 12
Altitude Zone: Uplands - Highlands
Climatic Zone: Moist - Wet - Very Wet
Geology: Alluvium, Colluvium, Metamorphics, Granites or Rhyolites
Non Rainforest Habitats
Road
Wet Tropics Bioregion
Water Bodies
Guide to Groups for Species Selection
N
Kilometres
0
4
8
12

GROUP 1: MOIST LOWLANDS ON ALLUVIUM

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	May - Jan
*Alstonia scholaris**	Milky pine	Apocynaceae	Dec - Feb
Archontophoenix alexandrae	Alexander palm	Arecaceae	All year
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Dec - Mar
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Jul - Dec
*Carallia brachiata**	Corky bark	Rhizophoraceae	Sep - Nov
*Chionanthus ramiflora**	Native olive	Oleaceae	Sep - Dec
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
*Cryptocarya triplinervis**	Brown laurel	Lauraceae	Nov-Mar
Dysoxylum gaudichaudianum	Ivory mahogany	Meliaceae	Sep - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	May - Mar
Ficus racemosa var. racemosa	Cluster fig	Moraceae	May - Jan
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus virens	White fig	Moraceae	Aug - Apr
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
*Glochidion philippicum**	Buttonwood	Phyllanthaceae	Jun - Mar
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
*Macaranga tanarius**	Macaranga	Euphorbiaceae	Sep - Mar
*Mallotus philippensis**	Red kamala	Euphorbiaceae	Nov - Apr
Nauclea orientalis	Leichhardt's pine	Rubiaceae	Jan - Apr
Pouteria obovata	Yellow boxwood	Sapotaceae	Jan - Mar
Pleiogynium timorense	Burdekin plum	Anacardiaceae	Mar - Oct
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Argyrodendron polyandrum	Booyong	Sterculiaceae	Nov-Feb
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Bischofia javanica	Java cedar	Philydraceae	Sep - Oct
Blepharocarya involucrigera	Rose butternut	Anacardiaceae	Sep - Mar
Buchanania arborescens	Buchanania	Anacardiaceae	Sep - Feb
Cananga odorata	Perfume tree	Annonaceae	Nov - Mar
Castanospermum australe	Black bean	Fabaceae	All year
*Cleistanthus apodus**	Weeping cleistanthus	Phyllanthaceae	Sep - Mar
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	Aug - Dec
Diploglottis diphyllostegia	Northern tamarind	Sapindaceae	Sep - Nov
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Ficus albipila	Figwood	Moraceae	Apr-Nov
*Ficus copiosa**	Plentiful fig	Moraceae	Aug - Nov
Ganophyllum falcatum	Scaly ash	Sapindaceae	Dec - Feb
Jagera pseudorhus var. integerrima	Pink tamarind	Sapindaceae	Jul - Nov
Millettia pinnata	Pongamia	Fabaceae	Sep - Apr
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Sep - Dec
*Paraserianthes toona**	Acacia cedar	Mimosaceae	Aug - Sep
Podocarpus grayae	Brown pine	Podocarpaceae	Oct - Jan
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

** = 'edge sealing' species*

GROUP 2: MOIST FOOTHILLS ON BASALT

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	May - Jan
Alphitonia oblata	Sarsaparilla	Rhamnaceae	Oct - Jan
Alstonia scholaris *	Milky pine	Apocynaceae	Dec - Feb
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Dec - Mar
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Jul - Dec
Carallia brachiata *	Corky bark	Rhizophoraceae	Sep - Nov
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Chionanthus ramiflora *	Native olive	Oleaceae	Sep - Dec
Cordia dichotoma	Snotty-gobble	Boraginaceae	Oct - Feb
Cryptocarya triplinervis *	Brown laurel	Lauraceae	Nov - Mar
Diploglottis diphyllostegia	Northern tamarind	Sapindaceae	Sep - Nov
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	May - Mar
Euroschinus falcata var. falcata	Pink poplar	Anacardiaceae	Nov - Feb
Ficus congesta var. congesta *	Water fig	Moraceae	All year
Ficus septica *	Septic fig	Moraceae	Feb - Jun
Ficus virens	White fig	Moraceae	Aug - Apr
Guioa acutifolia *	Glossy tamarind	Sapindaceae	Nov - Jan
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Leea indica *	Bandicoot berry	Vitaceae	Dec - May
Litsea fawcettiana	Brown beech	Lauraceae	Oct - Jan
Macaranga tanarius *	Macaranga	Euphorbiaceae	Sep - Mar
Mallotus philippensis *	Red kamala	Euphorbiaceae	Nov - Apr
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Pittosporum venulosum *	Brown pittosporum	Pittosporaceae	Nov - Mar
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb
Trema tomentosa var. viridis *	Poison peach	Ulmaceae	Nov - May

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Aphananthe philippinensis	Native holly	Ulmaceae	Dec - Apr
Archidendron hendersonii	Tulip siris	Mimosaceae	Dec - Jan
Arytera divaricata *	Rose tamarind	Sapindaceae	Sep - Dec
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Buchanania arborescens	Buchanania	Anacardiaceae	Sep - Feb
Castanospermum australe	Black bean	Fabaceae	All year
Cordia dichotoma	Snotty-gobble	Boraginaceae	Oct - Feb
Cupaniopsis foveolata	White tamarind	Sapindaceae	Oct - Jan
Diploglottis smithii	Smith's tamarind	Sapindaceae	Nov - Feb
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Melicope rubra *	Little evodia	Rutaceae	Feb - May
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Sep - Dec
Palaquium galactoxylon	Red silkwood	Sapotaceae	Oct - Feb
Rhysotoechia robertsonii	Robert's tuckeroo	Sapindaceae	Oct - Feb
Syzygium cormiflorum *	Bumpy satinash	Myrtaceae	Aug - Feb
Toona ciliata	Red cedar	Meliaceae	Oct - Jan

** = 'edge sealing' species*

GROUP 3: WET TO VERY WET LOWLANDS AND FOOTHILLS ON ALLUVIUM

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
*Acmena hemilampra ssp. hemilampra**	Blush satinash	Myrtaceae	Mar - Jul
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	May - Jan
Alphitonia oblata	Sarsaparilla	Rhamnaceae	Oct - Jan
*Alstonia scholaris**	Milky pine	Apocynaceae	Dec - Feb
Archontophoenix alexandrae	Alexander palm	Arecaceae	All year
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Jul - Dec
Breynia cernua	Coffee bush	Phyllanthaceae	All year
*Carallia brachiata**	Corky bark	Rhizophoraceae	Sep - Nov
*Cardwellia sublimis**	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
*Chionanthus ramiflora**	Native olive	Oleaceae	Sep - Dec
Claoxylon tenerifolium	Qld brittlewood	Euphorbiaceae	Aug - Jan
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
*Cryptocarya triplinervis**	Brown laurel	Lauraceae	Nov - Mar
Dysoxylum gaudichaudianum	Ivory mahogany	Meliaceae	Sep - Feb
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Sep - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	May - Mar
*Ficus congesta var. congesta**	Water fig	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Feb
Ficus racemosa var. racemosa	Cluster fig	Moraceae	May - Jan
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus variegata	Green fruited fig	Moraceae	Nov - Jul
Ficus virens	White fig	Moraceae	Aug - Apr
Ganophyllum falcatum	Scaly ash	Sapindaceae	Dec - Jan
*Glochidion philippicum**	Buttonwood	Phyllanthaceae	Jun - Mar
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
*Leea indica**	Bandicoot berry	Vitaceae	Dec - May
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Macaranga involucrata var. mallotoides	Macaranga	Euphorbiaceae	Nov - Mar
*Macaranga tanarius**	Macaranga	Euphorbiaceae	Sep - Mar
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Melicope xanthoxyloides	Yellow evodia	Rutaceae	Apr - Aug
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
*Rhodamnia sessiliflora**	Iron malletwood	Myrtaceae	Dec - May
*Rhus taitensis**	Sumac	Anacardiaceae	Feb - Nov
Symplocos cochinchinensis var. pilosiuscula	White hazelwood	Symplocaceae	Oct - Dec
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb

* = *'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Acronychia vestita	White aspen	Rutaceae	Jun - Oct
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron hendersonii	Tulip siris	Mimosaceae	Dec - Jan
Archidendron vaillantii	Salmon bean	Mimosaceae	Jan - Jun
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Arytera pauciflora	Small leaf tamarind	Sapindaceae	Aug - Jan
*Atractocarpus fitzalanii ssp. fitzalanii**	Brown gardenia	Rubiaceae	May - Oct
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Barringtonia racemosa	Barringtonia	Lecythidaceae	Mar - Apr

Scientific name	Common name	Family	Indicative fruiting times
Beilschmiedia bancroftii	Yellow walnut	Lauraceae	Oct - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Cananga odorata	Perfume tree	Annonaceae	Nov - Mar
Canarium australianum	Scrub turpentine	Burseraceae	Jun - Oct
Castanospermum australe	Black bean	Fabaceae	All year
Cerbera floribunda	Grey milkwood	Apocynaceae	Jan - Oct
Cleistanthus apodus *	Weeping cleistanthus	Phyllanthaceae	Sep - Mar
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	All year
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Cryptocarya oblata	Tarzali silkwood	Lauraceae	Nov - Apr
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Decaspermum humile *	Brown myrtle	Myrtaceae	May - Sep
Deplanchea tetraphylla	Bignonia	Bignoniaceae	Nov - Dec
Dillenia alata	Red beech	Dilleniaceae	Sep - Feb
Diploglottis smithii	Smith's tamarind	Sapindaceae	Nov - Feb
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus bancroftii	Kuranda quandong	Elaeocarpaceae	Feb - Apr
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Jul - Jan
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
Ficus copiosa *	Plentiful fig	Moraceae	Jan - Nov
Ficus microcarpa	Small fruited fig	Moraceae	Jan - Jun
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
Gmelina dalrympleana	White beech	Verbenaceae	Jan - Apr
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
Grevillea baileyana	Findlay's silky oak	Proteaceae	Oct - Feb
Helicia nortoniana *	Norton's silky oak	Proteaceae	All year
Hibiscus tiliaceus *	Coast cottonwood	Malvaceae	Nov - Feb
Hollandaea sayeriana	Mueller's oak	Proteaceae	Dec - Mar
Homalium circumpinnatum *	Brown boxwood	Flacourtiaceae	Nov - Feb
Idiospermum australiense	Ribbonwood	Idiospermaceae	Jun - Oct
Macaranga subdentata	Needlebark	Euphorbiaceae	Nov - Jul
Millettia pinnata	Pongamia	Fabaceae	Sep - Apr
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Ormosia ormondii	Yellow bean	Fabaceae	Oct - Apr
Ostrearia australiana	Hard pink alder	Hamamelidaceae	Nov - Apr
Palaquium galactoxylon	Red silkwood	Sapotaceae	Oct - Feb
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Aug - May
Pilidiostigma tropicum *	Apricot myrtle	Myrtaceae	Dec - Mar
Prunus turneriana	Almondbark	Rosaceae	Jul - Nov
Ptychosperma elegans	Solitaire palm	Arecaceae	Apr - Nov
Rhysotoechia robertsonii	Robert's tuckeroo	Sapindaceae	Oct - Feb
Ristantia pachysperma	Yellow penda	Myrtaceae	Oct - Jan
Scolopia braunii *	Flintwood	Flacourtiaceae	Dec - Mar
Sloanea langii	White carabeen	Elaeocarpaceae	Jun - Jan
Synima cordierorum	Synima	Sapindaceae	Dec - Jan
Syzygium alliiligneum	Onionwood	Myrtaceae	May - Oct
Syzygium angophoroides *	Lost dog	Myrtaceae	Nov - Apr
Syzygium cormiflorum *	Bumpy satinash	Myrtaceae	Aug - Feb
Syzygium fibrosum *	Fibrous satinash	Myrtaceae	Sep - Feb
Syzygium gustavioides	Water gum	Myrtaceae	May - Sep
Syzygium kuranda	Kuranda satinash	Myrtaceae	May - Aug
Syzygium luehmannii *	Cherry satinash	Myrtaceae	Nov - Apr
Syzygium sayeri *	Pink satinash	Myrtaceae	Nov - Mar
Ternstroemia cherryi	Beach cherry	Theaceae	All year
Waterhousea hedraiophylla *	Red satinash	Myrtaceae	Jan - Mar

** = 'edge sealing' species*

GROUP 4: WET TO VERY WET LOWLANDS AND FOOTHILLS ON METAMORPHICS AND GRANITES

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Acacia celsa *	Brown salwood	Mimosaceae	Oct - Feb
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	May - Jan
Alphitonia oblata	Sarsaparilla	Rhamnaceae	Oct - Jan
Alstonia scholaris *	Milky pine	Apocynaceae	Dec - Feb
Archontophoenix alexandrae	Alexander palm	Arecaceae	All year
Backhousia bancroftii *	Johnstone R. hardwood	Myrtaceae	Sep - Jan
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Jul - Dec
Carallia brachiata *	Corky bark	Rhizophoraceae	Sep - Nov
Cardwellia sublimis *	Northern silky oak	Proteaceae	Oct - Feb
Chionanthus ramiflora *	Native olive	Oleaceae	Sep - Dec
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug – Feb
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	May - Mar
Ficus congesta var. congesta *	Water fig	Moraceae	All year
Ficus drupacea	Drupe fig	Moraceae	Jan- Sept
Ficus racemosa var. racemosa	Cluster fig	Moraceae	May - Jan
Glochidion philippicum *	Buttonwood	Phyllanthaceae	Jun - Mar
Grevillea baileyana	Findlay's silky oak	Proteaceae	Oct - Feb
Helicia nortoniana *	Norton's silky oak	Proteaceae	All year
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Leea indica *	Bandicoot berry	Vitaceae	Dec - May
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Melicope xanthoxyloides	Yellow evodia	Rutaceae	Apr - Aug
Neolitsea dealbata *	White bollywood	Lauraceae	Oct - May
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Rhus taitensis	Sumac	Anacardiaceae	Feb - Nov
Symplocos cochinchinensis var. pilosiuscula	White hazelwood	Symplocaceae	Oct - Dec
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb
Trema tomentosa var. viridis *	Poison peach	Ulmaceae	Nov - May

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
*Atractocarpus fitzalanii ssp. fitzalanii**	Brown gardenia	Rubiaceae	May - Oct
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Beilschmiedia bancroftii	Yellow walnut	Lauraceae	Oct - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Buchanania arborescens	Buchanania	Anacardiaceae	Sep - Feb
Cananga odorata	Perfume tree	Annonaceae	Nov - Feb
Carnarvonia araliifolia	Caledonian oak	Proteaceae	Sep - Mar
Castanospermum australe	Black bean	Fabaceae	All year
Cerbera floribunda	Grey milkwood	Apocynaceae	Jan - Oct
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	All year
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Davidsonia pruriens	Davidson's plum	Davidsoniaceae	All year
*Decaspermum humile**	Brown myrtle	Myrtaceae	May - Sep
Deplanchea tetraphylla	Bignonia	Bignoniaceae	Nov - Dec
Dillenia alata	Red beech	Dilleniaceae	Sep - Feb
Dysoxylum papuanum	Spicy mahogany	Meliaceae	Oct - Feb
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus bancroftii	Kuranda quandong	Elaeocarpaceae	Feb - Apr
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Jul - Jan
Elaeocarpus stellaris	Star quandong	Elaeocarpaceae	Sep - Jan
Endiandra hypotephra	Rose walnut	Lauraceae	Aug - Nov
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus variegata	Green fruited fig	Moraceae	Nov - Jul
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Ganophyllum falcatum	Scaly ash	Sapindaceae	Dec - Jan
Gmelina fasciculiflora	Northern white beech	Verbenaceae	Dec - Mar
*Gossia dallachiana**	Lignum	Myrtaceae	All year
Jagera pseudorhus var. integerrima	Pink tamarind	Sapindaceae	Jul - Nov
Litsea bindoniana	Big leaf bollywood	Lauraceae	Oct - Dec
Mallotus polyadenos	Kamala	Euphorbiaceae	All year
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Ormosia ormondii	Yellow bean	Fabaceae	Oct - Apr
Palaquium galactoxylon	Red silkwood	Sapotaceae	Nov - Jan
*Pilidiostigma tropicum**	Apricot myrtle	Myrtaceae	Dec - Mar
Podocarpus grayae	Brown pine	Podocarpaceae	Oct - Jan
Prunus turneriana	Almondbark	Rosaceae	Jul - Dec
Ptychosperma elegans	Solitaire palm	Arecaceae	Apr - Nov
Rhysotoechia robertsonii	Robert's tuckeroo	Sapindaceae	Oct - Feb
Ristantia pachysperma	Yellow penda	Myrtaceae	Oct - Jan
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar
Syzygium alliiligneum	Onionwood	Myrtaceae	May - Oct
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
*Syzygium fibrosum**	Fibrous satinash	Myrtaceae	Sep - Feb
Syzygium kuranda	Kuranda satinash	Myrtaceae	May - Aug
*Syzygium luehmannii**	Cherry satinash	Myrtaceae	Nov - Apr
*Syzygium sayeri**	Pink satinash	Myrtaceae	Nov - Mar
Toona ciliata	Red cedar	Meliaceae	Oct - Jan
*Waterhousea unipunctata**	Rolypoly satinash	Myrtaceae	Jun - Dec
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

