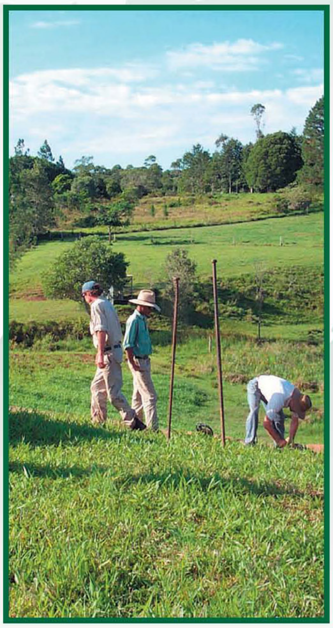
WORKSHOP PROCEEDINGS



Animal-Plant Interactions in Rainforest Conservation and Restoration

Edited by J. Kanowski, C.P. Catterall, A.J. Dennis and D.A. Westcott

Rainforest CRC

Cooperative Research Centre for Tropical Rainforest Ecology and Management

ANIMAL-PLANT INTERACTIONS IN RAINFOREST CONSERVATION AND RESTORATION

Workshop Proceedings
11 November 2003

Edited by John Kanowski[1], Carla P. Catterall[1],
Andrew J. Dennis[2] and David A. Westcott[2]
[1]Environmental Sciences, Griffith University
[2]CSIRO Sustainable Ecosystems

Rainforest CRC

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SUMMARY

Animals play key roles in rainforest dynamics, through their activities in pollination, seed dispersal, and predation of seeds and seedlings. Most rainforest plants rely on insects for pollination and vertebrates for seed dispersal, and their seeds and seedlings are eaten by both. The large number of animal-plant interactions is a fascinating and exciting facet of rainforest biodiversity, and discovering and understanding their role in undisturbed forest has been a major challenge for biologists.

However, the clearing and fragmentation of rainforest has changed the population size, distribution, assemblage composition and behaviour of rainforest animals. These changes have implications for the maintenance of biodiversity in remnant forests, for the restoration of forest on degraded land, and for the interaction of rainforests with their surrounding landscapes. Understanding and managing animal-plant interactions in human-dominated, multiple-use, landscapes poses an important challenge for scientists and managers. Significantly, meeting this challenge will require a long-term view.

This book presents the outcomes of a workshop held at the Rainforest CRC 2003 conference. The workshop brought together researchers and land managers to consider the role of animal-plant interactions in rainforest conservation and restoration, with particular reference to Australia's tropics and subtropics. Eight short papers, three workshop reports and two overviews present the central issues, indicate areas of key scientific or management importance, areas in which further research is needed, ways in which the perspectives of managers and researchers intersect or differ, and prospects for the future.

1. The white-tailed rat *Uromys caudimaculatus* is an important predator of large-seeded rainforest plants in tropical Australia, and may influence the species composition and density of forest regeneration (photo: Terry Reis)
2. Red-necked pademelons *Thylogale thetis* prefer to feed at edges between rainforest and pasture. Their browsing affects rainforest regeneration at edges and can also inhibit tree establishment in revegetated plots (photo: Terry Reis)
3. The figbird *Specotheres viridis* is a frugivore which occurs in a wide range of habitats, from intact rainforest to scattered trees in pasture. It is probably one of the few species capable of moving larger-seeded plants in highly-cleared landscapes (photo: Terry Reis)
4. A superb fruit-dove *Ptilinopus superbus* with the fruits of *Polyscias australiana*. Fruit-doves eat the fruits of many rainforest plants and disperse their seeds. This is one of many species that diminishes in abundance in a fragmented landscape, particularly in smaller fragments (photo: Andrew J. Dennis)
5. Native rainforest beetles are potentially useful pollinators of custard apples (photo: Rob Bauer)

Different types of reforestation in former rainforest landscapes. *Top left:* monoculture timber plantation; *Top right*: mixed species cabinet timber plot; *Bottom left*: diverse ecological restoration style planting; *Bottom right*: regrowth dominated by camphor laurel (*Cinnamomum camphora*) (Photos: John Kanowski)

Rainforest (complex notophyll vineforest) in north-east New South Wales, part of the former 'Big Scrub' (photo: John Kanowski)

Large areas of former rainforest land were cleared for pasture, but are regenerating following declines in the dairy industry. View from Millaa Millaa lookout, Atherton Tableland (photo: Heather Proctor)

Remnant rainforest (complex notophyll vineforest) on the Atherton Tableland, north Queensland (photo: Heather Proctor)

Restoration practitioners, north Queensland (photo: John Kanowski)

Introduction

Carla P. Catterall[1], David A. Westcott[2], John Kanowski[1] and Andrew J. Dennis[2]
[1]Rainforest CRC at Environmental Sciences, Griffith University, Nathan and
[2] Rainforest CRC at CSIRO Sustainable Ecosystems, Atherton.

BACKGROUND

Rainforests are well known for supporting large numbers of different animal and plant species per unit area, compared with other vegetation types. Furthermore, in rainforests the three processes that are crucial to the regeneration of plants are all strongly influenced by interactions with animals. These are:

1. *Pollination*. Most rainforest plants rely on animals (mainly insects, but also birds and mammals) for pollination. Interactions between pollinating insects and flowering plants in rainforests include some remarkable interdependencies between species (for example, between fig trees and fig-wasps).
2. *Dispersal*. Most rainforest plants rely on animals (mainly birds and mammals) to disperse their seeds away from the parent, in order that some may end up in sites suitable for germination and growth. To encourage this, most rainforest plants package their seeds within fleshy fruits which provide food for potential dispersers.
3. *Recruitment*. Plants produce many more seeds than needed to replace their parents. At times the forest floor may be carpeted with seeds and seedlings. Their predators, which are mainly mammals or insects such as beetles and moths, have a major influence on their survival. Animals which disturb the leaf litter on the forest floor in search of food can also limit seedling regeneration.

Interactions such as these are a fascinating and exciting facet of rainforest biodiversity, and continue to intrigue scientists and the general public alike. Describing and understanding these interactions and their consequences has been a major challenge for biologists. For example, can the multiple animal-plant interactions that determine the dispersal and regeneration of plants provide an explanation for the high diversity of plant species in tropical rainforests? The answer to this and other related questions remains the subject of intense scientific debate. Understanding the ecological and evolutionary processes which underly the generation and maintenance of high diversity and complex interactions will also influence future approaches to the conservation and management of rainforests.

Around the world, rainforests have been, and continue to be, extensively cleared and fragmented. In Australia, most level and arable land in rainforest landscapes has been converted to areas of pasture or cropland, leaving only small, scattered patches of remnant rainforest. Extensive rainforest tracts are confined to steep mountain ranges, where most are now protected within conservation reserves. Many of the scattered remnants are privately owned and some are still at risk of being cleared. However, a growing number of landholders are attempting to manage remnant forests in a manner that retains or restores their biological diversity. In many over-cleared areas, governments and citizens are also working actively to restore rainforest cover.

The future of the vegetation in all these areas is very strongly influenced by the interactions between animals and plants, and some animals are greatly affected by rainforest clearing and disturbance. For example, the cassowary *Casuarius casuarius* - a declining bird of tropical Australian rainforests - is also an important and wide-ranging seed-disperser. Its local extinction would greatly reduce the dispersal of many large-seeded rainforest plants. However, the cassowary and other fruit-eating birds are also responsible for the spread of many fleshy-fruited weeds, such as pond apple *Annona glabra*. Another example of the complex influence that disruptions to animal-plant interactions may have on rainforest conservation is provided by the loss of native rodent species from some rainforest remnants. This might result in an over-representation of rodent-predated plants in the next generation of trees, which could in turn lead to declines in other species.