** = 'edge sealing' species*

GROUP 5: WET TO VERY WET LOWLANDS AND FOOTHILLS ON BASALT

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	May - Jan
Alphitonia oblata	Sarsaparilla	Rhamnaceae	Oct - Jan
*Alstonia scholaris**	Milky pine	Apocynaceae	Dec - Feb
Archontophoenix alexandrae	Alexander palm	Arecaceae	All year
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Dec - Mar
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Jul - Dec
Breynia cernua	Coffee bush	Phyllanthaceae	All year
*Carallia brachiata**	Corky bark	Rhizophoraceae	Sep - Nov
*Cardwellia sublimis**	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Claoxylon tenerifolium	Qld Brittlewood	Euphorbiaceae	Aug - Jan
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
*Cryptocarya triplinervis**	Brown laurel	Lauraceae	Nov - Mar
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	May - Mar
*Ficus congesta var. congesta**	Water fig	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Feb
Ficus racemosa var. racemosa	Cluster fig	Moraceae	May - Jan
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus variegata	Green fruited fig	Moraceae	Nov - Jul
Ficus virens	White fig	Moraceae	Oct - Jun
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
*Glochidion philippicum**	Buttonwood	Phyllanthaceae	Jun - Mar
*Guioa lasioneura**	Silky tamarind	Sapindaceae	Nov - Mar
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
*Leea indica**	Bandicoot berry	Vitaceae	Dec - May
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
*Macaranga tanarius**	Macaranga	Euphorbiaceae	Sep - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
*Neolitsea dealbata**	White bollywood	Lauraceae	Oct - May
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias australiana	Ivory basswood	Araliaceae	Dec - Mar
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Prunus turneriana	Almondbark	Rosaceae	Jul - Dec
*Rhodamnia sessiliflora**	Iron malletwood	Myrtaceae	Dec - May
*Sloanea macbrydei**	Grey carabeen	Elaeocarpaceae	Sep - Mar
Symplocos cochinchinensis var. pilosiuscula	White hazelwood	Symplocaceae	Oct - Dec
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
*Syzygium sayeri**	Pink satinash	Myrtaceae	Nov - Mar
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb
*Trema tomentosa var. viridis**	Poison peach	Ulmaceae	Nov - May

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acmena graveolens	Cassowary satinash	Myrtaceae	Apr - Nov
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Acronychia vestita	White aspen	Rutaceae	Jun - Oct
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Arytera pauciflora	Small leaf tamarind	Sapindaceae	Aug - Jan
*Backhousia bancroftii**	Johnstone River hardwood	Myrtaceae	Sep - Jan
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Barringtonia racemosa	Barringtonia	Lecythidaceae	Mar - Apr
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Cananga odorata	Perfume tree	Annonaceae	Nov - Mar
Castanospermum australe	Black bean	Fabaceae	All year
Cerbera floribunda	Grey milkwood	Apocynaceae	Jan - Oct
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	All year
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Cryptocarya oblata	Tarzali silkwood	Lauraceae	Nov - Apr
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Diploglottis smithii	Smith's tamarind	Sapindaceae	Nov - Feb
Dysoxylum papuanum	Spicy mahogany	Meliaceae	Oct - Feb
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus bancroftii	Kuranda quandong	Elaeocarpaceae	Feb - Apr
Endiandra hypotephra	Rose walnut	Lauraceae	Aug - Nov
Endiandra insignis	Hairy walnut	Lauraceae	Oct - Aug
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
*Ficus copiosa**	Plentiful fig	Moraceae	Jan - Nov
*Ficus hispida**	Hairy fig	Moraceae	All year
Ficus pleurocarpa	Banana fig	Moraceae	All year
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Ganophyllum falcatum	Scaly ash	Sapindaceae	Dec - Jan
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
*Gossia dallachiana**	Lignum	Myrtaceae	All year
*Helicia nortoniana**	Norton's silky oak	Proteaceae	All year
Hollandaea sayeriana	Mueller's oak	Proteaceae	Dec - Mar
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Ostrearia australiana	Hard pink alder	Hamamelidaceae	Nov - Apr
Palaquium galactoxylon	Red silkwood	Sapotaceae	Nov - Jan
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Aug - May
*Pilidiostigma tropicum**	Apricot myrtle	Myrtaceae	Dec - Mar
Pitaviaster haplophyllus	Yellow aspen	Rutaceae	Feb - Aug
Prunus turneriana	Almondbark	Rosaceae	Jul - Dec
Sloanea langii	White carabeen	Elaeocarpaceae	Jun - Jan
Syzygium alliiligneum	Onionwood	Myrtaceae	May - Oct
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
Syzygium gustavioides	Water gum	Myrtaceae	May - Sep
Syzygium kuranda	Kuranda satinash	Myrtaceae	May - Aug
Ternstroemia cherryi	Cherry beech	Theaceae	All year

** = 'edge sealing' species*

GROUP 6: MOIST UPLANDS ON ALLUVIUM, COLLUVIUM, METAMORPHICS AND GRANITES

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	Apr - Dec
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
Alstonia scholaris *	Milky pine	Apocynaceae	Dec - Feb
Archirhodomyrtus beckleri *	Rose myrtle	Myrtaceae	Sep - Feb
Cardwellia sublimis *	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Cryptocarya triplinervis *	Brown laurel	Lauraceae	Nov - Mar
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Mar - Dec
Euroschinus falcata var. falcata	Pink poplar	Anacardiaceae	Nov - Feb
Ficus leptoclada	Atherton Fig	Moraceae	Oct - Mar
Ficus obliqua	Figwood	Moraceae	All year
Ficus septica *	Septic fig	Moraceae	Feb - Jun
Ficus superba	Superb fig	Moraceae	All year
Ficus virens	White fig	Moraceae	Oct - Jun
Ficus watkinsiana *	Watkin's fig	Moraceae	Aug - Apr
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
Ganophyllum falcatum	Scaly ash	Sapindaceae	Dec - Feb
Glochidion harveyanum	Buttonwood	Phyllanthaceae	Dec - Apr
Glochidion sumatranum	Buttonwood	Phyllanthaceae	Nov - Feb
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
Grevillea baileyana	Findlay's silky oak	Proteaceae	Oct - Feb
Guioa acutifolia *	Glossy tamarind	Sapindaceae	Nov - Jan
Guioa lasioneura *	Silky tamarind	Sapindaceae	Nov - Mar
Helicia nortoniana *	Norton's silky oak	Proteaceae	May - Dec
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Mallotus philippensis *	Red kamala	Euphorbiaceae	Nov - Apr
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Neolitsea dealbata *	White bollywood	Lauraceae	Jan - Jun
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Pullea stutzeri	Hard alder	Cunoniaceae	Dec- May
Rhodamnia sessiliflora *	Iron malletwood	Myrtaceae	Dec - May
Syzygium cormiflorum *	Bumpy satinash	Rutaceae	Aug - Feb
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb

* = *'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Agathis robusta *	Queensland kauri	Araucariaceae	Nov - Feb
Alloxylon wickhamii	Satin oak	Proteaceae	Aug - Oct
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron hendersonii	Tulip siris	Mimosaceae	Dec - Jan
Arytera divaricata *	Rose tamarind	Sapindaceae	Sep - Dec
Athertonia diversifolia	Atherton oak	Proteaceae	Oct - Feb
Beilschmiedia obtusifolia	Blush walnut	Lauraceae	Aug - Nov
Blepharocarya involucrigera	Rose butternut	Anacardiaceae	Sep - Mar
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec

Scientific name	Common name	Family	Indicative fruiting times
*Buckinghamia celsissima**	Spotted silky oak	Proteaceae	May - Nov
Carnarvonia araliifolia	Caledonian oak	Proteaceae	Sep - Mar
Castanospermum australe	Black bean	Fabaceae	All year
Cerbera inflata	Grey milkwood	Apocynaceae	Oct – Jan
Cryptocarya corrugata	Corduroy laurel	Lauraceae	Jun - Jan
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	May - Jan
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Davidsonia pruriens	Davidson's plum	Davidsoniaceae	All year
*Decaspermum humile**	Brown myrtle	Myrtaceae	Jul - Nov
Diospyros cupulosa	Ebony	Ebenaceae	Jun - Nov
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Elaeocarpus bancroftii	Kuranda quandong	Elaeocarpaceae	Feb - Apr
Elaeocarpus largiflorens ssp. largiflorens	Tropical quandong	Elaeocarpaceae	Nov - Mar
Elaeocarpus ruminatus	Brown quandong	Elaeocarpaceae	Mar - Sep
Endiandra hypotephra	Rose walnut	Lauraceae	Sep - Nov
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
*Ficus hispida**	Hairy fig	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Apr
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Feb - Dec
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
Galbulimima baccata	Magnolia	Himantandraceae	Feb - Sep
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
*Gossia dallachiana**	Lignum	Myrtaceae	All year
*Grevillea hilliana**	Hill's silky oak	Proteaceae	Jan - Mar
Harpullia pendula	Tulipwood	Sapindaceae	Mar - Dec
*Homalium circumpinnatum**	Brown boxwood	Flacourtiaceae	Nov - Feb
Jagera pseudorhus var. integerrima	Pink tamarind	Sapindaceae	Jul - Nov
Litsea bindoniana	Big leaf bollywood	Lauraceae	Oct - Dec
Litsea connorsii	Bollywood	Lauraceae	Oct - Dec
*Melicope rubra**	Little evodia	Rutaceae	Feb - May
*Mischarytera lautereriana**	Corduroy tamarind	Sapindaceae	Oct - Dec
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Mischocarpus pyriformis ssp. pyriformis	Tamarind	Sapindaceae	Dec - Jun
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Opisthiolepis heterophylla	Blush silky oak	Proteaceae	Aug - Nov
Paraserianthes toona	Acacia cedar	Mimosaceae	Jul - Sep
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Jan - Jun
Podocarpus grayae	Brown pine	Podocarpaceae	Oct - Jan
Prunus turneriana	Almondbark	Rosaceae	Jul - Jan
Rhysotoechia robertsonii	Robert's tuckeroo	Sapindaceae	Oct - Feb
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar
Sloanea langii	White carabeen	Elaeocarpaceae	Sep - Apr
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
Sundacarpus amarus	Black pine	Podocarpaceae	Dec - Mar
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
*Syzygium cryptophlebium**	Plum satinash	Myrtaceae	Sep - Jan
Syzygium endophloium	Bark in the wood	Myrtaceae	Sep - Feb
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
*Syzygium luehmannii**	Cherry satinash	Myrtaceae	Nov - Apr
Syzygium papyraceum	Paperbark satinash	Myrtaceae	Dec - Feb
Ternstroemia cherryi	Cherry beech	Theaceae	All year
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

** = 'edge sealing' species*

GROUP 7: MOIST UPLANDS AND HIGHLANDS ON BASALT

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	All year
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
*Alstonia scholaris**	Milky pine	Apocynaceae	Dec - Feb
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Aug - Jan
Argyrodendron trifoliolatum	Brown tulip oak	Sterculiaceae	Dec - Feb
*Cardwellia sublimis**	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Cordia dichotoma	Snotty-gobble	Boraginaceae	Oct - Feb
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
*Cryptocarya triplinervis**	Brown laurel	Lauraceae	Nov - Mar
Elaeocarpus coorangooloo	Brown quandong	Elaeocarpaceae	Dec - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Mar - Dec
Euroschinus falcata var. falcata	Pink poplar	Anacardiaceae	Nov - Feb
*Ficus congesta var. congesta**	Water fig	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Apr
*Ficus hispida**	Hairy fig	Moraceae	All year
*Ficus leptoclada**	Atherton Fig	Moraceae	Oct - Mar
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus superba	Superb fig	Moraceae	All year
Ficus virens	White fig	Moraceae	Oct - Jun
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
Glochidion harveyanum	Buttonwood	Phyllanthaceae	Dec - Apr
Guioa acutifolia *	Glossy tamarind	Sapindaceae	Nov - Jan
*Guioa lasioneura**	Silky tamarind	Sapindaceae	Nov - Mar
*Helicia nortoniana**	Norton's silky oak	Proteaceae	May - Dec
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
*Leea indica**	Bandicoot berry	Vitaceae	Dec - May
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Mallotus mollissimus	Kamala	Euphorbiaceae	Dec - May
*Mallotus philippensis**	Red kamala	Euphorbiaceae	Nov - Apr
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
*Neolitsea dealbata**	White bollywood	Lauraceae	Jan - Jun
*Pilidiostigma tropicum**	Apricot myrtle	Myrtaceae	Dec - Mar
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
*Syzygium sayeri**	Pink satinash	Myrtaceae	Nov - Mar
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb
*Trema tomentosa var. viridis**	Poison peach	Ulmaceae	Nov - May

* = *'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
*Acmena resa**	Red Eungella satinash	Myrtaceae	Oct - Apr
Aglaia sapindina	Boodyarra	Meliaceae	Nov - Apr
Alloxylon flammeum	Satin oak	Proteaceae	Sep – Jan
Alphitonia petriei	Pink ash	Rhamnaceae	Feb - Aug
Aphananthe philippinensis	Native holly	Ulmaceae	Dec - Apr
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Athertonia diversifolia	Atherton oak	Proteaceae	Oct - Feb
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	May - Jan
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Davidsonia pruriens	Davidson's plum	Davidsoniaceae	All year
*Decaspermum humile**	Brown myrtle	Myrtaceae	Jul - Nov
Diploglottis diphyllostegia	Northern tamarind	Sapindaceae	Aug - Dec
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus ruminatus	Brown quandong	Elaeocarpaceae	Mar - Sep
Endiandra palmerstonii	Queensland walnut	Lauraceae	Dec - May
*Ficus obliqua**	Figwood	Moraceae	All year
Ficus pleurocarpa	Banana fig	Moraceae	Aug - Dec
*Ficus watkinsiana**	Watkin's fig	Moraceae	Jan - Oct
Firmiana papuana	Lacewood	Sterculiaceae	Mar - Jun
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
Harpullia pendula	Tulipwood	Sapindaceae	Mar - Dec
Hodgkinsonia frutescens	Turkey bush	Rubiaceae	Sep - Mar
Jagera pseudorhus var. integerrima	Pink tamarind	Sapindaceae	Jul - Nov
*Melicope rubra**	Little evodia	Rutaceae	Feb - May
*Mischarytera lautereriana**	Corduroy tamarind	Sapindaceae	Oct - Dec
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Pararchidendron pruinosum	Tulip siris	Mimosaceae	Nov - Jun
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Jan - Jun
Prunus turneriana	Almondbark	Rosaceae	Jul - Jan
Rhysotoechia robertsonii	Robert's tuckeroo	Sapindaceae	Oct - Feb
Sauropus macranthus	Atherton sauropus	Euphorbiaceae	Mar - Nov
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
*Syzygium cryptophlebium**	Plum satinash	Myrtaceae	Sep - Jan
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
*Syzygium luehmannii**	Cherry satinash	Myrtaceae	Nov - Apr
Syzygium papyraceum	Paperbark satinash	Myrtaceae	Dec - Feb
Ternstroemia cherryi	Cherry beech	Theaceae	All year
Toona ciliata	Red cedar	Meliaceae	Oct - Jan
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

* = *'edge sealing' species*

GROUP 8: WET UPLANDS ON ALLUVIUM, COLLUVIUM, METAMORPHICS AND GRANITES

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
*Acacia celsa**	Brown salwood	Mimosaceae	Oct - Feb
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	All year
Alphitonia petriei	Pink ash	Rhamnaceae	Feb - Aug
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
*Cryptocarya triplinervis**	Brown laurel	Lauraceae	Nov - Mar
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Mar - Dec
Euroschinus falcata var. falcata	Pink poplar	Anacardiaceae	Nov - Feb
*Ficus congesta var. congesta**	Water fig	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Apr
*Ficus septica**	Septic fig	Moraceae	Feb - Jun
Ficus virens	White fig	Moraceae	Oct - Jun
*Ficus watkinsiana**	Watkin's fig	Moraceae	Jan - Oct
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Glochidion harveyanum	Buttonwood	Phyllanthaceae	Dec - Apr
Grevillea baileyana	Findlay's silky oak	Proteaceae	Oct - Feb
*Guioa lasioneura**	Silky tamarind	Sapindaceae	Nov - Mar
*Helicia nortoniana**	Norton's silky oak	Proteaceae	May - Dec
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
*Neolitsea dealbata**	White bollywood	Lauraceae	Jan - Jun
*Pilidiostigma tropicum**	Apricot myrtle	Myrtaceae	Dec - Mar
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Polyscias murrayi	White basswood	Araliaceae	Jun - Oct
Pouteria brownlessiana	Boxwood	Sapotaceae	Oct - Feb
Pullea stutzeri	Hard alder	Cunoniaceae	Dec - May
*Rhodamnia sessiliflora**	Iron malletwood	Myrtaceae	Dec - May
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb
*Trema tomentosa var. viridis**	Poison peach	Ulmaceae	Nov - May

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Acronychia vestita	White aspen	Rutaceae	Jun - Oct
Agathis atropurpurea	Black kauri	Araucariaceae	Dec - Jan
Agathis microstachya	Bull kauri	Myrtaceae	Dec - Jan
*Agathis robusta**	Queensland kauri	Araucariaceae	Nov - Feb
Alloxylon wickhamii	Satin oak	Proteaceae	Aug - Oct
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron grandiflorum	Tulip siris	Mimosaceae	Aug - Feb
*Archirhodomyrtus beckleri**	Rose myrtle	Myrtaceae	Sep - Feb
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Athertonia diversifolia	Atherton oak	Proteaceae	Oct - Feb
Beilschmiedia bancroftii	Yellow walnut	Lauraceae	Oct - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
*Buckinghamia celsissima**	Spotted silky oak	Proteaceae	May - Nov
Canarium australasicum	Mango bark	Burseraceae	Jun - Jan
*Cardwellia sublimis**	Northern silky oak	Proteaceae	Oct - Feb
Cerbera inflata	Grey milkwood	Apocynaceae	Oct - Jan
Cryptocarya angulata	Ivory laurel	Lauraceae	Jul - Dec
Cryptocarya corrugata	Corduroy laurel	Lauraceae	Jun - Jan
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	May - Jan
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Davidsonia pruriens	Davidson's plum	Davidsoniaceae	All year
*Decaspermum humile**	Brown myrtle	Myrtaceae	Jul - Nov
Diospyros pentamera	Grey persimmon	Ebenaceae	Jan - Jul
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Jul - Jan
Elaeocarpus largiflorens ssp. largiflorens	Tropical quandong	Elaeocarpaceae	Nov - Mar
Elaeocarpus ruminatus	Brown quandong	Elaeocarpaceae	Mar - Sep
Endiandra hypotephra	Rose walnut	Lauraceae	Sep - Nov
Endiandra palmerstonii	Queensland walnut	Lauraceae	Dec - May
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Endiandra wolfei	Walnut	Lauraceae	Aug - Dec
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
*Ficus copiosa**	Plentiful fig	Moraceae	Aug - Nov
*Ficus hispida**	Hairy fig	Moraceae	All year
Ficus pleurocarpa	Banana fig	Moraceae	Aug - Dec
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
Franciscodendron laurifolium	Tulip sterculia	Sterculiaceae	Nov - Mar
Galbulimima baccata	Magnolia	Himantandraceae	Feb - Sep
Gillbeea adenopetala	Pink alder	Cunoniaceae	Aug - Feb
*Gossia dallachiana**	Lignum	Myrtaceae	All year
Grevillea hilliana	Hill's silky oak	Proteaceae	Jan - Mar
Hicksbeachia pilosa	Red bauple nut	Proteaceae	Aug - Jan
*Homalium circumpinnatum**	Brown boxwood	Flacourtiaceae	Nov - Feb
Litsea bindoniana	Big leaf bollywood	Lauraceae	Oct - Dec
Litsea connorsii	Bollywood	Lauraceae	Oct - Dec
Mischarytera lautereriana	Corduroy tamarind	Sapindaceae	Oct - Dec
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Opisthiolepis heterophylla	Blush silky oak	Proteaceae	Aug - Nov
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Jan - Jun
Pittosporum rubiginosum	Red pittosporum	Pittosporaceae	Mar - Sep
Placospermum coriaceum	Rose silky oak	Proteaceae	Mar - Oct
Podocarpus grayae	Brown pine	Podocarpaceae	Oct - Jan
Prunus turneriana	Almondbark	Rosaceae	Jul - Jan
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar

Scientific name	Common name	Family	Indicative fruiting times
Sloanea langii	White carabeen	Elaeocarpaceae	Sep - Apr
Stenocarpus davallioides	Fern-leaf stenocarpus	Proteaceae	Oct - Feb
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
Sundacarpus amarus	Black pine	Podocarpaceae	Dec - Mar
*Syzygium canicortex**	Yellow satinash	Myrtaceae	Apr - Nov
*Syzygium cryptophlebium**	Plum satinash	Myrtaceae	Sep - Jan
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
*Syzygium luehmannii**	Cherry satinash	Myrtaceae	Nov - Apr
Syzygium trachyphloium	Rough barked satinash	Myrtaceae	Nov - Mar
Ternstroemia cherryi	Cherry beech	Theaceae	All year
Waterhousea unipunctata	Rolypoly satinash	Myrtaceae	Jun - Dec
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

* = *'edge sealing' species*

GROUP 9: WET TO VERY WET UPLANDS ON BASALT

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Acacia melanoxylon *	Black wattle	Mimosaceae	Sep - Dec
Acmena resa *	Red Eungella satinash	Myrtaceae	Oct - Apr
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	All year
Alphitonia petriei	Pink ash	Rhamnaceae	Feb - Aug
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
Alstonia scholaris *	Milky pine	Apocynaceae	Dec - Feb
Archirhodomyrtus beckleri	Rose myrtle	Myrtaceae	Sep - Feb
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Aug - Jan
Argyrodendron trifoliolatum	Brown tulip oak	Sterculiaceae	Dec - Feb
Cardwellia sublimis *	Northern silky oak	Proteaceae	Oct - Feb
Cryptocarya triplinervis *	Brown laurel	Lauraceae	Nov - Mar
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
Dysoxylum mollissimum ssp. molle	Miva mahogany	Meliaceae	Oct - Feb
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Mar - Dec
Euroschinus falcata var. falcata	Pink poplar	Anacardiaceae	Nov - Feb
Ficus congesta var. congesta *	Water fig	Moraceae	All year
Ficus copiosa *	Plentiful fig	Moraceae	Jan - Nov
Ficus destruens	Rusty-leaved fig	Moraceae	Nov - Apr
Ficus hispida *	Hairy fig	Moraceae	All year
Ficus obliqua	Figwood	Moraceae	All year
Ficus pleurocarpa	Banana fig	Moraceae	Aug - Dec
Ficus septica *	Septic fig	Moraceae	Feb - Jun
Ficus variegata	Green fruited fig	Moraceae	Nov - Jul
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
Glochidion harveyanum	Buttonwood	Phyllanthaceae	Dec - Apr
Guioa acutifolia *	Glossy tamarind	Sapindaceae	Nov - Jan
Guioa lasioneura *	Silky tamarind	Sapindaceae	Nov - Mar
Helicia nortoniana *	Norton's silky oak	Proteaceae	May - Dec
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Macaranga tanarius *	Macaranga	Euphorbiaceae	Sep - Feb
Melia azedarach	White cedar	Meliaceae	Nov - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Neolitsea dealbata *	White bollywood	Lauraceae	Jan - Jun
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Planchonella myrsinodendron	Yellow boxwood	Sapotaceae	May - Nov
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Prunus turneriana	Almondbark	Rosaceae	Jul - Jan
Pullea stutzeri	Hard alder	Cunoniaceae	Dec - May
Rhodamnia sessiliflora *	Iron malletwood	Myrtaceae	Dec - May
Sloanea macbrydei *	Grey carabeen	Elaeocarpaceae	Sep - Mar
Syzygium cormiflorum *	Bumpy satinash	Myrtaceae	Aug - Feb
Trema tomentosa var. viridis *	Poison peach	Ulmaceae	Nov - May

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Alloxylon flammeum	Satin oak	Proteaceae	Sep - Jan
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
Arytera pauciflora	Small leaf tamarind	Sapindaceae	Aug - Jan
Athertonia diversifolia	Atherton oak	Proteaceae	Oct - Feb
Beilschmiedia bancroftii	Yellow walnut	Lauraceae	Oct - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
*Buckinghamia celsissima**	Ivory curl tree	Proteaceae	May - Nov
Canarium australasicum	Mango bark	Burseraceae	Jun - Jan
Carnarvonia araliifolia	Caledonian oak	Proteaceae	Sep - Mar
Cerbera inflata	Grey milkwood	Apocynaceae	Oct - Jan
Cinnamomum laubatii	Pepperwood	Lauraceae	Aug - Nov
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Cryptocarya oblata	Tarzali silkwood	Lauraceae	Nov - Apr
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	Nov - Apr
Darlingia ferruginea	Rose silky oak	Proteaceae	Aug - Jan
Davidsonia pruriens	Davidson's plum	Davidsoniaceae	All year
*Decaspermum humile**	Brown myrtle	Myrtaceae	Jul - Nov
Diploglottis bracteata	Boonjee tamarind	Sapindaceae	Nov - Jan
Dysoxylum alliaceum	Buff mahogany	Meliaceae	Apr - Jun
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus eumundi	Eumundi quandong	Elaeocarpaceae	Sep - Apr
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Jul - Jan
Elaeocarpus largiflorens ssp. largiflorens	Tropical quandong	Elaeocarpaceae	Nov - Mar
Endiandra palmerstonii	Queensland walnut	Lauraceae	Dec - May
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Endiandra wolfei	Walnut	Lauraceae	Aug - Dec
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
Ficus crassipes	Figwood	Moraceae	Jul - May
Ficus virens	White fig	Moraceae	Oct - Jun
*Ficus watkinsiana**	Figwood	Moraceae	Jan - Oct
Flindersia acuminata	Silver silkwood	Rutaceae	Aug - Dec
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Galbulimima baccata	Magnolia	Himantandraceae	Feb - Sep
Geissois biagiana	Brush mahogany	Cunoniaceae	Jan - Mar
Gillbeea adenopetala	Pink alder	Cunoniaceae	Aug - Feb
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
*Gossia dallachiana**	Lignum	Myrtaceae	All year
Helicia lamingtoniana	Lamington's silky oak	Proteaceae	Sep - Nov
Hicksbeachia pilosa	Red bauple nut	Proteaceae	Aug - Jan
Hollandaea sayeriana	Mueller's oak	Proteaceae	Dec - Mar
Hymenosporum flavum	Native frangipani	Pittosporaceae	Dec - Apr
Jagera pseudorhus var. integerrima	Pink tamarind	Sapindaceae	Jul - Nov
Litsea connorsii	Bollywood	Lauraceae	Oct - Dec
Mischarytera lautereriana	Corduroy tamarind	Sapindaceae	Oct - Dec
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Opisthiolepis heterophylla	Blush silky oak	Proteaceae	Aug - Nov
Phaleria clerodendron	Scented daphne	Thymelaeaceae	Jan - Jun
Pitaviaster haplophyllus	Yellow aspen	Rutaceae	Feb - Aug
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar
Sloanea langii	White carabeen	Elaeocarpaceae	Sep - Apr
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
Sundacarpus amarus	Black pine	Podocarpaceae	Dec - Mar
Syzygium cryptophlebium *	Plum satinash	Myrtaceae	Sep - Jan
Syzygium gustavioides	Water gum	Myrtaceae	May - Sep
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
Syzygium papyraceum	Paperbark satinash	Myrtaceae	Dec - Feb
Waterhousea unipunctata	Rolypoly satinash	Myrtaceae	Jun - Dec
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

** = 'edge sealing' species*

GROUP 10: WET TO VERY WET HIGHLANDS ON BASALT

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Acacia melanoxylon *	Black wattle	Mimosaceae	Sep - Dec
Acmena resa *	Red Eungella satinash	Myrtaceae	Oct - Apr
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	Apr - Dec
Alphitonia petriei	Pink ash	Rhamnaceae	Feb - Aug
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
Alstonia scholaris *	Milky pine	Apocynaceae	Dec - Feb
Argyrodendron peralatum	Red tulip oak	Sterculiaceae	Aug - Jan
Argyrodendron trifoliolatum	Brown tulip oak	Sterculiaceae	Dec - Feb
Cardwellia sublimis *	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	Nov - Apr
Cryptocarya triplinervis *	Brown laurel	Lauraceae	Nov - Mar
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Dec - Apr
Ficus congesta var. congesta *	Water fig	Moraceae	All year
Ficus obliqua	Figwood	Moraceae	Sep - Mar
Ficus pleurocarpa	Banana fig	Moraceae	Mar - Dec
Ficus septica *	Septic fig	Moraceae	Feb - Jun
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
Guioa acutifolia *	Glossy tamarind	Sapindaceae	Nov - Jan
Guioa lasioneura *	Silky tamarind	Sapindaceae	Nov - Mar
Guioa montana	Tamarind	Sapindaceae	Nov - Jan
Helicia nortoniana *	Norton's silky oak	Proteaceae	All year
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Mallotus mollissimus	Kamala	Euphorbiaceae	All year
Mallotus philippensis *	Red kamala	Euphorbiaceae	Nov - Apr
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Neolitsea dealbata *	White bollywood	Lauraceae	Feb - May
Pilidiostigma tropicum *	Apricot myrtle	Myrtaceae	Dec - Mar
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Pouteria brownlessiana	Boxwood	Sapotaceae	Oct - Feb
Prunus turneriana	Almondbark	Rosaceae	Nov - Mar
Rhodamnia sessiliflora *	Iron malletwood	Myrtaceae	Dec - May
Sloanea macbrydei *	Grey carabeen	Elaeocarpaceae	Sep - Mar
Syzygium cormiflorum *	Bumpy satinash	Myrtaceae	Aug - Feb
Syzygium sayeri *	Pink satinash	Myrtaceae	Nov - Mar

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Alloxylon flammeum	Satin oak	Proteaceae	Sep - Jan
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron vaillantii	Salmon bean	Mimosaceae	Jan - Jun
Archirhodomyrtus beckleri	Rose myrtle	Myrtaceae	Sep - Feb
Beilschmiedia bancroftii	Yellow walnut	Lauraceae	Oct - Aug
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Carnarvonia araliifolia	Caledonian oak	Proteaceae	Sep - Mar
Cerbera inflata	Grey milkwood	Apocynaceae	Nov - May
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Cryptocarya oblata	Tarzali silkwood	Lauraceae	Nov - Apr
Cryptocarya onoprienkoana	Rose maple	Lauraceae	Jun - Nov
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Darlingia ferruginea	Rose silky oak	Proteaceae	Aug - Jan
Dysoxylum parasiticum	Spur mahogany	Meliaceae	Nov - Feb
Elaeocarpus eumundi	Eumundi quandong	Elaeocarpaceae	Sep - Apr
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Aug - Mar
Elaeocarpus largiflorens ssp. largiflorens	Tropical quandong	Elaeocarpaceae	Nov - Mar
Endiandra insignis	Hairy walnut	Lauraceae	Oct - Jul
Endiandra palmerstonii	Queensland walnut	Lauraceae	Dec - May
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
*Ficus copiosa**	Plentiful fig	Moraceae	Jan - Nov
Ficus crassipes	Figwood	Moraceae	All year
Ficus destruens	Rusty-leaved fig	Moraceae	Mar - Dec
*Ficus watkinsiana**	Watkin's fig	Moraceae	Sep - Apr
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia schottiana	Silver ash	Rutaceae	Dec - Mar
Galbulimima baccata	Magnolia	Himantandraceae	Feb - Sep
Gillbeea adenopetala	Pink alder	Cunoniaceae	Aug - Feb
Gmelina fasciculiflora	Northern White beech	Verbenaceae	Dec - Mar
Hymenosporum flavum	Native frangipani	Pittosporaceae	Dec - Apr
Litsea connorsii	Bollywood	Lauraceae	Oct - Dec
*Mischarytera lautereriana**	Corduroy tamarind	Sapindaceae	Oct - Dec
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Opisthiolepis heterophylla	Blush silky oak	Proteaceae	Aug - Nov
Pararchidendron pruinosum	Tulip siris	Mimosaceae	Nov - Jun
Pullea stutzeri	Hard alder	Cunoniaceae	Dec - May
*Scolopia braunii**	Flintwood	Flacourtiaceae	Dec - Mar
Sloanea langii	White carabeen	Elaeocarpaceae	Jun - Jan
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
Sundacarpus amarus	Black pine	Podocarpaceae	Dec - Mar
*Syzygium cryptophlebium**	Plum satinash	Myrtaceae	Sep - Jan
Syzygium gustavioides	Water gum	Myrtaceae	May - Sep
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
Syzygium papyraceum	Paperbark satinash	Myrtaceae	Dec - Feb
Waterhousea unipunctata	Rolypoly satinash	Myrtaceae	Jun - Dec

** = 'edge sealing' species*

GROUP 11: MOIST TO VERY WET LOWLANDS ON COASTAL DUNES

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Acacia oraria	Wattle	Mimosaceae	Sep - Oct
Acmena hemilampra ssp. hemilampra *	Blush satinash	Myrtaceae	Mar - Jul
Canarium australianum	Scrub turpentine	Burseraceae	Jun - Oct
Carallia brachiata *	Corky bark	Rhizophoraceae	Sep - Nov
Chionanthus ramiflora *	Native olive	Oleaceae	Sep - Dec
Cordia dichotoma	Snotty-gobble	Boraginaceae	Oct - Feb
Cryptocarya triplinervis *	Brown laurel	Lauraceae	Nov - Mar
Cupaniopsis anacardioides	Green leaved tamarind	Sapindaceae	May - Aug
Dillenia alata	Red beech	Dilleniaceae	Sep - Feb
Ficus hispida *	Hairy fig	Moraceae	All year
Ficus microcarpa	Small fruited fig	Moraceae	Jan - Jun
Ficus virens var. virens	White fig	Moraceae	Aug - Apr
Flindersia schottiana	Tropical ash	Rutaceae	Dec - Mar
Glochidion harveyanum	Buttonwood	Phyllanthaceae	Dec - Apr
Glochidion philippicum *	Daintree cheese tree	Phyllanthaceae	Jun - Mar
Grevillea baileyana	Findlay's silky oak	Proteaceae	Oct - Feb
Hibiscus tiliaceus *	Coast cottonwood	Malvaceae	Nov - Feb
Homalanthus novoguineensis	Bleeding heart	Euphorbiaceae	Sep - Apr
Macaranga tanarius *	Macaranga	Euphorbiaceae	Sep - Mar
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Millettia pinnata	Pongamia	Fabaceae	Sep - Apr
Pittosporum venulosum	Brown pittosporum	Pittosporaceae	Jul - Apr
Pleiogynium timorense	Burdekin plum	Anacardiaceae	Mar - Oct
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Rhus taitensis *	Sumac	Anacardiaceae	Feb - Nov
Scolopia braunii *	Flintwood	Flacourtiaceae	Dec - Mar
Syzygium angophoroides *	Lost dog	Myrtaceae	Nov - Apr
Terminalia sericocarpa	Damson plum	Combretaceae	Dec - Feb