Animal-plant interactions associated with rainforests may bring economic benefits, for example, if a rainforest patch provided a source of insects that pollinated tree crops in adjacent farmland, or if a restoration planting reduced rodent predation in adjacent crops. Some rainforest animals may also adversely affect production systems: for example, as a result of their depredations on fruits and seeds.

Direct human intervention, such as weeding, seeding, tree planting or hand-pollinating, can substitute for some interactions between animals and plants in local areas. However, in the long term, the nature of future rainforest landscapes will depend on the ability of rainforest plants to replace themselves within remnant forest, to recolonise and establish themselves in areas formerly cleared and to persist in the face of colonisation by introduced plants. The future density and species mix of plants within the forest will, in turn, determine which animal species survive or thrive. In some cases, management of animal-plant interactions may be more effective than intervention which directly targets plants. Understanding and managing this cycle of reproduction, dispersal and recruitment is the focus of the present publication.

Much of the concern in rainforest management has been on mitigating external threats (such as clearing, climate change and fire), or on direct rehabilitation through replanting. The long-term and indirect nature of animal-plant interactions does not mesh well with the yearly or triennial budget and planning cycle that is typical of governments, management agencies and research granting organisations. Animal-plant interactions can seem like a peripheral issue to reserve managers; although the importance of seed-dispersal is clear to those concerned with reforestation or weed invasion. Are animal-plant interactions an important long-term issue in conservation and restoration, or a fascinating obsession for scientists and naturalists, or both? This book is the outcome of a workshop on "Animal-Plant Interactions in Rainforest Conservation and Restoration" which was held to discuss these issues.

THE WORKSHOP

The workshop was held at the Annual Conference of the Rainforest CRC in November 2003. Work relating to its theme has been under way since 1999 within two of the CRC's research programs; the "Biodiversity Values in Reforestation" Project within Program 5 (Restoration Ecology and Farm Forestry), and the "Seed Dispersal: A Threatened Ecological Process" project within Program 6 (Conservation Principles and Management).

The workshop aimed to bring together participants, information and viewpoints across several boundaries, including those of: (1) project and institutional affiliation; (2) biogeographical regions (Australian tropics and subtropics); and (3) scientists and on-ground managers. It also aimed to promote discussion and the development of ideas, and to communicate the outcome through publication.

There was an initial session of seven spoken presentations, from both scientists and managers, on research issues or practical viewpoints relating to the workshop theme. This was followed by a discussion session in which the attendees split into three groups, each addressing a number of predetermined questions (see Appendix 1), but applied to different dimensions of animal-plant interactions, *viz* pollination, seed dispersal, and seed and seedling predation. In a concluding plenary session, representatives of each discussion group reported back to all assembled workshop participants. To generate the discussion questions, eight members of an organising group had previously nominated questions which they felt were important for the workshop, and these were compiled and sifted into common themes (see Appendix 2).

The core organising group comprised Carla Catterall, Andrew Dennis, John Kanowski, and David Westcott. To develop questions for discussion the group was expanded to include Rosalind Blanche, Stephen Garnett, Peter Green, and Keith Smith. The workshop was attended by more than 46 participants (see Appendix 2), among whom 29 were affiliated with Universities or research institutions, 11 with management agencies or community organisations, and six were independent individuals. The latter two categories also accounted for 12 out of 21 people who attended the "seed dispersal" discussion, indicating the high level of interest in this issue among practitioners.

THIS VOLUME

This publication is concerned with on the animal-plant interactions that directly affect plant regeneration processes. Within this theme there is a focus on pollination by insects, seed dispersal by birds, and seed and seedling predation by mammals. This reflects the interests and expertise of participants, as well as the known importance of these processes. However, we acknowledge that pollination by birds and bats, seed dispersal by mammals, and seed and seedling predation by insects and other animals are by no means insignificant processes and also deserving of attention. Our geographical bias is the Australian tropics and subtropics, but the general issues discussed have broad applicability to tropical and subtropical rainforest regions in Africa, America and Asia.

There are other forms of animal-plant interactions which are important in rainforest ecology, conservation and restoration, but which do not directly affect plant recruitment, and hence are beyond the scope of this volume. These include processes of decomposition and nutrient cycling, and the role of plants in providing habitat structure, food, and other resources for animals.

The structure of this publication mirrors the workshop. There are eight short papers, seven of which outline the information and views presented by the speakers at the workshop, with an additional paper contributed by invited practitioners who were unable to attend the workshop. These papers are followed by reports from each of the three workshop sessions (on "animal-plant interactions in conservation and restoration applied to the processes of pollination, dispersal, and seed and seedling predation”), and finally an overview of the workshop.

We hope that this publication will be useful to a variety of readers including students, management and restoration practitioners, researchers and interested individuals. We also hope that it will stimulate people to consider further the role of animal-plant interactions in conservation and restoration. The presentations and workshop reports present the central issues, indicate areas of key scientific or management importance, areas in which further research is needed, ways in which managers' and researchers' perspectives differ or concur, and prospects for the future. The presentations also give an entree to the diversity of recently-published literature on this issue. Some discuss new research results. These may not yet be published in the scientific literature, but such publication is likely in the near future.

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Cover photographs: Top – Andrew Dennis
Centre – John Kanowski
Bottom – Terry Reis

Insect Pollinators from Tropical Rainforest: their role in native forests, forest fragments and agricultural environments

K. Rosalind Blanche
Rainforest CRC at CSIRO Entomology, Atherton

POLLINATION OF TROPICAL RAINFOREST PLANTS AND AGRICULTURAL CROPS

Native insects responsible for pollinating tropical rainforest plants are often overlooked in conservation and management planning (Kearns *et al.* 1998; Black *et al.* 2001). Such insects are vital to the maintenance of genetic diversity and renewal of tropical rainforests and restoration plantings, and may also contribute to the pollination of agricultural crops. It has been estimated that in most north Queensland rainforest communities >80% of plant species are partly, or entirely, pollinated by insects (Irvine and Armstrong 1990). At least 35 Australian crops plus a wide range of pasture plants require insect pollination, or have yields, or quality, enhanced by insect pollination (Gordon and Davis 2003).

In spite of the importance of pollinating rainforest insects there are large gaps in our knowledge about their ecology. The role of rainforest insects in pollination has been documented in detail for only a handful of Australian rainforest plant species (Table 1) and for even fewer crop species. One example of a crop species pollinated by rainforest insects is papaya *Carica papaya*. Hawk moths *Macroglossum spp.* which are known to pollinate the rainforest tree *Syzygium tierneyanum* (Hopper 1980) are also effective pollinators of papaya (Morrisen 1995).

Table 1: Australian rainforest plants reported to have insects as pollinators.
Compiled from: Skutch 1932, Hopper 1980, Shaw and Cantrell 1983, Crome and Irvine 1986, Irvine and Armstrong 1987, Armstrong and Irvine 1989, House 1989, Gross 1993, Spencer *et al.* 1996, Williams *et al.* 2001.

Plant species	Reported pollinators
Alocasia macrorrhiza	beetles, bees, fly
Alphitonia petriei	beetles, flies, others
Archontophoenix cunninghamii	insects
Balanophora fungosa	beetles, ants, rats
Diospyros pentamera	insects – especially beetles
Eupomatia laurina	two weevils
Ficus variegata	wasps
Flindersia brayleyana	beetles, flies, other
Litsea leefeana	insects – especially flies
Melastoma affine	bees
Myristica insipida	beetles
Neolitsia dealbata	insects – especially flies
Syzygium tierneyanum	insects, birds, bats
Syzygium cormiflorum	insects, birds, bats, pigmy possum
Wilkiea huegeliana	thrips

POSSIBLE PRESSURES ON POLLINATORS

Rainforest insect pollinators are subject to similar human-induced pressures as those imposed on other rainforest animals and plants. These pressures include climate change, fragmentation of habitat, invasion by exotic species and toxic chemicals.