** = 'edge sealing' species*

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
*Acacia celsa**	Brown salwood	Mimosaceae	Oct - Feb
Adenanthera pavonina	Bead tree	Mimosaceae	Jun - Feb
Alstonia scholaris	Milky pine	Apocynaceae	Dec - Feb
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron grandiflorum	Tulip siris	Mimosaceae	Aug - Feb
Archidendron vaillantii	Salmon bean	Mimosaceae	Jan - Jun
*Arytera divaricata**	Rose tamarind	Sapindaceae	Sep - Dec
*Atractocarpus fitzalanii ssp. fitzalanii**	Brown gardenia	Rubiaceae	May - Oct
Barringtonia calyptrata	Mango pine	Lecythidaceae	Dec - Aug
Bombax ceiba	Kapok tree	Bombacaceae	Aug - Oct
Buchanania arborescens	Buchanania	Anacardiaceae	Sep - Feb
Calophyllum sil	Blush touriga	Clusiaceae	Aug - Nov
Canarium vitiense	Canarium	Burseraceae	Jun - Sep
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Deplanchea tetraphylla	Bignonia	Bignoniaceae	Nov - Dec
Elaeocarpus bancroftii	Kuranda quandong	Elaeocarpaceae	Feb - Apr
*Ficus opposita**	Sandpaper fig	Moraceae	Oct - Apr
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Gmelina dalrympleana	White beech	Verbenaceae	Jan - Apr
Morinda citrifolia var. citrifolia	Great morinda	Rubiaceae	Mar - Dec
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Paraserianthes toona	Acacia cedar	Mimosaceae	Aug - Sep
Sterculia quadrifida	Peanut tree	Sterculiaceae	May - Jan
*Syzygium cormiflorum**	Bumpy satinash	Myrtaceae	Aug - Feb
*Syzygium fibrosum**	Fibrous satinash	Myrtaceae	Sep - Feb
Syzygium forte ssp. forte	White apple	Myrtaceae	Sep - Dec
*Syzygium sharoniae**	Sharon's satinash	Myrtaceae	Jul - Aug
Syzygium suborbiculare	Forest satinash	Myrtaceae	All year
Terminalia catappa	Indian almond	Combretaceae	Oct - Feb
Ternstroemia cherryi	Cherry beech	Theaceae	All year

** = 'edge sealing' species*

GROUP 12: MOIST TO VERY WET UPLANDS AND HIGHLANDS ON ALLUVIUM, GRANITES AND METAMORPHICS

FRAMEWORK SPECIES

Scientific name	Common name	Family	Indicative fruiting times
Aleurites rockinghamensis	Candlenut	Euphorbiaceae	Apr - Dec
Alphitonia petriei	Pink ash	Rhamnaceae	Feb - Aug
Alphitonia whitei	Red ash	Rhamnaceae	Jan - Apr
Archirhodomyrtus beckleri *	Rose myrtle	Myrtaceae	Sep - Feb
Breynia cernua	Coffee bush	Phyllanthaceae	All year
Cardwellia sublimis *	Northern silky oak	Proteaceae	Oct - Feb
Castanospora alphandii	Brown tamarind	Sapindaceae	Nov - Feb
Claoxylon tenerifolium	Qld brittlewoood	Euphorbiaceae	Aug - Jan
Cryptocarya hypospodia	Northern laurel	Lauraceae	Aug - Feb
Darlingia darlingiana	Brown silky oak	Proteaceae	Nov - Jan
Elaeocarpus grandis	Blue quandong	Elaeocarpaceae	Dec - Apr
Ficus obliqua	Figwood	Moraceae	Sep – Mar
Ficus pleurocarpa	Banana fig	Moraceae	Mar - Sep
Ficus watkinsiana *	Watkin's fig	Moraceae	Sep - Apr
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Guioa lasioneura *	Silky tamarind	Sapindaceae	Nov - Mar
Helicia nortoniana *	Norton's silky oak	Proteaceae	All year
Litsea leefeana	Brown bollywood	Lauraceae	Jun - Nov
Mallotus mollissimus	Kamala	Euphorbiaceae	All year
Mallotus philippensis *	Red kamala	Euphorbiaceae	Nov - Apr
Melicope elleryana	Corkwood	Rutaceae	Apr - Aug
Mischocarpus lachnocarpus	Woolly pear fruit	Sapindaceae	Dec - Jul
Neolitsea dealbata *	White bollywood	Lauraceae	Feb - May
Pilidiostigma tropicum *	Apricot myrtle	Myrtaceae	Dec - Mar
Pittosporum rubiginosum	Red pittosporum	Pittosporaceae	Apr - Oct
Polyscias australiana	Ivory basswood	Araliaceae	Dec - Mar
Polyscias elegans	Celerywood	Araliaceae	Jun - Nov
Pouteria brownlessiana	Boxwood	Sapotaceae	Oct - Feb
Pullea stutzeri	Hard alder	Cunoniaceae	Dec - May
Syzygium cormiflorum *	Bumpy satinash	Myrtaceae	Aug - Feb

MAXIMUM DIVERSITY

Scientific name	Common name	Family	Indicative fruiting times
Acronychia acidula	Lemon aspen	Rutaceae	Apr - Aug
Alloxylon wickhamii	Satin oak	Proteaceae	Aug - Oct
Antidesma erostre	Currantwood	Phyllanthaceae	Jan - Nov
Archidendron vaillantii	Salmon bean	Mimosaceae	Jan - Jun
Brachychiton acerifolius	Flame tree	Sterculiaceae	Apr - Dec
Buckinghamia celsissima *	Ivory curl tree	Proteaceae	May - Nov
Canarium australasicum	Mango bark	Burseraceae	Nov - Jan
Castanospermum australe	Black bean	Fabaceae	Mar - Nov
Cryptocarya mackinnoniana	Rusty laurel	Lauraceae	Nov - Apr
Cryptocarya murrayi	Murray's laurel	Lauraceae	Oct - Dec
Elaeocarpus foveolatus	Northern quandong	Elaeocarpaceae	Aug - Mar
Elaeocarpus largiflorens ssp. largiflorens	Tropical quandong	Elaeocarpaceae	Nov - Mar
Endiandra hypotephra	Rose walnut	Lauraceae	Sep - Nov
Endiandra insignis	Hairy walnut	Lauraceae	Oct - Jul
Endiandra palmerstonii	Queensland walnut	Lauraceae	Dec - May
Endiandra sankeyana	Sankey's walnut	Lauraceae	May - Oct
Eupomatia laurina	Copper laurel	Eupomatiaceae	Apr - Aug
Flindersia bourjotiana	Queensland silver ash	Rutaceae	Nov - Apr
Flindersia brayleyana	Queensland maple	Rutaceae	Jun - Jan
Flindersia pimenteliana	Maple silkwood	Rutaceae	Sep - Dec
Franciscodendron laurifolium	Tulip sterculia	Sterculiaceae	Nov - Mar
Galbulimima baccata	Magnolia	Himantandraceae	Feb - Sep
Geissois biagiana	Brush mahogany	Cunoniaceae	Jan - Mar
Gillbeea adenopetala	Pink alder	Cunoniaceae	Aug - Feb
Macaranga subdentata	Needlebark	Euphorbiaceae	Nov - Jun
Mischarytera lautereriana *	Corduroy tamarind	Sapindaceae	Oct - Dec
Mischocarpus pyriformis ssp. pyriformis	Tamarind	Sapindaceae	Dec - Jan
Myristica globosa ssp. muelleri	Nutmeg	Myristicaceae	Aug - Dec
Pararchidendron pruinosum	Tulip siris	Mimosaceae	Nov - Jun
Pittosporum rubiginosum	Red pittosporum	Pittosporaceae	Apr - Oct
Prunus turneriana	Almondbark	Rosaceae	Nov - Mar
Pullea stutzeri	Hard alder	Cunoniaceae	Dec - May
Scolopia braunii *	Flintwood	Flacourtiaceae	Dec - Mar
Sloanea langii	White carabeen	Elaeocarpaceae	Jun - Jan
Stenocarpus sinuatus	Wheel of fire	Proteaceae	Dec - Jan
Sundacarpus amarus	Black pine	Podocarpaceae	Dec - Mar
Syzygium canicortex *	Yellow satinash	Myrtaceae	Apr - Nov
Syzygium cryptophlebium *	Plum satinash	Myrtaceae	Sep - Jan
Syzygium johnsonii	Rose satinash	Myrtaceae	Sep - Mar
Syzygium kuranda	Kuranda satinash	Myrtaceae	Aug - Nov
Syzygium luehmannii *	Cherry satinash	Myrtaceae	Nov - Apr
Syzygium papyraceum	Paperbark satinash	Myrtaceae	Dec - Feb
Syzygium trachyphloium	Rough barked satinash	Myrtaceae	Nov - Mar
Ternstroemia cherryi	Cherry beech	Theaceae	All year
Waterhousea unipunctata	Rolypoly satinash	Myrtaceae	Jun - Dec
Xanthostemon whitei	Red penda	Myrtaceae	Sep - Jan

REFERENCES

Adam, P. (1992). *Australian Rainforests*. Oxford Monographs on Biogeography. No.6 Clarendon Press, Oxford.

Aerts, R. & Honnay, O. (2011). Forest restoration, biodiversity and ecosystem functioning. *BMC Ecology* 11:29.

Aide, T.M., Zimmerman, J.K., Pascarella, J.B., Rivera, L. & Marcano-Vega H. (2000). Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. *Restoration Ecology* 8: 328-338.

Andren, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* 71: 355-366.

Armesto, J.J. & Rozzi, R. (1989). Seed Dispersal Syndromes in the Rain Forest of Chiloe: Evidence for the importance of Biotic Dispersal in a Temperate Rain Forest. *Journal Biogeography* 16: 219-226.

Arnaiz, O.L., Wilson, A.L., Watts, R.J. & Stevens, M.M. (2011). Influence of riparian condition in aquatic macroinvertebrate communities in an agricultural catchment in south-eastern Australia. *Ecological Research* 26: 123-131.

Ash, J. (1988). The location and stability of rainforest boundaries in north-eastern Queensland, Australia. J. *Biogeography* 15: 619– 630.

Baker, F.S. (1950). *Principles of Silviculture*. McGraw-Hill, New York, 414 pp.

Barlow, J., Overal, W, Araujo, I., Gardner, T. & Peres, C. (2007). The value of primary, secondary and plantation forests for fruit-feeding butterflies in the Brazilian Amazon. *Journal of Applied Ecology* 44: 1001–1012.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C.,Lindsey, E.L., Maguire, K.C., Mersey, B. & Ferrer, E.A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature* 471: 51-57.

Bawa, K.S. (1990). Plant–pollinator interactions in tropical rain forests. *Annual Review of Ecology and Systematics* 21: 399–422.

Bélisle, M. & Desrochers, A. (2002). Gap-crossing decisions by forest birds: an empirical basis for parameterizing spatially-explicit, individual-based models. *Landscape Ecology* 17: 219-231.

Bellingham, P.J. (2008). Cyclone effects on Australian rain forest: An overview. *Austral Ecology* 33: 580-584.

Bellingham, P.J., Tanner, E.V.J., & Healey, J.R. (2005). Hurricane disturbance accelerates invasion by the alien tree Pittosporum undulatum in Jamaican montane rain forest. Journal of Vegetation Science 16: 675-684.

Benitez-Malvido J. (1999). Litter cover variability affects seedling performance and herbivory. *Biotropica* 31: 596-606.

Benyus, J.M. (1997). Biomimicry: Innovation Inspired by Nature. William Morrow & Co. New York.

Bierregard, R.O., Lovejoy, T.E., Kapos, V., dos Santos, A.A. & Hutchings, R.W. (1992). The biological dynamics of tropical rainforest fragments. *Bioscience* 42: 859-866.

Bjorkman, O. & Ludlow, M.M. (1972). Characterization of the light climate on the floor of a Queensland rainforest. *Carnegie Institute of Washington Year Book* 71: 85-94.

Bostock, P.D. & Holland, A.E (2010). *Census of the Queensland Flora*. Qld Herbarium, Department of Environment and Resource Management, Brisbane.

Boulter, S. L., Kitching, R. L. & Howlett, B. G. (2006). Family, visitors and the weather – patterns of flowering in tropical rainforests of northern Australia. *Journal of Ecology* 94: 369–82.

Boulter, S.l., Kitching, R.L., Gross, C.L. Goodall, K.L. & Howlett, B.G. (2008). Floral morphology, phenology and pollination in the Wet Tropics. In: Stork, N.E. & Turton, S.M. (eds). L*iving in a Dynamic Tropical Forest Landscape*. Blackwell Publishing Ltd. Oxford.

Brodie, J.E., Kroon, F.J., Schaffelke, B., Wolanski, E.C., Lewis, S.E., Devlin, M.J., Bohnet, I.C., Bainbridge, Z.T., Waterhouse, J., & Davis, A.M. (2012). Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues priorities and management responses. *Marine Pollution Bulletin* 65: 81-100.

Bronstein, J.L. (1995). The plant–pollinator landscape. In: Hansson, L., Fahrig, L. & Merriam, G. (eds). *Mosaic Landscapes and Ecological Processes*. Chapman & Hall, London.

Bruce, C., Kroon, F., Sydes, D. & Ford, A. (2008). Cyclone damage sustained by riparian revegetation sites in the Tully-Murray floodplain, Queensland Australia. *Austral Ecology* 33: 516-524.

Bunn, S.E., Davies, P.M. & Mosisch, T.D. (1999). Ecosystem measures of river health and their response to riparian can catchment degradation. *Freshwater Biology* 41: 333-345.

Burcher, C.L., McTammany, M.E., Benfield, E.F. & Helfman, G.S. (2008). Fish assemblage responses to forest cover. *Environmental Management* 41: 338-346.

Cardinale, B.J., Palmer, M.A. & Collins, S.L. (2002). Species diversity enhances ecosystem functioning through interspecific facilitation. *Nature* 415: 426-429.

Castro, S., Ferrero, V., Loureiro, J., Espadaler, X., Silveira, P. & Navarro, L. (2010). Dispersal mechanisms of the narrow endemic Polygala vayredae: dispersal syndromes and spatio-temporal variations in ant dispersal assemblages. *Plant Ecology* 207: 359-372.

Catterall, C.P., McKenna, S., Kanowski, J. & Piper, S.D. (2008). Do cyclones and forest fragmentation have synergistic effects? A before-after study of rainforest vegetation structure at multiple sites. *Austral Ecology* 33: 471-484.

Celentano, D., Zahawi, R.A., Finegan, B., Ostertag. R., Cole, R.J. & Holl, K.D. (2011). Litterfall dynamics under different tropical forest restoration strategies in Costa Rica. *Biotropica* 43: 279-287.

Chapin, F.S. III, Torn, M.S. & Tateno, M. (1996). Principles of ecosystem sustainability. *American Naturalist* 148: 1016–1037.

Charles-Dominique, P. (1993). Speciation and coevolution: An interpretation of frugivory phenomena. *Vegetatio* 107: 75–84.

Chazdon, R.L. (2003). Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics* 6: 51-71.

Chazdon, R.L. (2008). Chance and determinism in tropical forest succession. In: Carson, W.P. & Schnitzer, S.A. (eds). *Tropical Forest Community Ecology*. Blackwell Scientific Oxford. p. 384-408.

Chesson, P. & Huntley, N. (1997). The roles of harsh and fluctuating conditions in the dynamics of ecological communities. *American Naturalist* 150: 519–53.

Childs, D.Z., Metcalf, C.J. & Rees, M. (2010). Evolutionary bet-hedging in the real world: empirical evidence and challenges revealed by plants. Proceedings of the Royal Society of London B: Biological Sciences 277: 3055–3064.

Clifford, H.T. & Mott, J.J. (1986). Regenerative processes. In: Clifford, H.T. & Specht, R.L.(eds). *Tropical Plant Communities*. Department of Botany, University of Queensland, Brisbane. pp 68-77.

Coates-Estrada, R. & Estrada, A. (1986). Fruiting and frugivores at a strangler fig in the tropical rain forest of Los Tuxtlas, Mexico. *Journal of Tropical Ecology* 2: 349–357.

Cole, R.J., Holl, K.D., Keene, C.L. & Zahawi, R.A. (2011). Direct seeding of late-successional trees to restore tropical montane forest. *Forest Ecology and Management* 261: 1590-1597.

Cooper, W. & Cooper, W.T. (2004) *Fruits of the Australian Tropical Rainforest*. Nokomis Editions, Melbourne.

Connell, J.H. & Green, P.T. (2000). Seedling dynamics over thirty-two years in a tropical rain forest tree. *Ecology* 81: 568–584.

Connell, J.H. & Slatyer, R.O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist* 111: 1119-1144.

Connell, J.H. (1975). Some mechanisms producing structure in natural communities: a model and evidence from field experiments. In: Cody, M. & Diamond, J. (eds). *Ecology and Evolution of Communities*. Harvard University Press, Mass. pp. 460-490.

Corlett, R.T. (1998). Frugivory and seed dispersal by vertebrates in the oriental (Indomalayan) region. *Biological Review* 73: 413-448.

Corlett, R.T. (2002). Frugivory and seed dispersal in degraded tropical East Asian landscapes. In: Levey, D.J., Silva, W.R. & Galetti, M. (eds). *Seed Dispersal and Frugivory: Ecology, Evolution and Conservation*. Wallingford, UK: CAB International. pp. 451-465.

Crome, F.H.J. (1975). The foraging ecology of fruit pigeons in tropical Northern Queensland. *Australian Wildlife Research* 2: 155–85.

Crome, F.H.J. (1990). Vertebrates and successions. In: Webb, L.J. & Kikkawa, J. (eds). *Australian Tropical Rainforests: Science – Values – Meaning*. CSIRO Publications. Melbourne, pp. 53-64.

Crome, F.H.J. & Irvine, A.K. (1986). "Two bob each way." The pollination and breeding system of the Australian rainforest tree, Syzygium cormiflorum. *Biotropica* 18: 115-125.

Crome, F.H.J. & Moore, L.A. (1990). Cassowaries in north-eastern Queensland: Report of a survey and a review and assessment of their status and conservation and management needs. Australian Wildlife Research 17: 369-385.

Dalling, J.W. & Hubbell, S.P. (2002). Seed size, growth rate and gap microsite conditions as determinants of recruitment success for pioneer species. *Journal of Ecology* 90: 557-568.

Davis, M.A., Grime, J.P. & Thompson, K. (2000). Fluctuating resources in plant communities: a general theory of invasibility. *Journal of Ecology* 88: 528–34.

Davis, M.A., Wrage, K.J. & Reich, P.B. (1998). Competition between tree seedlings and herbaceous vegetation support of a theory of resource supply and demand. *Journal of Ecology* 86: 652-661.

Debussche, M. & Isenmann, P. (1994). Bird-dispersed seed rain and seedling establishment in patchy Mediterranean vegetation. *Oikos,* 69:414-426.

Dennis, A.J. & Marsh, H. (1997). Seasonal reproduction in musky rat-kangaroos, Hypsiprymnodon moschatus, a response to changes in resource availability. *Wildlife Research* 24: 561–78.

Dennis, A.J. & Westcott, D.A. (2006). Reducing complexity when studying seed dispersal at community scales: a functional classification of vertebrate seed dispersers in tropical forests. *Oecologia* 149: 620-634.

Denslow, J.S. (1987). Tropical rainforest gaps and tree species diversity. *Annual Review of Ecology and Systematics* 18: 431–451.

Devlin, M.J. & Brodie, J. (2005). Terrestrial discharge into the Great Barrier Reef Lagoon: nutrient behaviour in coastal waters. *Marine Pollution Bulletin* 51: 9-22.

Dew, J.L. & Boubli, J.P. (2005). Fruits and Frugivores: *The Search for Strong Interactors*. Kluwer Academic Publishers, New York.

Dosskey, M.G. (2001). Toward quantifying water pollution abatement in response to installing buffers on crop land. *Environmental Management* 28: 577-598.

Doust, S.J. (2004). Seed and seedling ecology in the early stages of rainforest restoration. PhD thesis, School of Integrative Biology, University of Queensland, Brisbane.

Doust, S.J. (2010). Seed removal and predation as factors affecting seed availability of tree species in degraded habitats and restoration plantings in rainforest areas of Queensland, Australia. *Restoration Ecology* 19: 617-626.

Du, Y., Mi, X., Liu, X., Chen, L. & Ma, K. (2009). Seed dispersal phenology and dispersal syndromes in a subtropical broad-leaved forest of China. *Forest Ecology and Management* 258: 1147-1152.

Egler, F.E. (1954). Vegetation science concepts I. Initial floristic composition - a factor in old field vegetation development. *Vegetation* 4: 412-417.

Elliott, S., Blakesley, D., Maxwell, J.F., Doust, S. & Suwannaratana, S. (2006). *How to Plant a Forest: The Principles and Practice of Restoring Tropical Forests* (1st edition). Chiang Mai University, Thailand.

Elmouttie, D. (2009). *Utilisation of seed resources by small mammals: a two-way interaction*. PhD thesis, Queensland University of Technology, Brisbane.

Erskine, P.D., Catterall, C.P., Lamb, D. & Kanowski, J. (2007). Patterns and processes of old field reforestation in Australian rainforest landscapes. In: Cramer, V. A. and Hobbs, R. J. (eds.) *Old Fields: Dynamics and Restoration of Abandoned Farmland*. Island Press. Washington. p. 119-144.

Fischer, K.E. & Chapman, C.A. (1993). Frugivores and fruit syndromes: differences in patterns at the genus and species level. *Oikos*, 66: 472-482.

Floyd, A.G. (1987). Status of rainforests in northern New South Wales. In: Werren, G.L. & Kershaw, A.P. (eds). *The Rainforest Legacy,* Vol. 1. Australian Government Publishing Service, Canberra, pp. 95–118.

Folke, C. (2006). Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253–267.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. & Holling, C.S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics* 35: 557–581.

Foster, S.A. & Janson, C.H. (1985). The relationship between seed size and establishment conditions in tropical woody plants. *Ecology* 66: 773-780.

Fox, J.W. (2010). Partitioning the effects of species loss on community variability using multi-level selection theory. *Oikos* 119: 1823–1833.

Frankie, G.W., Baker, H.G. & Opler, P.A. (1974). Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *Journal of Ecology* 62:881-919.

Friedman, W.E. (2009). The meaning of Darwin's "abominable mystery". American Journal of Botany 96: 5-21.

Futuyma, D. J. (2010). Evolutionary constraint and ecological consequences. *Evolution* 64: 1865–1884.

Ganade, G. & Brown, V. (2002). Succession in old pastures of Central Amazonia: role of soil fertility and plant litter. *Ecology* 83: 743-754.

Gibbons P. & Lindenmayer, D. (2002). *Tree Hollows and Wildlife Conservation*. CSIRO Publishing, Melbourne.

Gomez-Roldan, V., Fermas, S., Brewer, P.B., Puech-Pagès, V., Dun, E.A., Pillot, J-P., Letisse, F., Matusova, R., Danoun, S., Portais, J-C., Bouwmeester, H., Bécard, G., Beveridge, C.A., Rameau, C. & Rochange, S.F. (2008). Strigolactone inhibition of shoot branching. *Nature* 455: 189–194.

Goosem, M. (2000). Effects of tropical rainforest roads on small mammals: edge changes in community composition. *Wildlife Research* 27: 151-163.

Goosem, M. (2002). Effects of tropical rainforest roads on small mammals: fragmentation, edge effects and traffic disturbance. *Wildlife Research* 29: 277-289.

Goosem, S.P. (2003). Landscape processes relevant to weed invasion in Australian rainforests and associated ecosystems. In: Grice, A. C. & Setter, M. J. (eds). *Weeds of Rainforests and Associated Ecosystems*. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Rainforest CRC, Cairns.

Goosem, S. (2008). Invasive weeds in the Wet Tropics. In: Stork, N.E and Turton, S.M. (eds). *Living in a Dynamic Tropical Forest Landscape*. Blackwell Publishing Ltd. Oxford. Pp. 307-321.

Goosem, S.P. & Tucker, N.I.J. (1995). Repairing the Rainforest: *Theory and Practice of Rainforest Re-establishment in north Queensland's Wet Tropics*. Wet Tropics Management Authority. Cairns.

Griffiths, J.F. (1972). Climates of Africa. In: *World Survey of Climatology*, Vol. 10. Amsterdam: Elsevier.

Grime, J.P. (1979). *Plant Strategies and Vegetation Processes*. New York: John Wiley and Sons. 222 pp.

Grubb, P.J. (1998) Seeds and fruits of tropical rainforest plants: interpretation of the range in seed size, degree of defence and flesh/seed quotients. In: Newbery,D.M., Prins, H.H.T. & Brown, N.D. (eds). *Dynamics of Tropical Communities*. Blackwell Scientific, Oxford, pp. 1-24.

Guevara, S. & Laborde, J. (1993). Monitoring seed dispersal at isolated standing trees in tropical pastures: consequences for local species availability. *Vegetatio* 107/108: 319-338.

Guevara, S., Meave, J., Moreno-Casasola, P. & Laborde, J. (1992). Floristic composition and structure of vegetation under isolated trees in neotropical pastures. *Journal of Vegetation Science* 3: 655-664.

Gustafson, E.J. (1998). Quantifying landscape spatial pattern: what is state of the art? *Ecosystems* 1: 143-156.

Harper, J.L., Lovell, P.H. & Moore, K.G. (1970). The shapes and sizes of seeds. Annual Review of Ecology and Systematics. 1: 327-356.

Harper, J.L. (1977). *Population Biology of Plants.* Academic Press, London.

Hartshorn, G.S. (1980). Neotropical forest dynamics. *Biotropica (Supplement)* 12: 23–30.

Harvey, C.E., Tucker, N.I.J & Estrada, A. (2004). The role of isolated trees, live fences and windbreaks in the conservation of tropical biodiversity. In: Scroth, G., Gascon, C., Izac, I.M.N. & Harvey, C. (eds). *Tropical biodiversity and the role of agroforestry. Island Press.* Washington, D.C.

Heartstill-Scalley, T. & Aide, T.M. (2003). Riparian vegetation and stream condition in a tropical agriculture-secondary forest mosaic. *Ecological Application*s 13: 225-234.

Henriquez, J.M. & Lusk, C.H. (2005). Facilitation of *Nothofagus antarctica* (Fagaceae) seedlings by the prostrate shrub *Empetrum rubrum* (Empetraceae) on glacial moraines in Patagonia. *Austral Ecology* 30: 877–882

Herrera, C.M. (1985). Determinants of plant–animal coevolution: the case of mutualistic dispersal of seeds by vertebrates. *Oikos* 44: 132–41.

Herrera, C.M. (2002). Seed dispersal by vertebrates. In: Herrera, C.M. & Pellmyr, O. (eds.). *Plant animal interactions. An evolutionary approach*. Blackwell, Oxford, pp.185–208.

Hill, J.L. & Hill, R.A. (2001). Why are tropical rain forests so species rich? Classifying, reviewing and evaluating theories. *Progress in Physical Geography* 25: 326-354.

Holl, K.D. (1998). Do bird perching structures elevate seed rain and seedling establishment in abandoned tropical pasture? *Restoration Ecology* 6: 253-261.

Holl, K.D. (1999). Factors limiting tropical rain forest regeneration in abandoned pasture: seed rain, seed germination, microclimate and soil. *Biotropica* 31: 229-242.

Holl, K.D., Loik, M.E., Lin, E.H.V. & Samuels, I.A. (2000). Tropical montane forest restoration in Costa Rica: overcoming barriers to dispersal and establishment. *Restoration Ecology* 8: 339-349.

Hollander, J.L. & Vander Wall, S.B. (2009). Dispersal syndromes in North American Ephedra. *International Journal of Plant Science* 170: 323-330.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1-23.

Hooper, E., Legendre, P. & Condit, R. (2005). Barriers to forest regeneration of deforested and abandoned land in Panama. *Journal of Applied Ecology* 42: 1165-1174.

Hopkins, M.S. (1975). *Species Diversity and Pattern in the Subtropical Rainforest.* Ph.D. Thesis, University of Queensland, Brisbane.

Hopkins, M.S. (1981). Disturbance and change in rainforests and the resulting problems of functional classification. In: Gillison, A.N. & Anderson, D.J. (eds) *Vegetation Classification in Australia*. Australian National University Press, Canberra pp. 42-52.

Hopkins, M.S., Kikkawa, J., Graham, A.W., Tracey, J.G. & Webb, L.J. (1976). An ecological basis for the management of rain forest. In: Monroe, R. & Stevens, N.C. (eds). The Border Ranges. *A Land Use Conflict in Regional Perspective*. Royal Society of Queensland, Brisbane, pp. 57-66.

House, S.M. (1989). Pollen movement to flowering canopies of pistillate individuals of three rainforest tree species in tropical Australia. *Australian Journal of Ecology* 14: 77–94.

House, S.M. (1993). Pollination success in a population of dioecious rain forest trees. *Oecologia* 96: 555–61.

Howe, H.F. (1977). Bird activity and seed dispersal of a tropical wet forest tree. *Ecology* 58: 539-50.

Howe, H.F. (1984). Implications of seed dispersal by animals for tropical reserve management. *Biological. Conservation* 30: 261- 81.

Howe, H.F. & Smallwood, J. (1982). Ecology of seed dispersal. *Annual Review of Ecology and Systematics* 13: 201-228.

Howe, H.F. (1989). Scatter and clump-dispersal and seedling demography: hypothesis and implications. *Oecologia, 79*: 417–426.

Howe, H.F. & Westley, L.C. (1986). Ecology of pollination and seed dispersal. In: Crawley, M. (ed). *Plant Ecology.* Blackwell, pp. 185-215.

Hubbell, S.P., Foster, R.B., O'Brien, S.T., Harms, K.E., Condit, R., Wechsler, B., Wright, S.J. & Loo de Lao, S. (1999). Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science* 283: 554-57.

Hutchings, P., Haynes, D., Goudkamp, K. & McCook, L. (2005). Catchment to Reef: Water quality issues in the Great Barrier Reef Region - An overview of papers. *Marine Pollution Bulletin* 51: 3-8.

Irvine, A.K. & Armstrong, J.E. (1990). Beetle pollination in tropical forests of Australia. In: Bawa, K. & Hadley, M. (eds). *Reproductive Ecology of Tropical Forest Plants,* UNESCO Parthenon, Park Ridge, NJ, pp. 135–49.

Irvine, A.K. and Armstrong, J. (1988). Beetle pollination in Australian tropical rainforests. *Proceedings of the Ecological Society of Australia* 15: 107-113.

Jansen, A. (2005). Avian use of restoration plantings along a creek linking rainforest patches on the Atherton Tablelands, North Queensland. *Restoration Ecology* 13: 275-283.

Janzen, D.H. (1967). Synchronization of sexual reproduction of trees within the dry season in Central America. *Evolution* 21: 620-637.

Janzen, D.H. (1975). *Ecology of Plants in the Tropics*. Edward Arnold, London.

Jenny, H. (1941). *Factors of Soil Formation. A System of Quantitative Pedology.* McGraw Hill, New York.

Jenny, H. (1958). Role of the plant factor in the pedogenic functions. *Ecology* 39: 5-16.

Jones, R.E. & Crome, F.H.J. (1990). The biological web - plant/animal interactions in the rainforest. In: Webb, L.J., & Kikkawa, J. (eds) *Australian Tropical Rainforest: Science - Values – Meaning*. CSIRO Publishing, Melbourne. pp. 74-87.

Jordano, P. (1992). Fruits and frugivory. In: Fenner, M. (ed). Seeds: *The Ecology of Regeneration in Plant Communities.* CABI, Wallingford, UK, pp. 105–56.

Jordano, P. (2000). Fruits and frugivory. In: Fenner, M. (ed.). Seeds. *The ecology of regeneration in plant communities.* CABI, Wallingford, pp. 125–165.

Kanowski, J., Catterall, C.P., McKenna, S.G. & Jensen, R. (2008). Impacts of Cyclone Larry on the vegetation structure of timber plantations, restoration plantings and rainforest on the Atherton Tableland, Australia. *Austral Ecology* 33: 485-494.

Kidson, R. & Westoby, M. (2000). Seed mass and seedling dimensions in relation to seedling establishment. *Oecologia* 125: 11-17.

Kitamura, S., Yumoto, T., Poonswad, P.,Chuailua, P., Plongmai, K., Maruhashi, T. & Noma, N. (2002). Interactions between fleshy fruits and frugivores in a tropical seasonal forest in Thailand. *Oecologia* 133: 559-572.

Knowlton, N. (1992). Thresholds and multiple stable states in coral reef community dynamics. *American Zoologist* 32: 674–682.

Lambert, F. (1989). Fig-eating by birds in a Malaysian lowland rain-forest. *Journal of Tropical Ecology* 5: 401–412.

Laurance, S.G. & Laurance, W.F. (1999). Tropical wildlife corridors: use of linear rainforest remnants by arboreal mammals. *Biological Conservation* 91: 231-239.

Laurance, W.F. (1997). Responses of mammals to rainforest fragmentation in tropical Queensland: a review and synthesis. *Wildlife Research* 24: 603-612.

Laurance, W.F. (1999). Reflections on the tropical deforestation crisis. *Biological Conservation* 91: 109-117.