Climate change

In north Queensland, high altitude rainforest environments of simple notophyll and simple microphyll vine fern forest and thickets are predicted to decrease in area by 50% with only 1º C warming (Hilbert *et al.* 2001). The loss of suitable habitat could cause a decline in insect pollinators adapted to these high altitude environments.

Fragmentation

Fragmentation of habitat by clearing, for uses such as agriculture or urban development, may have mixed results on plant-pollinator interactions (Renner 1996). On the one hand, fragmentation may have a negative effect on some pollinating insect species by:

- reducing total habitat area;
- creating remnants that are too far apart, or with an intervening land use matrix too hostile for insects to move freely between them;
- reducing the population sizes and number of plant species that provide nectar and pollen;
- reducing availability of suitable insect breeding sites in soil or tree hollows; or
- eliminating, or reducing, abundance of larval food plant species, or other larval food sources such as rotting fruit (Kevan 1991; Kremen and Ricketts 2000).

The proportion of ‘edge’ environment, which may be hotter, drier and windier than environments deep in rainforest, is increased with fragmentation. Increased ‘edge’ environment may favour insects adapted to such conditions but disadvantage ‘centre’ specialists (Tscharntke *et al.* 2002).

On the other hand, fragmented landscapes may contain areas that act as refuges for pollinating insects, for example gardens or some cropping systems (Black *et al.* 2001). The composition of the fragmented landscape and the habitat requirements of the insects influence the outcome of fragmentation (Ricketts 2001). The same is true for revegetation areas. These are also likely to be small fragments compared with the original forest, contain only a sub-set of the original plant species and be separated from intact rainforest by a variety of different environments.

Exotic species

Invasions of exotic pollinators can also have mixed results. These are likely to be negative if the invading species displaces enough native pollinators, or causes pollen availability to be low enough to reduce seed set. For example, in north Queensland, European honeybees *Apis mellifera* reduce the fitness of the rainforest pioneer shrub *Melastoma affine* by disturbing native bee species and by actively removing pollen from stigmas, as well as depositing less pollen on stigmas than native bees (Gross and Mackay 1998). Conversely, honeybees effectively replace native stingless bees *Trigona spp.* as pollinators of macadamia *Macadamia integrifolia* in orchards on the Atherton Tableland (Blanche unpublished data).

Toxic chemicals

The effects of pesticides on pollinating insects can be limited to direct mortality within the crop, or extend to surrounding areas via pesticide drift, or, in the case of pollinators like bees, the transport of contaminated nectar and pollen back to the hive (Kevan 1991). Herbicides can disadvantage pollinating insects by eliminating plant species that serve as alternative nectar and/or pollen sources or larval host plants (Kevan 1991)

THE NEED FOR HONEYBEE REPLACEMENTS

Although honeybees can pollinate many crops, they may be less effective pollinators than native insects. The value of using a diverse range of native pollinators, rather than relying on a single species, is becoming increasingly apparent now that honeybees are threatened worldwide by parasitism and disease (Cunningham *et al.* 2002). To ensure sustainable food supplies for the future, we need to find native insects that can replace honeybees and to learn how to manage crop environments to attract and maintain native pollinators in crops. Given the importance of insect pollination in Australian tropical rainforests, such forests are likely to contain a large reservoir of pollinators that might be suitable for pollinating crops. A recent study of pollination of custard apple (*Annona squamosa* x *A. cherimola* hybrids) on the Atherton Tableland supports this idea. The work identified at least five species of native rainforest beetle with the potential to augment the number of species available for pollination of custard apple and possibly eliminate the current need for costly hand-pollination (Blanche *et al.* in review).

CONSERVATION AND MANAGEMENT

Insects that pollinate tropical rainforest plants are vitally important to the continuing health and regeneration of tropical rainforests and are likely to have an expanding role in production of agricultural crops. We do not yet have enough detailed knowledge to effectively manage rainforests to conserve pollinator services. Neither can we predict how human-induced pressures will impact on most species of pollinating insects and the plants they pollinate. The limited information we have suggests that some species may prosper while others may decline. Until we have a more comprehensive understanding of the ecology of pollinating rainforest insects it would seem wise to continue monitoring possible pressures, to mitigate impacts known to be negative and to promote a heightened awareness in people of the valuable services these insects have to offer us.

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Fruit removal rates across a landscape

[1]Andrew J. Dennis, [1]David A. Westcott, [2]Adam McKeown, [2]Matt Bradford and [2]Graham Harrington
[1]Rainforest CRC at CSIRO Sustainable Ecosystems, Atherton, [2]CSIRO Sustainable Ecosystems, Atherton

INTRODUCTION

Animal populations are frequently affected by habitat fragmentation. This is particularly true for terrestrial and arboreal mammals (Harrington *et al.* 2001; Laurance 1997; Asquith *et al.* 1997), but has also been demonstrated for volant birds (Warburton 1997). How much these changes in animal distribution and abundance affect fundamental ecological processes is a question still poorly addressed. However, it is likely that processes heavily reliant on animals to carry out a service will suffer impacts (e.g., Duncan and Chapman 2002). Such processes include pollination, seed dispersal, seed and seedling herbivory, decomposition and nutrient cycling. The former three processes have significant influence over the reproductive success of plants and therefore in the structuring of plant populations (Levin 1986; Terborgh *et al.* 2002). In this paper we examine the effects of habitat fragmentation on aspects of the processes of seed dispersal and seed predation.

Seed dispersal is an ecological process that influences plants at many levels. At the level of the individual, seed dispersal determines the final location of a seed, which influences its probability of germinating and prospering. Seed dispersal affects populations of plants by influencing their size, dynamics and genetic structure. This process also influences the distribution of species, their ability to colonise new areas and the evolutionary trajectories of various species' traits (Levey *et al.* 2002). Importantly, seed dispersal influences diversity within plant communities, their floristic and physical structure and the trajectories of change in plant associations (Janzen 1970; Connell 1971; Schupp *et al.* 2002; Terborgh *et al.* 2002). This comes about through the influence that dispersal has on determining the distribution of seeds of different species in space and thereby determining the recruitment surface for subsequent generations of plants. In tropical rainforests, this occurs in the context of the seeds of a large number of species being dispersed unevenly across the same landscape. In Australia's tropical rainforests between 75 and 95% of plant species produce fleshy fruits attractive to and dispersed by animals (Jones and Crome 1990).

FRUGIVORE ASSEMBLAGES AND FRUIT REMOVAL RATES IN FOREST FRAGMENTS

In this paper, we examine the broad patterns of the impact of habitat fragmentation on one aspect of seed dispersal: the rates of removal of fruits from plants by volant frugivores. We do this by using over 2500 hours of observation of animal behaviour at fruiting trees on the Atherton Tablelands in north-eastern Australia. The focal plants were located across the landscape from intact forest through large fragments (277, 470, 604, 674, 1200 ha), small fragments (2.5, 3.5, 4.1, 11.9, 14.7, 34.8, 35, 50.3, 68 ha) to isolated clusters of paddock trees (0.07, 0.28, 0.56, 0.97 ha).