Laurance, W.F. (2002). Hyperdynamism in fragmented habitats. *Journal of Vegetation Science* 13: 595-602.

Laurance, W.F. (2011). Original and the best: nothing beats primary forests for biodiversity. *The Conversation*, 15 September 2011. http://theconversation.edu.au/original-and-the-best-nothing-beats-primary-forests-for-biodiversity-3388

Laurance, W.F., Goosem, M. & Laurance, S.G.W. (2009). Impacts of roads and linear clearings on tropical forests. T*rend in Ecology and Evolution* 24: 659-669.

Lawson, T., Gillieson, D. & Goosem, M. (2008a). Assessment of riparian rainforest vegetation change in Tropical North Queensland for management and restoration purposes. *Geographical Research* 45: 387-397.

Lawson, T., Goosem, M. & Gillieson, D. (2008b). Rapid assessment of habitat quality in riparian rainforest vegetation. *Pacific Conservation Biology* 14: 20-33.

Lees, A.C. & Peres C.A. (2008). Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. *Conservation Biology* 22: 439-449.

Letcher, S.G. (2009). Phylogenetic structure of angiosperm communities during tropical forest succession. *Proceedings of Royal Society* B 277: 97-104.

Levey, D.J. (1987). Seed size and fruit-handling techniques of avian frugivores. *American Naturalist* 129: 471–80.

Lomascolo, S.B., Speranza, P. & Kimball, R.T. (2008). Correlated evolution of fig size and color supports the dispersal syndromes hypothesis. *Oecologia* 158: 783-796.

Lorion, C.M. & Kennedy, B.P. (2009). Relationships between deforestation, riparian forest buffers and benthic macroinvertebrates in neotropical headwater streams. *Freshwater Biology* 54: 165-180.

Lowrance, R., Todd, R., Fail, J., Hendrickson, O., Leonard, R. & Asmussen, L. (1984). Riparian forests as nutrient filters in agricultural watersheds. Bioscience 34: 374-377.

Mabi Forest Working Group (2000). *Vanishing Vegetation of Far North Queensland:* Mabi (5b) Forest. Mabi Forest Working Group.

MacArthur, R.H. & Wilson, E.O. (1967). T*he Theory of Island Biogeography.* Princeton Univ. Press, Princeton. 203 pp.

Maeterlinck, M. (2008). The Intelligence of Flowers. (Translation of the original 1907 publication by Mosley, P.). State University of New York Press.

Maggs, J. & Hewett, B. (1993). Organic C and nutrients in surface soils from some primary rainforest, derived grasslands and secondary rainforests of the Atherton Tableland in North East Queensland. *Australian Journal of Soil Research* 31: 343-350.

Martinez-Garza, C. & Howe, H.F. (2003). Restoring tropical diversity: beating the time tax on species loss. *Journal of Applied Ecology* 40: 365-79.

McClanahan, T.R. & Wolfe, R.W. (1993). Accelerating forest succession in a fragmented landscape: the role of birds and perches. *Conservation Biology* 7: 279-288.

McClanahan, T.R., Polunin, N. & Done, T.J. (2002). Ecological states and the resilience of coral reefs. *Conservation Ecology* 6: 18.

Meiners, S.J., Pickett, S.T.A. & Cadenasso, M.L. (2002). Exotic plant invasions over 40 years of old field successions: community patterns and associations. *Ecography* 25: 215-233.

Metcalfe, D.J. & Ford, A.J. (2009). A re-evaluation of Queensland's Wet Tropics based on primitive plants. *Pacific Conservation Biology* 15: 80–86.

Moilanen, A. & Nieminen, M. (2002). Simple connectivity measures in spatial ecology. *Ecology* 83: 1131-1145.

Moore, L.A. (2001). *The Cassowaries of Mission Beach: Population number, densities, distribution, demography and implications for conservation*. Report commissioned by the Department of Main Roads.

Moran, C., Catterall, C.P. & Kanowski, J. (2009). Reduced dispersal of native plant species as a consequence of the reduced abundance of frugivore species in fragmented rainforest. B*iological Conservation* 141: 541-552.

Mudappa, D. & Raman, T.R.S. (2010). Rainforest Restoration: *A Guide to Principles and Practice*. Nature Conservation Foundation, Mysore.

Murcia, C. (1995). Edge effects in fragmented forests: implications for conservation. *Tree* 10: 58–62.

Murphy, H.T., Metcalfe, D.J., Bradford, M.G., Ford, A.F., Galway, K.E., Sydes, T.A. & Westcott, D.J. (2008). Recruitment dynamics of invasive species in rainforest habitats following Cyclone Larry. *Austral Ecology* 33: 495-502.

Nadolny, C. (1999). Recruitment and survival of Argyrodendron actinophyllum seedlings in an Australian rainforest. *Australian Journal of Ecology* 24: 258-269.

Naeem, S. (2006). Biodiversity and ecosystem functioning in restored ecosystems: extracting principles for a synthetic perspective. In: Falk, D.A., Palmer, M.A. & Zedler, J.B. (eds). *Foundations of Restoration Ecology*. Society for Ecological Restoration International, Island Press. Washington, D.C, pp. 210-237.

National Land and Water Resources Audit (2001). CSIRO Land and Water Technical Report Number 15/01.

Natural Resource Management Ministerial Council. (2007). Australian Weeds Strategy – A national strategy for weed management in Australia. Canberra.

Neidel, J.D., Consunji, H., Labozetta, J., Calle, A. & Mateo- Vega, J (eds). (2012). *Mainstreaming Native Species-Based Forest Restoration: ELTI Conference Proceedings*. New Haven, CT: Yale University; Panama City: Smithsonian Tropical Research Institute.

Neilan, W., Catterall, C.P., Kanowski, J. & McKenna S. (2006). Do frugivorous birds assist rainforest succession in weed dominated oldfield regrowth of sub-tropical Australia. *Biological Conservation* 129: 393-407.

Nepstad, D., Uhl, C. & Serrão, E.A. (1991). Recuperation of a degraded Amazonian landscape: forest recovery and agricultural restoration. *AMBIO*, 20:248-255.

Neville, P.J. & Black, D.G. (1997). Animals on the edge: the "cancelling out" effect. *Memoirs of Museum of Victoria* 56: 623-630.

Niering, W.A. (1987). Vegetation Dynamics (Succession, Climax) in Relation to Plant Community Management. *Conservation Biology* 1: 287-95.

Norden, N., Chazdon, R.L., Chao, A., Jiang, Y.H. & Vilchez Alvarado, B. (2009). Resilience of tropical rain forests: tree community reassembly in secondary forests. *Ecology Letters* 12: 384–394.

Noss, R.F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* 4: 355-364.

Novák, J. & Prach, K. (2003).Vegetation succession in basalt quarries: pattern on a landscape scale. *Applied Vegetation Science* 6: 111–116.

O'Brien, T.G.O., Kinnaird, M.F., Dierenfeld, E.S., Conklin-Brittain, N.L., Wrangham, R.W. & Silver, S.C. (1998).What's so special about figs? *Nature* 392: 668.

Olson, D.M., Dinerstein, E., Abell, R., Allnutt, T., Carpenter, C., McClenachan, L., D'Amico, J., Hurley, P., Kassem, K., Strand, H., Taye, M. & Thieme, M. (2000). The Global 200: *A Representation Approach to Conserving the Earth's Distinctive Ecoregions*. Conservation Science Program, World Wildlife Fund-US.

Osborne, P. L. (2000). *Tropical Ecosystems and Ecological Concepts*. Cambridge University Press, Cambridge, pp. 238-279.

Paetkau, D., Vazquez-Dominguez, E., Tucker, N.I.J. & Moritz, C. (2009). Monitoring movement into and through a newly planted rainforest corridor using genetic analysis of natal origin. *Ecological Management & Restoration* 10: 210-216.

Palmer, M.A., Ambrose, R.F. & Poff, N.L. (1997). Ecological theory and community restoration ecology. *Restoration Ecology* 5: 291-300.

Parrotta, J.A., Turnbull, J.W. & Jones N. (1997). Catalyzing native forest regeneration on degraded tropical lands. *Forestry Ecology and Management* 99: 1-7.

Paton, P.W.C. (1994). The effect of edge on avian nest success: how strong is the evidence? *Conservation Biology* 8: 17-26.

Paul, M., Catterall, C.P., Kanowski, J. & Pollard, P.C. (2012). Recovery of rain forest soil seed banks under different reforestation pathways in eastern Australia. *Ecological Management & Restoration* 13: 140-150.

Peel, B. (2010). Rainforest Restoration Manual for South-Eastern Australia. CSIRO Publishing.

Peña-Claros, M. & de Boo, H. (2002). The effects of forest successional stage on seed removal of tropical rainforest tree species. *Journal of Tropical Ecology* 18: 261-274.

Peres, C.A. & van Roosmalen, M.G.M. (2002). Patterns of primate frugivory in Amazonia and the Guianan shield: implications to the demography of large-seeded plants in overhunted forests. In: Levey, D.J., Silva, W.R. & Galetti, M. (eds). *Seed Dispersal and Frugivory: Ecology, Evolution and Conservation.* CABI, Wallingford, UK.

Pimm, S.L. & Raven, P. (2000). Extinction by numbers. *Nature* 403: 843-845.

Pohlman, C.L., Goosem, M. & Turton, S.M. (2008). Effects of Severe Tropical Cyclone Larry on rainforest vegetation and understorey microclimate near a road, powerline and stream. *Austral Ecology* 33: 503-515.

Poulson, T.L. & Platt, W.J. (1989). Gap light regimes influence canopy tree diversity. *Ecology* 70: 553-555.

Primack, R.B. (1987). Relationships among flowers, fruits, and seeds. *Annual Review of Ecology and Systematics* 18: 409-430.

Sagan, C. (1997). *The Demon-Haunted World: Science as a Candle in the Dark.* Ballantine Books. New York.

Sakai, S., Momose, K., Yumoto, T., Kato, M. & Inoue, T. (1999). Beetle pollination of *Shorea parvifolia* (section Mutica, Dipterocarpaceae) in a general flowering period in Sarawak, Malaysia. A*merican Journal of Botany* 86: 62–9.

Sattler, P. S. & Williams, R. (1999). *The Conservation Status of Queensland's Bioregional Ecosystems.* Environmental Protection Agency, Queensland Government, Brisbane.

SCBD (Secretariat of the Convention on Biological Diversity) (2010) *Global Biodiversity Outlook* 3. Montréal, 94 pages. http://www.cbd.int/doc/publications/gbo/gbo3-final-en.pdf

SCBD (Secretariat of the Convention on Biological Diversity) (2011). *Ways and Means to Support Ecosystem Restoration,* Recommendation XV/8 by the Executive Secretary– Subsidiary Body On Scientific, Technical and Technological Advice Fifteenth meeting, Montréal, 7-11 November 2011: http://www.cbd.int/doc/?meeting=SBSTTA-15

Schmidt, V., Schaefer, H.M. & Winkler, H. (2004). Conspicuousness, not colour as foraging cue in plant- animal signalling. *Oikos* 106: 551–557.

Schnitzer, S.A. & Bongers, F. (2011). Increasing liana abundance and biomass in tropical forests: emerging patterns and putative mechanisms. Ecological Letters 14: 397-406.

Seaman, B.S. & Schulze, C.H. (2010). The importance of gallery forests in the tropical lowlands of Costa Rica for understorey birds. *Biological Conservation* 143: 391-389.

Seimann, E. & Rodgers, W. (2003). Changes in light and nitrogen availability under pioneer trees may indirectly facilitate tree invasions of grasslands. *Journal of Ecology* 91: 923-931.

SER (Society for Ecological Restoration International Science & Policy Working Group. (2004). *The SER International Primer on Ecological Restoration.* www.ser.org & Tucson: Society for Ecological Restoration International. www.ser.org/pdf/primer3.pdf

Shanahan, M.S, Compton, S.G. & Corlett, R. (2001). Fig-eating by vertebrate frugivores: a global review.

Biological Reviews 76: 529–572.
Shiels, A.B. (2011). Frugivory by introduced black rats (Rattus rattus) promotes dispersal of invasive plant seed. *Biological Invasions* 13: 781-792.

Slocum, M.G. & Horvitz, C.C. (2000). Seed arrival under different genera of trees in a neotropical pasture. *Plant Ecology* 149:51–62.

Specht, R.L. (1970). Vegetation. In: Leeper, G.W. (ed). *The Australian Environment.* CSIRO, Melbourne pp 44-67.

Stiles, E.W. (1992). Animals as seed dispersers. In: Fenner, M. (ed.). *Seeds: the Ecology of Regeneration in Plant Communities.* C.A.B. International, pp. 87-104.

Stork, N.E., Goosem, S & Turton, S.M. (2008). Australian rainforests in a global context. In: Stork, N.E & Turton, S.M. (eds). *Living in a Dynamic Tropical Forest Landscape*. Blackwell Publishing Ltd. Oxford.

Stork, N.E., Goosem, S. & Turton, S.M. (2011). Status and threats in the dynamic landscapes of northern Australia's tropical rainforest biodiversity hotspot: the Wet Tropics. In: Zachos, F.E. & Habel, J.C. (eds). *Biodiversity Hotspots. Distribution and Protection of Conservation Priority Areas*. Springer-Verlag Berlin Heidelberg, pp. 311 – 332.

Sun, D. & Dickinson, G.R. (1996). The competition effect of *Brachiaria decumbens* on the early growth of direct-seeded trees of *Alphitonia petriei* in tropical North Australia. *Biotropica* 28: 272-276.

Swaine, M.D. & Whitmore, T.C. (1988). On the definition of ecological species groups in tropical rain forests. *Vegetatio* 75: 81-86.

Tabacchi, E., Correll, D.L., Hauer, R., Pinay, G., Planty-Tabacchi, A. & Wissmar, R.C. (1998). Development, maintenance and role of riparian vegetation in the river landscape. *Freshwater Biology* 40: 497-516.

Taylor, P.D., Fahrig, L. Henein, K. & Merriam,G. (1993). Connectivity is a vital element of landscape structure. *Oikos* 68: 571-572.

TEEB (2010). T*he Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*.

TEEB (2011). *The Economics of Ecosystems and Biodiversity in National and International Policy Making.* Earthscan, London and Washington.

Terborgh, J. (1986a). Community aspects of frugivory in tropical forests. In: Estrada, A & Fleming, T. H. (eds). *Frugivores and Seed Dispersal.* W. Junk Publishers, Dordrecht, pp. 371–384.

Terborgh, J. (1986b). Keystone plant resources in the tropical forests. In: Soulá, M.E. (ed). *Conservation Biology: The Science of Scarcity and Diversity.* Sinauer Associates, Sunderland, MA, pp. 330–344.

Tewksbury, J.J. & Nabhan, G.P. (2001). Seed dispersal – directed deterrence by capsaicin in chillies. *Nature* 412: 403–404.

Tilman, D. (1997). Community invasibility, recruitment limitation and grassland biodiversity. Ecology 78: 81-92.

Toh I., Gillespie M. & Lamb D. (1999). The role of isolated trees in facilitating tree seedling recruitment at a degraded sub-tropical rainforest site. *Restoration Ecology* 7: 288–297.

Tracey, J.G. (1982). *The Vegetation of the Humid Tropical Region of North Queensland.* CSIRO, Melbourne.

Tracey J.G. & Webb, L.J. (1975). *Vegetation of the Humid Tropical Region of North Queensland* (15 maps at 1:100,000 scale + key). CSIRO Long Pocket Laboratory, Indooroopilly, Brisbane.

Tucker, N. & Murphy, T. (1997). The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of North Queensland. *Forest Ecology and Management* 99: 133-152.

Tucker, N. & Simmons, T. (2004). Animal-plant interactions in tropical restoration: observations and questions from north Queensland. In: Kanowski, J., Catterall, C.P., Dennis, A.J. & Westcott, D.A. (eds). Animal- Plant Interactions in Conservation and Restoration. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns, Qld.

Tucker, N. & Simmons, T. (2009). Restoring a rainforest habitat linkage in north Queensland: Donaghy's Corridor. *Ecological Management and Restoration* 10: 98-112.

Turton, S.M. (1988). Solar radiation regimes in a north Queensland rainforest. P*roceedings of the Ecological Society of Australia* 15: 101-105.

Turton, S.M., Hutchinson, M.F, Accad, A., Hancock, P.E. & Webb, T. (1999). Producing fine-scale rainfall climatology surfaces for Queensland's wet tropics region. In: Kesby, J.A., Stanley, J.M., McLean, R.F. & Olive, L.J. (eds). Geodiversity: *Readings in Australian Geography at the close of the 20th Century.* Special Publication Series No. 6, Canberra, ACT, School of Geography and Oceanography, University College, ADFA, pp. 415-428.

Turton, S.M. & Siegenthaler, D.T. (2004). Immediate impacts of a severe tropical cyclone on the microclimate of a rain-forest canopy in north-east Australia. *Journal of Tropical Ecology* 20: 583-586.

Uhl, C., Buschbacher, R. & Serrao, E.A.S. (1988). Abandoned pastures in eastern Amazonia 1. Patterns of plant succession. *Journal of Ecology* 76: 663-681.

van der Pijl, L. (1982). *Principles of Dispersal in Higher Plants*. Springer, Berlin, Germany.

van Schaik, C.P., Terborgh, J.W. & Wright, S.J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annual Reviews of Ecology and Systematics* 24: 353–377.