The community composition of frugivores showed no consistent pattern with landscape context. Some species were observed only in continuous forest and some only in fragments. Other species decreased in abundance in fragments relative to intact forest, while some others increased. However, the frugivore community was much more stable in continuous forest sites than in habitat fragments. This was demonstrated by a 4.5 times greater variance in the probability of encountering a species in fragmented forest than in continuous forest. Fruit removal rates by seed dispersing birds were greater in continuous forests than in habitat fragments. On average, fruiting trees in habitat fragments had a 33% lower rate of fruit removal than trees in continuous forest. This difference was similar for all fruits, including small fruits (defined here as <18.5 mm width), which are potentially dispersed by most volant frugivores. For fruits larger than this, removal rates were 90% lower in habitat fragments than in continuous forests. These results, combined with the absence of other major seed dispersers (the cassowary *Casuarius casuarius* and the musky rat-kangaroo *Hypsiprymnodon moschatus*) from most habitat fragments in the study area, suggest we are looking at a significant reduction in seed dispersal services for fruits of all sizes in habitat fragments.

A very large amount of inherent variation in removal rates was evident even within continuous forest. Despite this, trends were evident in the data. These were due to two effects of habitat fragmentation: fragment size and isolation. Fruit removal rates increased as fragment size increased. The trend was strongest for larger fruits. Distance to continuous forest, a measure of isolation, showed negative relationships with fruit removal, particularly for larger fruits.

For seed predatory birds, removal rates were not significantly different between continuous forest and habitat fragments. However, they did show a trend toward greater removal rates at sites more distant from continuous forest. Seed predatory birds include gristmill predators such as brown cuckoo-doves *Macropygia amboinensis* and white-headed pigeons *Columba leucomela*, and those that chew seeds before ingestion such as parrots. While dispersal of seeds can occasionally occur with these birds, their contribution is insignificant compared to species whose treatment of seeds in the gut is benign. Separate work has demonstrated that seed predatory rodents also have an equivalent rate of predation across the landscape (Dennis *et al.* in press).

While there is much variation in the detail that is not discussed here, these results demonstrate significant changes in a process fundamental to the long-term structure of the plant communities in fragmented forests. Fruit removal rates, and therefore seed dispersal rates, decline in habitat fragments while predation rates remain essentially unchanged. The decline in removal rates is particularly important for medium to large fruit.

IMPLICATIONS FOR CONSERVATION

Conservation of matrix habitats is important. Governments at all levels currently have written policy setting goals for ecological sustainability across the landscape. In addition, many animals, including threatened species, require a landscape matrix of native vegetation in order to access seasonal resources either within the matrix or at a location beyond it.

Our data demonstrate the significant degradation of an ecological process fundamental to structuring and maintaining vegetation communities. This degradation is likely to cause long-term changes in plant community structure and floristic diversity and probably contributes significantly to the extent of the “relaxation” of species diversity that occurs after fragmentation of habitat. The implications for the persistence of native ecosystems are as yet unknown but are likely to be significant. Finally, a healthy, fully functional ecosystem is likely to be more resilient to disturbance than one that is suffering degradation of important processes. But disturbance is generally at higher frequencies in habitat fragments than in intact forest. These findings indicate that if we seek to retain functional and sustainable ecosystems within altered landscapes, then the matrix needs to be managed to enhance and restore seed dispersal processes.

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The role of seed and seedling predators in determining plant abundance and diversity in natural and fragmented landscapes

Peter T. Green
Research School of Biological Sciences, Australian National University, Canberra

INTRODUCTION

Animals that eat seeds and seedlings are a ubiquitous component of terrestrial plant communities, especially tropical rain forests. The high species richness of plants, and the generalized diets of many consumers, makes the number of possible pair-wise animal-plant interactions very large. These interactions are susceptible to disruption by anthropogenic disturbance, but in many tropical forests, forest fragmentation and ensuing ecosystem decay pose the greatest threat to native biodiversity (Laurance and Bierregaard 1997, Laurance *et al.* 2002). In this paper, I consider one general class of animal-plant interactions widely perceived to be key to the maintenance of plant diversity in tropical rainforests, that between herbivores and the seeds and seedlings they consume. First I review the evidence that post-dispersal seed and seedling predators are important determinants of seedling abundance and diversity in undisturbed forests. Next I consider how forest fragmentation might affect the role of seed and seedling predators in determining plant species diversity in forest remnants. I conclude by discussing the need for managing this particular class of animal-plant interaction against a hierarchy of other impacts that demonstrably affect plant diversity in fragmented landscapes.

SEED AND SEEDLING PREDATORS AND PLANT DIVERSITY IN UNDISTURBED FOREST

Seed and seedling predators include both invertebrates (mainly predators of seeds) and vertebrates (predators of both seeds and seedlings). This work was stimulated by seminal papers by Janzen (1970) and Connell (1971), both of whom suggested that intense seed and seedling predation near conspecific parents, but not further away, could maintain species diversity by preventing domination by just a few common species. There have been a plethora of studies showing that both insects and vertebrates can drastically lower the survival probabilities of seeds and seedlings in tropical rain forests. Further, there is evidence that the “Janzen-Connell” effect is relatively common in tropical rainforests; Hammond and Brown (1998) found significantly lower seed or seedling performance near conspecific adults in 17 of 46 studies they reviewed. This is consistent with the idea that seed and seedling predators may contribute to the maintenance of plant diversity in the manner suggested by Janzen (1970) and Connell (1971). However, Wright (2002) has pointed out that a renewed theoretical effort is needed to relate diversity to the reduction of seedling recruitment near conspecific adults.

Virtually all studies of the impact of seed and seedling predators on seedling recruitment have considered just one or several species at a time, and as such, cannot provide a direct assessment of the general hypothesis that by differentially consuming the seeds and seedlings of some species but not others, seed and seedling predators play a key role in the maintenance of plant diversity in tropical rainforests. Obviously, studies that compare plots with and without suites of important predators would be revealing. One approach has been to compare forests that have sustained heavy hunting of important vertebrate seed and seedling predators, to those with an intact fauna. In Mexico, Dirzo and Miranda (1991) found that although the abundance of plants in the understorey was lower in forest with an intact suite of seed and seedling predators, diversity was higher than in forest where important predators had been hunted to low levels. In contrast, Roldán and Simonetti (2001) found no clear evidence that understorey plant diversity in Bolivia was lower in forest where large vertebrates had been intensively hunted.

Another way of evaluating the seed and seedling predator/ diversity hypothesis is to experimentally exclude seed and seedling predators from large fenced plots, and to compare the abundance and diversity of all seedling recruits with adjacent control plots. Despite being an obvious way of testing the hypothesis, this approach has only rarely been attempted. On Christmas Island, Green *et al.* (1997) found that omnivorous red land crabs *Gecarcoidea natalis* have an overwhelmingly large negative impact on both the abundance and diversity of seedlings. These impacts have since been confirmed on a landscape scale following the deletion of red crabs from large tracts of forest by an invasive ant *Anoplolepis gracilipes* (O'Dowd *et al.* 2003). Two (as yet unpublished) exclusion studies in mainland tropical forests in north Queensland (T. Theimer and C. Gehring, Northern Arizona University) and Barro Colorado Island in Panama (W. Carson, University of Pittsburgh) are yielding similar results; after several years, seedling densities are significantly higher in the absence of seed and seedling predators, but inconsistent with the hypothesis, there is no evidence that seedling diversity is higher in the presence of seed and seedling predators. The Queensland study is excluding just ground-dwelling vertebrates, whereas the Barro Colorado Island experiment has both vertebrate and insect exclusion treatments.