Vazques-Yanes, C. (1976). Studies on the germination of seeds: *Orchroma laqopus Schartz. Turrialba* 24: 176-179.

Walker, B., Hollin, C.S., Carpenter, S.R. & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9: 5.

Ward, D., Tucker, N. & Wilson, J. (2003). Cost-effectiveness of revegetating degraded riparian habitats adjacent to macadamia orchards in reducing rodent damage. *Crop Protection* 22: 935-940.

Waser, N.M. (1983). Competition for pollination and floral character differences among sympatric plant species: a review of evidence. In: Jones, C. E. & Little, R. J. (eds). H*andbook of Experimental Pollination Biology.* Van Nostrand Reinhold, New York, pp. 277–93.

Waser, N.M., Chittka, L., Price, M.V., Williams, N.M. & Ollerton, J. (1996). Generalization in pollination systems, and why it matters. *Ecology* 77: 1043-1060.

Webb, L.J. (1958). Cyclones as an ecological factor in tropical lowland rain-forest, north Queensland. *Australian Journal of Botany* 6: 220-228.

Webb, L.J. (1959). A physiognomic classification of Australian rainforests. *Journal of Ecology* 47: 551-570.

Webb, L.J. (1968). Environmental relationships of the structural types of Australian rain-forest vegetation. *Ecology* 49: 296-311.

Webb, L.J. (1978). A general classification of Australian rainforests. *Australian Plants* 9: 349-363.

Webb, L.J. & Tracey, J.G. (1981). Australian rainforests: patterns and change. In: Keast, A. (ed.). *Ecological Biogeography in Australia*. Junk, The Hague, pp. 605-694.

Webb, L.J., Tracey, J.G. & Jessup, L.W. (1986). Recent evidence for autochtony of Australian tropical and subtropical rainforest floristic elements. *Telopea* 2: 575-589.

Webb, L.J., Tracey, J.G. & Williams, W.T. (1972). Regeneration and pattern in subtropical rainforest. *Journal of Ecology* 60: 675-695.

Webb, L.J., Tracey, J.G. & Williams, W.T. (1976). The value of structural features in tropical forest typology. *Australian Journal of Ecology* 1: 3-28.

Webb, L.J., Tracey, J.G., Williams, W.T. & Lance, G.N. (1967). Studies in the numerical analysis of complex rainforest communities. I. A. comparison of methods applicable to site/species data. *Journal of Ecology* 55: 171-191.

Webb, L.J., Tracey, J.G., Williams, W.T. & Lance, G.N. (1970). A comparison of the properties of floristic and physiognomic-structural data. *Journal of Ecology* 58:203-232.

Werren, G.L., Goosem, S., Tracey, J.G. & Stanton, J.P. (1995). The Australian Wet Tropics centre of plant diversity. In: Davies, S.D., Heywood, V.H. & Hamilton, A.C. (eds). *World Centres of Plant Diversity.* WWF/IUCN, Oxford Information Press, pp. 500-506.

Westcott, D.A., Bradford, M.G., Dennis, A.J. & Lipsett-Moore, G. (2005). Key fruit resources in Australia's tropical rain forests. In: Dew, J.L. & Boubli, J.P. (eds). *Fruits and Frugivores: The Search for Strong Interactors*. Kluwer Academic Publishers, New York, pp. 236–60.

Westcott, D.A., Dennis, A.J., Bradford ,M.G., Harrington, G.N. & McKeown, A. (2008). Seed dispersal processes in Australia's tropical rainforests. In: Stork, N.E. & Turton, S.M. (eds). *Living in a Dynamic Tropical Forest Landscape.* Blackwell Publishing Ltd. Oxford, pp 211-224.

Westoby, M., Leishman, M. & Lord, J. (1996). Comparative ecology of seed size and dispersal. *Philosophical Transactions of the Royal Society* 351: 1309-1318.

Westra, L., Miller, P., Karr, J.R., Rees, W.E. & Ulanowitz, R.E. (2000). Ecological integrity and the aims of the global ecological integrity project. In: Pimentel, D., Westra, L. & Noss, R.F. (eds). *Ecological Integrity: Integrating Environment, Conservation and Health,* Island Press, pp 19–44.

Wheelwright, N.T. (1993). Fruit size in a tropical tree species, variation, preference by birds and heritability. *Vegetatio* 108: 163–74.

White, E., Tucker, N., Meyers, N. & Wilson, J. (2004). Seed dispersal to isolated revegetated rainforest patches in North Queensland. *Forest Ecology and Management* 192: 409-426.

White, E., Vivian-Smith, G. & Barnes, A. (2009). Variation in exotic and native seed arrival and recruitment of bird dispersed species in subtropical forest restoration and regrowth. *Plant Ecology* 204: 231-246.

Whitmore, T.C. (1975). *Tropical Rain Forests of the Far East.* Clarendon Press, Oxford.

Whitmore, T.C. (1978). Gaps in the forest canopy. In: Tomlinson, P.B. & Zimmerman, M.H. (eds). *Tropical Trees as Living Systems.* Cambridge University Press, Cambridge, pp. 639-655.

Whitmore, T.C. (1982). Pattern and process in forests. In: Newman, E.I. (ed). *The Plant Community as a Working Mechanism*. Blackwell, Oxford, pp. 45-59.

Whitmore, T.C. (1984). *Tropical Rain Forests of the Far East.* Second Edition. Clarendon Press. Oxford.

Wiens, J.J., et al. (2010). Niche conservatism as an emerging principle in ecology and conservation biology. *Ecology Letters* 13: 1310–1324.

Williams, G. & Adam, P. (2010). *The Flowering of Australia's Rainforests. A Plant and Pollination Miscellany.* CSIRO Publishing, Collingwood, Australia.

Williams, J., Read, C., Norton, A., Dovers, S., Burgman, M., Proctor, W. & Anderson, H. (2001). *Australia State of the Environment Report* 2001 (Biodiversity Theme Report): CSIRO on behalf of the Department of the Environment and Heritage, Canberra. http://www.environment.gov.au/soe/2001/publications/theme-reports/biodiversity/biodiversity01-3.html

Williams, S.E. (2006). *Vertebrates of the Wet Tropics Rainforests of Australia: Species Distributions and Biodiversity.* Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns, Australia (282 pp.)

Willson, M.F. & Crome, F.H.J. (1989). Patterns of seed rain at the edge of a tropical Queensland rain forest. *Journal of Tropical Ecology* 5: 301-308.

Willson, M.F., Irvine, A.K. & Walsh, N.G. (1989). Vertebrate dispersal syndromes in some Australian and New Zealand plant-communities, with geographic comparisons. *Biotropica* 21: 133–47.

Willson, M.F. & Traveset, A. (2000). The ecology of seed dispersal. In: Fenner, M. (ed). Seeds: *The Ecology of Regeneration in Plant Communities.* 2nd ed. Wallingford: CAB International, pp. 85–110.

Willson, M.F. & Whelan, C.J. (1990). The evolution of fruit color in fleshy-fruited plants. American Naturalist 136: 790–809.

Wilson, E.O. (2002). *The Future of Life*. Alfred E. Knopf, New York.

Wilson, J. & Whisson, D. (1993). *The Management of Rodents in North Queensland Cane Fields*. Publication BS16S. (Sugar Research and Development Corporation: Brisbane).

Woodford, R. (2000). Converting a dairy farm back to a rainforest water catchment. *Ecological Management and Restoration* 1: 83-93.

Worboys, G.L., Francis, W.L. & Lockwood, M. (2010). *Connectivity Conservation Management: A Global Guide*, Earthscan, London.

Wright, S.J. (2010). The future of tropical forests. *Annals of the New York Academy of Science* 1195: 1–27.

WTMA (2012). *Vegetation of the Wet Tropics of Queensland*. Edition 1. (35 maps at 1:50,000 scale + key). Wet Tropics Management Authority, Cairns.

Wunderle, J.R. (1997). The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. *Forest Ecology and Management* 99: 223-235.

WWF (2012). *Living Planet Report. World Wildlife Fund*, Gland, Switzerland.

Yachi, S. & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Sciences USA* 96: 1463–1468.

Yahner, R.H. (1988). Changes in wildlife communities near edges. *Conservation Biology* 2: 333-339.

Yates, D.J., Unwin, G.L. & Doley, D. (1988). Rainforest environment and physiology. *Proceedings of the Ecological Society of Australia* 15: 31-37.

Young P.A.R. & McDonald W.J. (1987). The distribution, composition and status of rainforests in southern Queensland. In: Werren, G.L. & Kershaw, A.P. (eds). *The Rainforest Legacy, Australian National Rainforest* Study, Vol. 1. Australian Heritage Commission, AGPS, Canberra.

APPENDIX 1

KEY TO THE RAINFOREST TYPES OF THE WET TROPICS

Step 1: Identify size of mature, exposed canopy or 'sun' leaves
(Refer to Explanatory notes at end of key for leaf size determination rules)

Mesophyll and notophyll leaf sizes most common in canopy.
.... **Group A**

OR

Palm leaves (feather or fan) most common in canopy.
.... **Group B**

OR

Notophyll and microphyll leaf sizes most common in canopy.
.... **Group C**

OR

Microphyll leaf size most common in canopy.
.... **Group D**

OR

Sclerophyll leaf species emergent or common in canopy.
.... **Group E**

GROUP A
MESOPHYLL LEAF SIZES MOST COMMON IN CANOPY

1.

- Leaves or leaflets generally exceed 12.5 centimetres in length
- Robust lianes, vascular epiphytes, plank buttresses, and compound leaves common and/or conspicuous
- Trunk surfaces generally obscured by aroids, epiphytes and climbing palms
- Stem diameters of canopy trees irregular, many average 60-120 centimetres
- Canopy height 20-40 metres

.... **2**

OR

- Leaves or leaflets generally exceed 12.5 centimetres in length
- Robust lianes and vascular epiphytes uncommon and/or inconspicuous in upper tree layers
- Spur rather than plank buttresses occasional but conspicuous
- Trunk spaces open, stem diameters of canopy trees generally regular and average 60 centimetres
- Canopy height 25-35 metres
- Sclerophyll species such as *Acacia* spp. may be scattered in canopy

.... **5**

2.

- Deciduous emergent and top canopy trees rare not evident

.... **3**

OR

- Deciduous emergent and top canopy trees present or conspicuous

.... **7**

GROUP A MESOPHYLL LEAF SIZES MOST COMMON IN CANOPY

3.

- Feather palm trees abundant in canopy .... **GROUP B**

OR

- Fan palm trees abundant in canopy .... **GROUP B**

OR

- Palm trees not evident or uncommon in canopy **4**

GROUP A MESOPHYLL LEAF SIZES MOST COMMON IN CANOPY	RAINFOREST CODE
4. COMPLEX MESOPHYLL VINE FOREST	**CMVF**
i) Very wet and wet lowlands and foothills mainly on alluvium and basalts.	**1a**
ii) Moist to very wet (± cloud) uplands mainly on basalts and alluvium.	**1b**
iii) Moist to wet lowlands and foothills on alluvium – gallery forest.	**1c**
iv) Very wet foothills on basaltic terraces and scree slopes - dominated by *Backhousia bancroftii*. [subtype of 1a]	**1d**
v) Very wet lowlands on calcareous sand ridges - characterised by *Intsia bijuga, Beilschmiedia obtusifolia* and *Palaquium galactoxylon*. [variant of 1a]	**1e**

5.

- Palm trees not evident or uncommon in canopy **6**

6. MESOPHYLL VINE FOREST	**MVF**
i) Very wet to moist lowlands, foothills and uplands on a variety of geologies	**2a**
ii) Very wet lowlands on dunes.	**2b**
iii) Wet to very wet lowlands on alluvium - with *Archontophoenix alexandrae* prominent in the sub-canopy and canopy. [subtype of 2a]	**2c**
iv) Very wet lowlands on seasonally inundated alluvium - characterised by *Barringtonia racemosa, Hibiscus tiliaceus* and *Heritiera littoralis* with *Archontophoenix alexandrae and Licuala ramsayi var. ramsayi* in the sub-canopy. [subtype of 2a]	**2d**
v) Very wet lowlands on dunes - characterised by *Calophyllum inophyllum, Terminalia arenicola, Dillenia alata, Myristica insipida var. insipida, Planchonella myrsinodendron, Millettia pinnata* and *Hibiscus tiliaceus*. [variant of 2b]	**2e**
vi) Wet to very wet uplands on unstable metamorphic rock slopes - commonly with Ficus spp., *Schefflera actinophylla* and *Alstonia scholaris*. [variant of 2a]	**2f**

7. • Deciduous and semi-deciduous emergent and top canopy present or conspicuous - *Deciduous refers to certain individuals in the species population completely losing their leaves for a time during the year and this leaf loss is obligatory for the species* - *Semi-deciduous refers to deciduous species whose leaf fall is controlled by the severity of the dry season, rather than being obligate.* **8**	
8. SEMI-DECIDUOUS MESOPHYLL VINE FOREST	**SDMVF**
i) Moist to wet lowlands and foothills on a variety of geologies	**3a**
ii) Wet lowlands on alluvium (coarse granitic outwash) - characterised by *Nauclea orientalis, Cryptocarya hypospodia* and *Castanospermum australe*. [variant of 1c]	**3b**
iii) Wet foothills on metamorphics (on steep slopes) - occasional *Aleurites moluccana* and Alstonia scholaris with or without *Bombax* ceiba var. l*eiocarpum* emergents and variable sclerophyll species. [variant of 3a]	**3c**

GROUP B **PALM LEAVES MOST CONSPICUOUS IN CANOPY**	**RAINFOREST CODE**
1. • Feather palm trees abundant in canopy .... **2** OR • Fan palm trees abundant in canopy **3**	
2. FEATHER-PALM VINE FOREST	**FPVF**
i) Very wet lowlands on seasonally inundated alluvium – dominated by *Archontophoenix alexandrae.*	**4a**
ii) Very wet lowlands on seasonally inundated alluvium – characterised by *Archontophoenix alexandrae, Syzygium tierneyanum* and *Barringtonia racemosa.* [subtype of 4a]	**4b**
iii) Wet and very wet uplands on granites (steep upper slopes and gully bottoms) – dominated by *Archontophoenix alexandrae.* [subtype of 4a]	**4c**
3. FAN-PALM VINE FOREST	**FAPVF**
i) Wet and very wet lowlands, foothills and uplands on alluvium – dominated by *Licuala ramsayi var. ramsayi.*	**5a**
ii) Wet uplands on metamorphics, alluvium and granites – dominated by *Licuala ramsayi var. ramsayi and Pandanus* spp. (swamp). [variant of 5a]	**5b**

GROUP C
NOTOPHYLL LEAF SIZES MOST COMMON IN CANOPY

1.

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust and slender woody lianes, vascular epiphytes common and/or conspicuous
- Plank buttresses common and/or conspicuous
- Compound entire leaves common
- Trunk surfaces generally obscured by the aroid *Pothos*
- Stem diameters of canopy trees irregular, many average 60-120 centimetres

.... **2**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust lianes, vascular epiphytes and plank buttresses uncommon and/or inconspicuous
- Tree crowns mostly evergreen, but with a few semi-evergreen or deciduous species, i.e. structural features are intermediate between simple and complex types
- Canopy closure occurs at heights above 10 metres

.... **5**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Stunted tree growth in which canopy closes at 3-10 metres

.... **6**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust lianes and vascular epiphytes inconspicuous in tree tops
- Slender woody and wiry lianes common and conspicuous in understorey
- Plank buttresses uncommon and/or inconspicuous
- Simple toothed leaves common
- Trunk spaces open
- Stem diameters (except for emergents) generally regular average 60 centimetres
- Tree crowns evergreen and generally sparse and narrow
- Strong tendency to single species dominance (e.g. *Ceratopetalum* in upper tree layers)
- Canopy height even, averaging 20-35 metres
- Often with sclerophyllous emergents and co-dominants.

.... **7**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust, slender and wiry lianes uncommon and/or inconspicuous
- Fleshy vascular epiphytes may be conspicuous on trunks
- Plank buttresses inconspicuous
- Simple entire leaves common
- Deciduous species generally absent but many tree crowns become sparse during the dry season depending upon the severity of the dry season i.e. semi-evergreen
- Often with sclerophyllous emergents and co-dominants
- Canopy height generally 10-20 metres

.... **8**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust, slender and wiry lianes uncommon and inconspicuous
- Fleshy vascular epiphytes conspicuous on trunks
- Plank buttresses uncommon and inconspicuous
- Simple entire leaves common
- Deciduous species generally absent but many tree crowns become sparse during the dry season depending upon the severity of the dry season i.e. semi-evergreen
- Canopy trees commonly branched low down (shrub-like)
- Stunted canopy tree growth
- Canopy height even, average 3- 9 metres

.... **9**

OR

- Leaves or leaflets generally exceed 7.5 centimetres in length but generally less than 12.5 centimetres
- Robust and slender woody lianes and vascular epiphytes common and conspicuous
- Deciduous and semi-deciduous emergent and canopy tree species common

.... **10**

2.