Do seed and seedling predators promote plant diversity in the rain forest understorey? The evidence is not yet comprehensive enough to form solid conclusions; both studies of hunting were unreplicated comparisons, while two of the three experimental manipulations are incomplete and any conclusions derived from them possibly premature. However, it is noteworthy that so far, only one of the five studies listed here (Dirzo and Miranda 1991) provides any evidence that seed and seedling predators are central to the maintenance of species diversity in tropical rainforest. In the spirit of stimulating discussion on this point, I suggest that the prevailing viewpoint that post-dispersal seed and seedling predators are key to the maintenance of rainforest plant diversity may have been overstated.

SEED AND SEEDLING PREDATORS AND PLANT DIVERSITY IN FRAGMENTED LANDSCAPES

The theory of island biogeography (MacArthur and Wilson 1967) predicts that habitat fragments supersaturated with species at the time of isolation (i.e., they contain more species than can be maintained by colonization at equlibrium) will subsequently lose species through "relaxation". Species extinctions exceed colonization in fragments, so fragmented communities eventually decline to species poor, simplified systems. There is some evidence for this in tropical plant communities; in Brazil, the rate of tree turnover increases in very small fragments, while the species richness of seedlings in the understorey is declining (Laurance *et al.* 1998, Benítez-Malvido and Martínez-Ramos 2003).

Fragmentation has impacts on a wide range of faunal groups, including those that act as seed and seedling predators (Didham *et al.* 1996, Laurance *et al.* 2002 and references therein). Therefore, one hypothesis is that if seed and seedling predators are influential in determining patterns of tree diversity in intact forests, then changes to their abundance due to fragmentation may have significant consequences for plant diversity in remnant forests (e.g., Asquith *et al.* 1997, Harrington *et al.* 2001). However, the degree to which fragmentation-induced disruption to the seed and seedling predator fauna contributes to the long-term decline of plant diversity in remnant forest patches has not been rigorously assessed. The nature of the decline in plant diversity on small islands created by dam impoundments has been attributed to drastic alteration of the seed and seedling predator fauna (Leigh *et al.* 1993, see Terborgh *et al.* 2001, Rao *et al.* 2001). The supposed causal link between seed and seedling predators and plant dynamics in these systems is confounded by myriad other factors. Not least among these is the inherent spatial variability in tree communities prevalent in intact forest, but also factors that directly affect seedling recruitment and survival, such as pollination, canopy tree fecundity, seed dispersal, and edge effects in the forest understorey.

In north Queensland, the most important and widespread seed and seedling predators are the rodents (bush rats *Rattus fuscipes* and *R. leucopus*, fawn-footed melomys *Melomys cervinipes*, white-tailed rat *Uromys caudimaculatus*), the pademelon *Thylogale stigmata* and the chowchilla *Orthonyx spaldingii* (Harrington *et al.* 1997, Theimer and Gehring 1999). Fragmentation negatively affects the chowchilla and possibly *Uromys* and *R. fuscipes*, may be neutral for *Melomys*, and appears to favour the pademelon and *R. leucopus* (Warburton 1997, Harrington *et al.* 2001, A. Dennis pers. comm). Based on these data, it seems that the influence (if any, see above) exerted by vertebrate seed and seedling predators on plant abundance and diversity in north Queensland may vary substantially between intact and remnant forest, but this has never been rigorously tested (but see Harrington *et al.* 1997). We know nothing virtually about the role of invertebrate seed and seedling predators in the maintenance of plant diversity in either intact or fragmented forests in Queensland.

SEED AND SEEDLING PREDATORS, FOREST FRAGMENTATION, AND MANAGEMENT

Elucidating the role of seed and seedling predators in the maintenance of plant diversity in fragmented landscapes is a worthy goal in and of itself. If research does show that fragmentation significantly alters the influence of seed and seedling predators on plant diversity in fragments, it would be tempting to argue that management goals and prescriptions should be oriented towards the re-establishment of a more “normal” regime of seed and seedling predation in fragments.

I suggest that this would be naïve – obviously, there are issues beyond just seed and seedling predator-plant interactions that are important when deciding management priorities. For example, if fragmentation results in no net loss of biodiversity, despite declining in fragments, then does the conservation and restoration of fragments matter? Further, its seems probable that some factors are more influential than others in determining the abundance and diversity of the biota in forest remnants. Most influential would be fragment size and isolation – net species loss is expected in most tropical forest fragments, but the greatest losses will occur in the smallest, most isolated fragments. Similarly, edge effects will be greatest in the smallest fragments (Laurance 1991, Laurance *et al.* 1998). I suggest that any impacts of forest fragmentation on seed and seedling predator-plant interactions could be slight in comparison, and that management prescriptions aimed at species recovery in fragments might best be directed at managing these larger impacts.

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Animal-plant interactions: a rainforest conservation manager's perspective.

Keith Smith[1] and Stephen Garnett[2]
[1] Queensland Parks and Wildlife Service, Atherton
[2] Queensland Parks and Wildlife Service, Cairns

INTRODUCTION

Although rainforests only cover 6% of the Earth's surface, they are home to 50% of all animal and plant species. Loss of habitat is currently the greatest threat to the conservation of rainforest and its dependant species. Over three-quarters of Australia's rainforests have been destroyed since European colonisation. Rainforests now cover only about 0.25% of Australia's area. Habitat loss and fragmentation continue to pose challenges in North Queensland.

The interactions between rainforest animals and plants and interdependent relationships associated with such interactions are poorly understood for Australia's tropical rainforests. Past work by scientists has focussed on the role of insects, birds and mammals as pollinators and dispersal agents for rainforest plants. The seed dispersal function of species such as fruit-eating pigeons, fruit bats, the endangered southern cassowary *Casuarius casuarius* and the musky rat-kangaroo *Hypsiprymnodon moschatus,* provide an insight into the scope of these interactions (Stocker and Irvine 1983; Richards 1990; Dennis 2002). Some management implications have resulted from this work related to rainforest restoration. Some resources have been directed toward research into the use of insects as possible pathogens for the control of environmental weeds including lantana *Lantana camara.*

The importance of packaging scientific information and proposing monitoring and management recommendations for conservation managers and the wider community cannot be overstated. Community education and engagement is a critical element of conservation management. Not only can the wider community play an active role, for instance in habitat restoration, community awareness, interest and support can influence political and therefore financial support for conservation research and management actions.

WHO ARE RAINFOREST CONSERVATION MANAGERS?

In some countries, indigenous people continue to live within and depend upon rainforest communities. They could be considered to be an integral part of the ecosystem and indeed a key player in animal-plant interactions. To a lesser extent this is still the case for parts of Australia.

For most of Australia, State Government Agencies such as the Queensland Parks and Wildlife Service are the conservation managers. Some rainforest areas also occur on freehold and leasehold lands and State Reserves managed for purposes other than nature conservation. The range of individuals, groups and organisations that undertake management practices in these rainforest areas is very diverse, including Shire Councils, power supply corporations, Landcare groups and individual property owners.

WHAT DO CONSERVATION MANAGERS DO?

The major goals of rainforest management are the conservation of communities, the maintenance of biological diversity and maintenance of ecosystem processes that allow for evolutionary development. For rainforest conservation managers, managing threats is the overwhelming priority. For areas not already protected, planning for biodiversity conservation and tackling habitat loss and fragmentation are particularly important. For areas protected by World Heritage listing, or under a nature conservation tenure, planning and managing for sustainable use including visitation, are the major priorities. Management actions directed toward the natural resources are largely focussed on fire and pest species management. Minimal resources are directed towards restoration, threatened species and problem (native) species management.

WHERE DO ANIMAL-PLANT INTERACTIONS FIT IN?