- Canopy height uneven, average 20-45 metres
- Emergents mostly evergreen with broad umbrella-like branches

.... **3**

OR

- Canopy height uneven, average 15-35 metres
- Occasional deciduous species with emergent *Araucaria* or *Agathis* (35-50 metres) common.

.... **4**

GROUP C NOTOPHYLL LEAF SIZES MOST COMMON IN CANOPY	RAINFOREST CODE
3. COMPLEX NOTOPHYLL VINE FOREST	**CNVF**
i) Wet and moist (± cloud) uplands and highlands mostly on basalts.	**6a**
ii) Very wet lowlands and foothills on granite boulder fields.	**6b**
iii) Dry foothills on alluvium (riverine floodplains) - characterised by *Corymbia torelliana, Acacia celsa, Elaeocarpus grandis, Flindersia pimenteliana, Grevillea baileyana and emergent Argyrodendron polyandrum.* [variant of 7c]	**6c**

GROUP C NOTOPHYLL LEAF SIZES MOST COMMON IN CANOPY	RAINFOREST CODE
4. ARAUCARIAN NOTOPHYLL VINE FOREST	**ANVF**
i) Dry foothills and uplands on granites and rhyolites - characterised by Araucaria *cunninghamii var. cunninghamii emergents.*	**7a**
ii) Very wet uplands on granites (steep rocky slopes) - characterised by *Araucaria cunninghamii var. cunninghamii*. [variant of 7a]	**7b**
iii) Moist foothills and uplands on metamorphics and granites - often with emergent *Agathis robusta*.	**7c**
iv) Wet uplands and highlands on granites - characterised by *Araucaria bidwillii* emergents. [variant of 10a]	**7d**
5. NOTOPHYLL VINE FOREST	**NVF**
i) Moist lowlands on dunes.	**8a**
ii) Moist highlands on basalts.	**8b**
iii) Very wet foothills on unstable basalt escarpments - characterised by fern spp., Chionanthus ramiflora and *Schefflera actinophylla*. [variant of 2a]	**8c**
iv) Moist to very wet foothills and uplands on a variety of geologies - dominated by *Blepharocarya involucrigera*.	**8d**
v) Moist to very wet foothills to highland (on steep slopes) on granite characterised by *Planchonella euphlebia* and *Podocarpus grayae*. [subtype of 14a]	**8e**
6. NOTOPHYLL VINE THICKET	**NVT**
i) Wet lowlands on dunes with or without *Syzygium forte, Syzygium banksii, Acacia crassicarpa, Drypetes deplanchei* and *Elaeodendron melanocarpum* (restricted to Hinchinbrook Island). [variant of 8a]	**9a**
ii) Moist lowlands on granites (transported coastal cobble and boulder ridges). Restricted to Orpheus and Curacoa Islands. [variant of 8a]	**9b**
iii) Wet foothills on exposed rocky granite headlands.	**9c**
iv) Moist and very wet lowlands on dunes - dominated by *Blepharocarya involucrigera, Atractocarpus sessilis, Choriceras tricorne, Endiandra glauca* and *Syzygium banksii*.	**9d**

GROUP C NOTOPHYLL LEAF SIZES MOST COMMON IN CANOPY	RAINFOREST CODE
7. SIMPLE NOTOPHYLL VINE FOREST	**SNVF**
i) Moist to very wet uplands and highlands on metamorphics, granites and rhyolites.	**10a**
ii) Wet lowlands on seasonally inundated alluvium - with *Syzygium angophoroides*.	**10b**
iii) Moist to very wet lowlands on dunes - characterised by *Syzygium forte* subsp. *forte, Buchanania arborescens* and *Chionanthus ramiflora*.	**10c**
iv) Very wet uplands on granites and metamorphics - dominated by *Stockwellia quadrifida*.	**10d**
v) Moist foothills on metamorphics (in seepage areas) -characterised by *Grevillea baileyana, Fagraea cambagei, Garcinia warrenii, Mischocarpus exangulatus* and *Pandanus monticola*.	**10e**
vi) Moist highlands on rhyolites - characterised by *Pseudoweinmannia lachnocarpa* and emergent *Agathis microstachya*. [subtype of 10a]	**10f**
vii) Very wet uplands on granites - dominated by *Dryadodaphne trachyphloia*. [subtype of 10a]	**10g**
viii) Very wet uplands on metamorphics - dominated by *Ceratopetalum virchowii*. [subtype of 10a]	**10h**
ix) Wet uplands on granites - characterised by *Argyrodendron polyandrum and Flindersia brayleyana*. [variant of 10a]	**10i**
x) Wet foothills on sharply broken metamorphic topography - dominated by *Acacia celsa*. [variant of 10a]	**10j**
xi) Moist to very wet uplands and highlands on granites and metamorphics - shallow soils, severe drainage, wind shearing. [subtype of 10a]	**10k**
xii) Moist and very wet lowlands on alluvium (on shallow sand islands within swamps) - with *Blepharocarya involucrigera, Acacia celsa, Flindersia bourjotiana, Syzygium angophoroides and Dillenia alata*. [subtype of 2a]	**10l**
8. SIMPLE SEMI-EVERGREEN NOTOPHYLL VINE FOREST	**SSENVF**
i) Moist to dry foothills and uplands on granites and metamorphics [4a]	**11a**
9. SIMPLE SEMI-EVERGREEN NOTOPHYLL VINE THICKET	**SSENVT**
i) Dry uplands on rhyolites.	**12a**
ii) Moist uplands on granites - with emergent *Argyrodendron polyandrum*.	**12b**
iii) Dry uplands on rhyolites - characterised by *Argyrodendron polyandrum, Strychnos psilosperma, Croton insularis, Brombya platynema and Geijera salicifolia*.	**12c**

GROUP C NOTOPHYLL LEAF SIZES MOST COMMON IN CANOPY	RAINFOREST CODE
10. SEMI-DECIDUOUS NOTOPHYLL VINE FOREST	**SDNVF**
i) Moist and dry foothills and uplands on basalts.	**13a**
ii) Moist lowlands and foothills on metamorphic, alluvial and rhyolitic coastal headlands - charactered by *Terminalia arenicola* and *Acacia polystachya*. [variant of 13a]	**13b**
iii) Moist lowlands on dunes - characterised by *Melia azedarach, Pleiogynium timorense, Ganophyllum falcatum, Paraserianthes toona, Ficus racemosa, Argyrodendron polyandrum and Alstonia scholaris.* [variant of 7c]	**13c**
iv) Moist foothills and uplands on metamorphic and granitic rocky gorges and talus slopes - characterised by *Ganophyllum falcatum, Pleiogynium timorense, Argyrodendron polyandrum, Paraserianthes toona, Melia azedarach and Chionanthus ramiflora.* [subtype of 7c]	**13d**

GROUP D
MICROPHYLL LEAF SIZES MOST COMMON IN CANOPY

1.

- Leaves and leaflets generally less than 7.5 centimetres in length
- Mossy and vascular epiphytes inconspicuous in upper tree layers
- Robust lianes common and conspicuous
- Plank buttresses not evident
- Prickly and thorny species common and/or conspicuous in usually dense shrub understorey
- Ground layer sparse
- Compound leaves and entire leaf margins common

.... **2**

OR

- Leaves and leaflets generally less than 7.5 centimetres in length
- Mossy and vascular epiphytes common and/or conspicuous in upper tree layers
- Robust lianes inconspicuous
- Slender and wiry lianes generally common and conspicuous
- Plank buttresses absent
- Prickly and thorny species absent
- Simple leaves with toothed margins common
- Strong tendency to single species dominance in tree layer
- Tree ferns and ground ferns abundant and/or conspicuous
- Sclerophyll emergents generally present in marginal situations

.... **6**

2.

- Canopy height uneven, average 10-15 metres with mixed evergreen and semi-evergreen emergent and upper tree layer species
- Araucarian and deciduous emergents uncommon or absent

.... **3**

OR

- Canopy height uneven, average 5-10 metres with mixed evergreen, semi-evergreen and deciduous emergents to 10-20 metres
  .... **4**

OR

- Canopy height uneven and discontinuous, average 5-10 metres
- Most emergents deciduous and many understorey species are deciduous or semi-evergreen.
  .... **5**

GROUP D **MICROPHYLL LEAF SIZES MOST COMMON IN CANOPY**	**RAINFOREST CODE**
3. LOW MICROPHYLL VINE FOREST	**SMVF**
i) Moist to very wet highlands on granites, metamorphics and rhyolites – with ferns .	**14a**
ii) Moist uplands on granite dominated by *Agathis robusta* and *Argyrodendron polyandrum*. [variant of 7c]	**14b**
iii) Very wet highlands on exposed granitic ridges - characterised by *Ceratopetalum virchowii* plus vine and fern species. [subtype of 14a]	**14c**
iv) Very wet highlands on granites - characterised by *Cinnamomum propinquum* plus vine and fern species. [subtype of 14a]	**14d**
v) Very wet uplands on metamorphics - characterised by *Uromyrtus tenella* plus vine and fern species. [subtype of 14a]	**14e**
vi) Wet uplands on metamorphics - with *Syzygium kuranda, Pouteria euphlebia, Podocarpus grayae, Musgravea stenostachya, Stenocarpus cryptocarpus* and sedges. [subtype of 14a]	**14f**
4. SEMI-EVERGREEN VINE THICKET	**MVT**
i) Moist to dry foothills and uplands on granites and rhyolites - characterised by emergent *Araucaria cunninghamii* var. *cunninghamii.*	**15a**
ii) Dry uplands on basalts (unconsolidated pyroclastic volcanic cones).	**15b**
iii) Very wet uplands on granites and metamorphics (impeded drainage) - with emergent *Licuala ramsayi var. ramsayi and Oraniopsis appendiculat*a.	**15c**
iv) Moist to wet lowlands on dunes - commonly with *Mimusops elengi, with or without Terminalia muelleri, Sersalisia sericea and Exocarpos latifolius.* [subtype of 8a]	**15d**
5. DECIDUOUS VINE THICKET	**DVT**
i) Moist to dry foothills on granites.	**16a**
ii) Moist foothills on steep granitic rock talus and boulder slopes - with *Gossia bidwillii*. [subtype of 16a]	**16b**

6.

- Canopy trees stunted, generally even height and mixed with sclerophylls, average 5-10 metres **7**

7. MICROPHYLL FERN THICKET	**MFT**
i) Very wet (+ cloud) highlands on granites.	**17a**
ii) Wet uplands on steep granitic boulder fields and scree slopes - with *Trochocarpa bellendenkerensis, Uromyrtus tenella, Rhodomyrtus macrocarpa, Placospermum coriaceum and Musgravea stenostachya.* [subtype of 17a]	**17b**

GROUP E
SCLEROPHYLL LEAF SPECIES EMERGENT OR COMMON IN CANOPY

1.

- Canopy almost exclusively Acacia species
- Robust lianes, vascular epiphytes, plank buttresses absent or uncommon
- Slender woody and wiry lianes common in understorey
- Trunk surfaces generally unobscured
- Canopy height average 15–30 metres
- Stem diameters of canopy trees regular
- Understorey of variable height comprising rainforest species typical of adjacent mesophyll or notophyll rainforests

.... **2**

OR

- Canopy almost exclusively Acacia species
- Stunted tree growth in which canopy closes at 5-10 metres

.... **3**

OR

- Eucalypt species conspicuous in emergent or upper canopy
- Eucalypt component generally with large spreading crowns
- Robust lianes, vascular epiphytes, plank buttresses absent or uncommon
- Slender woody and wiry lianes common in understorey
- Canopy uneven, height average 10–25 metres
- Emergent eucalypts, average 30-36 metres when present
- Understorey of variable height comprising rainforest species typical of adjacent mesophyll or notophyll rainforests

.... **4**

OR

- Lophostemon species conspicuous in canopy
- Lophostemon species larger and more abundant in wet and alluvial situations
- Robust lianes, vascular epiphytes, plank buttresses absent or uncommon
- Slender woody and wiry lianes common in understorey
- Shrubs, sedges, ground ferns, tree ferns and climbing ferns abundant wherever canopy has been broken
- Canopy uneven, height average 10–25 metres
- Understorey of variable height comprising sclerophyll and rainforest species typical of adjacent mesophyll or notophyll rainforests

.... **5**

GROUP E SCLEROPHYLL LEAF SPECIES EMERGENT OR COMMON IN CANOPY	RAINFOREST CODE
2. CLOSED ACACIA FORESTS	**CAF**
i) **Closed *Acacia celsa* forest** with or without variable rainforest species. Very wet to dry foothills, uplands and highlands on granites and metamorphics.	**18a**
ii) **Closed *Acacia mangium* forest** with *Acacia celsa*. Moist to very wet lowlands and foothills mostly on granites.	**18b**
iii) **Closed *Acacia polystachya* forest** with variable rainforest species. Moist to very wet foothills and uplands on metamorphics and granites.	**18c**
iv) **Closed *Acacia melanoxylon* forest** with *Acacia celsa*. Wet highlands on granites and rhyolites.	**18d**
v) **Closed *Acacia polystachya* forest** with variable rainforest and sclerophyll forest species (on seasonal watercourses). Wet foothills on metamorphics.	**18e**
3. CLOSED ACACIA THICKETS	**CAT**
i) **Closed *Acacia mangium* thicket** with *Acacia crassicarpa, Hibiscus tiliaceus, Breynia cernua, Cupaniopsis anacardioides and Terminalia muelleri* (on shallow sand dunes overlying saline soils). Moist lowlands on dunes.	**18f**
4. CLOSED EUCALYPT FORESTS	**CEF**
i) **Closed *Corymbia torelliana* forest** with *Corymbia intermedia* with or without *Eucalyptus tereticornis subsp. tereticornis* and variable rainforest species. Wet to dry uplands on metamorphics, rhyolites and granites.	**19a**
ii) **Open to closed *Eucalyptus pellita* forest** with *Corymbia intermedia* and *Eucalyptus tereticornis subsp. tereticornis* with or without *Corymbia torelliana* and variable rainforest species. Wet to very wet lowlands and foothills mostly on metamorphics.	**19b**
5. CLOSED LOPHOSTEMON FORESTS	**CLF**
i) **Open to closed *Lophostemon confertus* forest** with variable rainforest and sclerophyll forest species. Very wet to dry foothills to highlands on a variety of geologies.	**20a**

EXPLANATORY NOTES

VARIANTS

Distinct unusual occurrences of a more common vegetation type that is able to be explained by atypical environmental controlling factors.

SUBTYPES

Major discernable floristic sub-associations of more common vegetation types generally found under similar habitat conditions to the more common type.

DETERMINING LEAF SIZES AND TYPES

Leaf sizes are classified into three classes with size determined by the length of the leaf blade as follows:
Mesophyll: large leaves longer than 12.5 centimetres but less than 25 centimetres.
Notophyll: leaves longer than 7.5 centimetres but less than 12.5 centimetres.
Microphyll: small leaves less than 7.5 centimetres long.

Sclerophyll leaves are defined in the traditional Australian sense as leaves from typically 'non-rainforest' tree genera such as Eucalyptus, Corymbia, Acacia and Lophostemon.

Rules for determining common leaf size:

- Only upper canopy tree leaves are considered
- In compound leaves, a leaflet is regarded as a leaf
- Leaf (or leaflet) shape such as lanceolate or elliptical is assumed to be regular
- Very deeply divided leaves such as palms, are ignored
- Apply only to mature, exposed sun leaves of evergreen (not deciduous) species
- Avoid shade leaves
- Where two adjacent leaf classes are most common, the larger leaf size is taken (e.g. mesophyll vine forest for mixed mesophyll-notophyll sizes).

Deciduous: are those rainforest communities in which at least certain individuals completely lose their leaves for a period of the year and that this behaviour is obligatory and fixed for the species.

Semi-deciduous: are those rainforest communities in which there are a number of periodically leafless species, but these deciduous species are facultative so that their leaf-fall is controlled by the severity of the dry season, rather than by being obligate.

Semi-evergreen: are those rainforest communities in which few or none of the species are truly deciduous, and most of those species that do shed their leaves do so incompletely depending on the severity of the dry season.

The global significance of The Wet Tropics of Queensland's rich natural values was recognised when it was inscribed on the World Heritage list in 1988.

Apart from its superlative natural beauty, the World Heritage Area is a refuge for numerous rare and unique plants and animals. It is a window to a world of ancestral beginnings reminiscent of our Gondwanan heritage. The forests here contain examples of some of the major leaps in the earth's evolutionary history, including the origin, evolution and dispersal of flowering plants. It is a historical timeline of the evolution of marsupials and the emergence and dispersal of songbirds. With the greatest diversity of plants and animals in Australia, the Wet Tropics of Queensland is one of the world's most significant conservation assets.

The mounting pressures of our modern world on the environment make it imperative that we act to ensure this living, vibrant legacy is passed on to future generations.

This book is a must for individuals and organisations involved in land care and rehabilitation of tropical forests. It is an informative hand book that delves into the theory of rainforest re-establishment while providing practical solutions for successful restoration.

BIOTROPICA
AUSTRALIA PTY LTD
www.biotropica.com.au

WET TROPICS
MANAGEMENT AUTHORITY
www.wettropics.gov.au

AUSTRALIA

CARING FOR OUR COUNTRY