On a day-to-day basis, conservation managers largely ignore the interaction between rainforest animals and plants. Management at this scale is a luxury that at best is afforded to threatened species such as the endangered southern cassowary (NCR 1994; EPBC 1999) and problematic (native) species such as the vulnerable spectacled flying fox *Pteropus conspicillatus* (EPBC 1999; EA 2002)

There is very little information that identifies dysfunctional animal-plant interactions, species at threat from such dysfunction, or environmental indicators that would allow conservation managers to detect the breakdown in any interaction.

The time scales over which a breakdown in animal-plant interaction results in outward signs of stress or species decline may well exceed the 12 month financial cycles or 3-5 year recovery plan and management plan cycles to which most conservation managers work. However, predicted changes in climate and an increased understanding of the dynamics of fragmented landscapes suggest that a knowledge of animal-plant interactions should inform planning for acquisition of protected areas or extension to landholders.

The nature of animal-plant interactions should determine the speed with which both native and exotic species can move along gradients and thus management strategies that should be employed to ameliorate the impacts of threats. Broader adoption of research findings by conservation managers will then require that the results are expressed prescriptively in terms of what weed to control where, which part of the landscape to restore with what species, and which part of the landscape to prioritise for acquisition or extension.

SUMMARY

Rainforest conservation management is largely driven by short-term priorities determined by political and financial imperatives with returns on management investment expected within a single electoral cycle. Animal-plant interactions, as critical ecosystem processes, are therefore relevant only to the small group of conservation managers concerned with long-term planning of protected area acquisition and ecosystem management. This group needs to understand these processes to cater for shifts in rainforest along ecological gradients in response to changes in climate or other landscape scale processes and to minimise the effects of exotic pests.

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Animal-plant interactions in rainforest restoration in tropical and subtropical Australia.

John Kanowski[1], Carla P. Catterall[1], Terry Reis[1] and Grant Wardell-Johnson [2]

Rainforest CRC at[1] Environmental Sciences, Griffith University, Nathan, [2] Rainforest CRC at Natural and Rural Systems Management, University of Queensland, Gatton

INTRODUCTION

The deliberate restoration of rainforest to cleared land is a recent phenomenon, barely two decades old in Australia. Consequently, research on restoration has largely been concerned with questions of establishment, such the design of reforestation projects and the costs/ benefits of different types of reforestation (Goosem and Tucker 1995; Kooyman 1996; Lamb 1998; Erskine 2002), while the longer-term dynamics of restored forests have rarely been considered (but see Catterall *et al.* in press). Nevertheless, these dynamics will determine whether restoration efforts succeed in re-establishing diverse forest cover on cleared land, or whether they will fail. For example, most planted forests are relatively simple and must rely on seed dispersal and seedling establishment to approach the species richness of intact forest (Wunderle 1997). Seed dispersal, seed predation and seedling herbivory, as well as a number of other processes important to rainforest dynamics, including pollination and litter disturbance, are largely mediated by animals (e.g., Bawa 1990; Theimer and Gehring 1999; Wright 2002). For these reasons, a good understanding of the role of animal-plant interactions in restored forests is required if practitioners are to meet the challenge of reforesting the vast areas of degraded former rainforest lands.

THE TWO PHASES OF REFORESTATION

The importance of animal-plant interactions in restored forests is likely to vary over the course of a reforestation project, particularly between the ‘establishment’ and ‘building’ phases. The establishment phase is the period from when seeds or seedlings are put in the ground until they have ‘captured’ the site. In rainforest, a reforestation project may be considered established when plants have formed a relatively closed canopy, suppressing competing pasture and weeds. In diverse, densely planted ‘ecological restoration’ style projects, the establishment phase may last 5 - 10 years on moist, fertile sites, by which time trees are typically 10 – 15 m high (Kanowski *et al.* 2003). In the building phase, the planted species mature, reproduce and die, and other species are recruited to the site. Ideally, after several cycles of regeneration (decades to centuries), the composition of the restored forest will resemble intact forest. However, for various reasons, including disruptions to animal-plant interactions, it is possible that restored forests may only attain a fraction of the richness of intact forest.

ANIMAL-PLANT INTERACTIONS DURING ESTABLISHMENT PHASE

Animals can have positive or negative impacts on the establishment of reforestation, depending on the type of reforestation and the intensity of particular interactions (Table 1). For example, pollination and seed dispersal are required to facilitate regrowth on cleared land, but both are irrelevant to reforestation using direct seeding or the planting of seedlings. Seed predation may limit the success of regrowth and direct seeding projects (Hau 1997). Litter disturbance may affect the recruitment of some species, particularly where intense, e.g., that associated with mound-building by megapodes such as the Australian brush-turkey *Alectura lathami* (Woodford 2000). Herbivory may compromise the success of all types of reforestation. For example, in north Queensland, about 15% of the plantings established by the Community Rainforest Reforestation Program (CRRP) failed due to cattle browsing (Vize and Creighton, 2001). In subtropical Australia, browsing by wallabies (including pademelons *Thylogale stigmatica* and *T. thetis*; and the swamp wallaby *Wallabia bicolor*) can reduce the abundance of palatable plant species in regenerating forest (Woodford 2000). However, wallabies may also assist reforestation by reducing competition from grasses and vines (Wahungu *et al.* 1999). Similarly, cattle are sometimes used to control weeds in young hoop pine *Araucaria cunninghamii* plantations. That is, herbivores can assist reforestation if planted or regrowth trees are relatively unpalatable, or at least have grown above the reach of herbivores.

Table 1. Potential impacts of animal-plant interactions on the establishment of different types of rainforest restoration. '+' positive impact; '-' negative impact

Revegetation type	Pollination	Seed dispersal	Seed predation	Litter disturbance	Herbivory
Planting seedlings					+/-
Direct seeding			-	-	+/-
Regrowth	+	+	-	-	+/-

ANIMAL-PLANT INTERACTIONS DURING BUILDING PHASE

Once a site has been reforested, animals play an important role in determining whether (and how fast) the forest develops towards the condition of intact forest. A range of animals are involved in these interactions (Table 2). Furthermore, the effects of animals on the dynamics of restored forests may vary considerably between sites, as the faunal assemblages of restored forests are likely to vary with habitat quality, patch area, proximity to intact forest, the composition of the surrounding landscape and time since establishment (Catterall *et al.* in press).

Table 2. Animal taxa which influence the building phase of rainforest restoration in Australia. '+++' dominant role; '++' major role; '+' minor role; '.' negligible role

Taxa	Pollination	Seed dispersal	Seed predation	Litter disturbance	Herbivory
Invertebrates	+++	+	++	.	++
Birds	++	+++	+	++	.
Mammals: volant (bats)	++	++	.	.	.
non-volant	+	+	+++	+	++

Pollination

Many rainforest plants can be pollinated by a range of animal taxa (Williams and Adam 1999), hence it could be assumed that pollination failure is unlikely to generally limit recruitment in reforested sites, except perhaps for the minority of plants with specialised pollination syndromes. However, we do not know whether pollination success will vary with factors mentioned above, such as habitat quality or proximity to intact forest.

Seed dispersal

Seed dispersal to reforested sites is affected by proximity to intact forest. For example, the number of rainforest seeds dispersed to reforested sites in north Queensland, and the number of rainforest plants recruited to those sites, has been shown to decline rapidly with increasing distance from intact forest (McKenna 2001). Seed disperal may also vary with the habitat quality of reforested sites, particularly the attractiveness of sites to frugivorous animals. For example, current research on the biodiversity values of reforestation provides indirect evidence for a positive feedback cycle between the presence of fleshy-fruited plants in restored forests and seed dispersal to those forests by birds (see Kanowski *et al.* 2003; Catterall *et al.* in press for details of study). In Australia, most restoration plantings use a wide range fleshy-fruited trees and shrubs, whereas timber plantations are typically dominated by a few wind-dispersed tree species. The assemblage composition and abundance of frugivorous birds vary between these different types of reforestation: in particular, monoculture plantations support very few medium- and large-gaped frugivorous birds. Not surprisingly, few medium- and large-seeded plants have recruited to monoculture plantations.

Seed predation

The recruitment of rainforest plants to restored forests may be affected by seed predation. Data from the *Biodiversity values of reforestation* project (Kanowski *et al.* 2003; Catterall *et al.* in press) show some variation in rates of seed predation between different types of reforestation, although this is overshadowed by marked variation in predation rates between tropical and subtropical sites. The regional differences presumably reflect the absence of the important seed predator, the white-tailed rat *Uromys caudimaculatus*, from subtropical sites.

Litter disturbance

Litter disturbance may have an important effect on the dynamics of reforested sites. For example, megapodes often successfully recolonise reforested sites. When present, their mound-building activities modify the litter layer and appear to affect seedling recruitment (Woodford 2000). However, we have no information as to the size of the effect, whether some species are affected more than others, or how patterns of litter disturbance vary between sites.

Herbivory

Herbivory is presumed to play an important role in rainforest dynamics (see Green, this volume), but little is known about rates of herbivory in reforested sites, or how herbivory varies with habitat quality or landscape context. For example, pademelons appear to be absent from some small, isolated remnants, but the intensity of herbivory is also affected by the abundance of other macropods, particularly swamp wallabies, which are not necessarily associated with rainforest.

Table 3. Some current research gaps involving animal-plant interactions in rainforest restoration.

Interaction	What we know	What we need to know
Pollination	• Many rainforest plants exhibit a generalist pollination syndrome, but some have specialised relationships.	• Is recruitment in restored forests limited by pollination? What plants are most affected? How can pollinator services be restored if necessary?
Seed dispersal	• Seed dispersal is affected by landscape context and isolation from intact forest.	• How does seed dispersal vary between different types of reforestation? What plants are most affected? How can the dispersal of affected plants be promoted?
Seed predation	• Seed predation varies between different types of reforestation and between regions.	• How does seed predation vary between different rodent assemblages? What plants are most affected? When should seed predators be restored to reforested sites?
Litter disturbance	• Litter disturbance can affect recruitment.	• How do the impacts of litter disturbance vary between different sites? What plants are most affected? Is it worth managing the agents of disturbance?
Herbivory	• Herbivory can have a severe impact on reforestation in some sites.	• What are the spatial and temporal factors affecting rates of herbivory? What plants commonly used in reforestation or that recruit naturally to reforestation are most affected?

SUMMARY

Animals can have a strong influence on the success of reforestation, both during establishment and subsequently, as the reforested sites mature. However, at present we have little understanding of the ways in which animal-plant interactions vary between different types of reforestation, or with factors such as landscape context (Table 3). An increased understanding of animal-plant interactions will assist the design and management of reforestation projects (e.g., Tucker *et al.* 2004), and should also provide insights into the dynamics of intact forest systems.

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Animal-plant interactions: their role in rainforest conservation and restoration at a community level in south-east Queensland.

Marc Russell
Barung Landcare, Maleny

INTRODUCTION

Animal-plant interactions play an important role in biodiversity conservation in subtropical areas. Our knowledge of many ecological relationships is still very primitive or non-existent, but the more we learn, the better we can contribute to conservation of flora and fauna diversity. Traditionally, much of the focus of reforestation has been on vegetation. More and more we are realising that we need to focus on habitat protection and enhancement, taking both flora and fauna requirements into account.

Barung Landcare has over 1000 members in an area with a population of 8000. Barung runs a wide education program including publication of flora and fauna articles, information nights and workshops, to increase local knowledge and enthusiasm for biodiversity conservation in the local area. Topics include spiders, reptiles, fish, frogs, birds, bats and butterflies, and their habitat requirements. By connecting with local fauna, many landholders then learn how to improve and conserve habitat on their own properties. Increasing ecological awareness results in greater appreciation of natural habitat and the important role of native vegetation in habitat management.

For example, in our local Landcare nurseries, many plants “sit on the shelves” unless we can inspire landholders with information on why they should incorporate these species into revegetation sites. A classic example is native laurels (*Lauraceae*). When the Barung Landcare nursery was established, no labels were available for any of our native laurels and many native plant nurseries were not propagating them because “they don’t sell”. Barung staff found that once landholders discover that these laurels attract and feed a large variety of local birds and butterflies, and that a variety of food plants is essential to prolong the feeding season, these same laurels sell like hot cakes. Many other plant species have similar success stories and we believe that landholder education (private and public land) is the key to improving conservation, habitat management and restoration.

SOME CASE STUDIES

(i) The Richmond birdwing butterfly

The ultimate success story would have to be the recovery process for the vulnerable Richmond birdwing butterfly *Ornithoptera richmondia*. Loss of rainforest habitat, fragmentation and pressures such as grazing and poaching, have led to the local extinction of this insect in some areas. An understanding of animal-plant relationships has led to a marked difference in attitudes, habitat management and conservation. Extensive educational campaigns have influenced individual landholders, school/university students, community groups and government/funding bodies to focus on habitat conservation, enhancement and extension, as follows:

- Habitat conservation – land acquisitions, Voluntary Conservation Agreements, fencing and better management through landholder appreciation.

- Habitat enhancement – planting of larval food plants (the birdwing vine *Pararistolochia praevenosa*) and weed control, especially the exotic vine Dutchman's pipe *Aristolochia elegans*, a relative of the birdwing vine. The butterfly will lay its eggs on the exotic vine, but its foilage is poisonous to the larvae.
- Habitat regeneration/ revegetation works to extend existing habitats and create rainforest corridors, in conjunction with breeding and release programs for the butterfly.

(ii) Coxen's fig-parrot

Another example of fauna-flora interrelationships affecting habitat restoration is that of the critically endangered Coxen's fig-parrot *Cyclopsitta diophthalma coxeni*. The combined efforts of Queensland and New South Wales Parks and Wildlife Services, Landcare groups, local government bodies and individuals has resulted in some protection of regional and altitudinal corridors, thanks to increased community awareness resulting from the production of promotional and educational materials, workshops and on-ground activities. Natural Heritage Trust funding has been focussed on conserving, extending and enhancing these corridors with fig-parrot requirements as a priority.

(iii) A special case: plants that don't utilise fauna for dispersal

While a large range of birds and mammals may distribute seeds on regeneration and revegetation sites, we are now learning to incorporate plant species that <u>don't</u> utilise fauna for seed dispersal. If the site is too far from existing seed sources, then species dispersed by wind (e.g., *Flindersia, Argyrodendron, Toona, Grevillea* and *Hymenosporum*) or other species not dispersed far by fauna or wind (e.g., *Medicosma, Backhousia, Macadamia*, etc), will not occur naturally, and must be introduced through planting or direct seeding. Cassowaries were believed to have once roamed south-east Queensland and must have been responsible for dispersing large seeded fruits (e.g., *Endiandra spp.*). These plants cannot recolonise without human intervention.

CHALLENGES FOR RESEARCH

Much of the scientific research carried out to date often raises more questions and confusion than providing answers. Often we need scientists to interpret results and relate these to planning or establishing projects. Common questions include:

- When is pure regeneration appropriate and when do we plant?
- What species may need to be introduced and where (e.g., medium-sized seeds)?
- Do we focus on weed removal from intact forest out?
- Do we focus on weed species that invade intact forest?
- What pioneers last long enough and provide conditions necessary for optimum regeneration?

Many on-ground workers are coming up with our own interpretations, however we are still learning by our mistakes and often don't have time to communicate with each other. What we do require from the scientific community are some best practice guidelines (with periodic review) and a bigger effort towards establishing universal monitoring systems before rehabilitation work commences to ensure communication flow both ways.

Human awareness and positive action never happens quickly enough for those of us with a passion for the environment and protecting our natural treasures. We must remember that everything we do and learn may be passed on to ten others, and each of these may pass it on to a further ten, etc, etc, etc. Like ripples in a pond our awareness grows at an accelerating rate, affecting more and more people until the scales tip and we realise we are part of nature and all life is interdependent.

Animal-plant interactions: applying the theory on the ground in north-east New South Wales.

Hank Bower
Byron Shire Council, Mullumbimby

INTRODUCTION

The Northern Rivers area of north-east New South Wales has been settled by Europeans for well over 150 years. During this time there has been a considerable amount of habitat clearance, fragmentation and disturbance. This is particularly evident in lowland areas with good soil. In areas such as the Big Scrub over 99% of the original native vegetation cover was removed, while in the Brunswick and Tweed Valleys 70% vegetation removal was more common. This level of clearing resulted in a landscape dominated by pastures and scattered human settlements, interspersed with a series of highly fragmented and widely dispersed remnants, most no larger than 5 - 20 ha. As a consequence, many plant and animal species have experienced localised declines and/ or extinctions and important animal-plant interactions have been disrupted. In the most isolated remnants, these declines, extinctions and disruptions are - or at least are expected to be - still occurring.

Declines in several traditional agricultural industries (e.g., dairy) in the late 1960s and early 1970s led to large areas of cleared land being 'let go' or subdivided and sold to ‘lifestylers’, hobby farmers and horticulturalists. Today’s landscape is more forested and varied, and exhibits a greater degree of connectivity, than has been the case for many decades, due to:

- the establishment of large areas of macadamia plantations (and other orchards) and hardwood windbreaks;
- the regeneration of regrowth forest (often dominated by weed species, especially camphor laurel *Cinnamomum camphora*) to the extent that mixed regrowth forest is now a dominant vegetation type in some districts of north-east NSW; and
- revegetation efforts by landholders for a variety of purposes, including forestry, conservation plantings and rural residential gardens.

In addition, extensive regeneration works have been undertaken in remnants that for decades were infested with weeds, resulting in the regeneration of healthy and well-structured systems. External impacts on remnant vegetation have been and are being addressed, allowing affected species and ecosystems to stabilise. As a result, a fascinating experiment is unfolding. Significant areas of of revegetation on formerly cleared land have been colonised by various fauna species, while several fauna species have recolonised areas from which they had been absent for many decades.

There has also been a significant shift in how people look at and treat the land. People understand that animals need vegetation as habitat and good vegetation management often results in suitable habitat for fauna. There is also a genuine desire by many to see a return of essential ecological functions into the landscape. However, knowing what processes are important or how to return them is not that well understood. There is also a growing understanding that animal-plant interactions can help us achieve restoration goals as animals help disperse seed and pollen and are also important contributors to pest control and nutrient turnover. It is also recognised that these processes are essential for healthy ecosystems and that healthy ecosystems are fundamental to life and well-being.

SOME CASE STUDIES

In north-east NSW there are many projects and/or project planning initiatives that have focussed on, or taken account of, animal-plant interactions in rainforest conservation and restoration. An overview of some of these projects follows.

Remnant care project

This project of the Big Scrub Rainforest Landcare Group seeks to:

1. Restore remnants through regeneration works and sound planning.
2. Educate the public on how to restore remnant vegetation and re-establish forest cover and fauna habitat on cleared and degraded landscapes.
3. Link remnants using riparian, stepping-stone and mixed regrowth corridors, and buffer remnants with plantings to limit the ingress of negative adjacent land-uses (e.g., reduce spray drift from orchards).
4. Increase the size of remnants to enhance their viability and value as feeding habitat.
5. Promote the planting and regeneration of fleshy-fruited plants on cleared land to assist the return of keystone frugivores such as wompoo fruit-dove *Ptilinopus magnificus* to remnants and regrowth vegetation. Attracting keystone frugivores will help in the dispersal of large fleshy-fruited plants across the landscape.
6. Incrementally replace exotic weeds with native species, particularly fleshy-fruited plants.
7. Involve macadamia farmers in linking the landscape and erecting nest/ roost boxes for owls and microchiropteran bats.

Isoglossa recovery project

This project of the Big Scrub Rainforest Landcare Group focussed on removing weeds from remnants and regenerating habitat for the nationally endangered herb – *Isoglossa eranthemoides*, an important host plant for the Australian leaf wing butterfly *Doleschallia bisaltied australis*. Restoration actions have assisted both the plant and the butterfly.

Figs on farms/ Coxen's fig-parrot recovery project

This project was initiated by Byron Shire Council and the Big Scrub Rainforest Landcare Group, with assistance from Environmental Training and Employment (ENVITE) Lismore and support from all local councils in the region. The project sought to restore critical feeding habitat for the endangered Coxen's fig-parrot *Cyclopsitta diophthalma coxeni* by establishing 10,000 fig trees (*Ficus spp.*) in the former Big Scrub region. The project should also benefit populations of other frugivores, thereby assisting seed and pollen dispersal and improving natural regeneration and genetic exchange across the region.

Byron Shire Council – Draft Biodiversity Conservation Strategy, 2003

The Strategy was developed to assist Byron Shire Council to better manage and sustain the diverse and unique flora, fauna, habitats and ecosystems in the Byron Local Government Area. The Strategy seeks to reverse the problems of biodiversity loss and decline by working in partnership with the community towards the following outcomes:

- identifying, protecting and managing lands of High Conservation Value;
- identifying and protecting a system of regional wildlife corridors across the Shire – which cover vegetated lands and non-vegetated lands to be targeted for revegetation;
- undertaking on-ground ecological restoration actions that lead to improved management of biodiversity resources (targeting High Conservation Value areas); and
- identifying and implementing incentives, educational materials, training and extension.

The Strategy's first priority is to secure existing vegetation and wildlife corridors through planning controls. It then seeks to attract reliable funding to implement actions on High Conservation Value vegetation and habitats on both public and private lands. It is anticipated that works implemented through the Strategy will have wide ranging benefits for biodiversity in general and more specifically for animal-plant interactions. Education and extension advice will be crucial to achieving outcomes.

CHALLENGES FOR RESEARCH

There are several key animal-plant interaction issues that the restoration industry is grappling with. These include:

- The positive and negative attributes of mixed weedy regrowth and how these attributes affect animal-plant interactions. Weeds can obviously hinder regeneration through competition for water, nutrients, light and space. However, weeds can also provide habitat resources, function as a seed sink and establish corridors across cleared land. As such, weedy regrowth can be useful for kick-starting regeneration on cleared land, particularly when manipulated to trigger regeneration. Investigation of which methods of manipulation best maintain wildlife habitat and trigger regeneration is required.
- Browsing of regeneration and planted trees by wallabies. The swamp wallaby *Wallabia bicolor* has benefited from the weedy matrix and is now present in areas where they were not previously known. Although a nuisance to people establishing trees, swamp wallabies may actually be benefiting regenerating forests, e.g., perhaps through the spread of mycorrhizal fungi. Again more investigation is required.
- Restoration practitioners are aware of genetic issues in the highly fragmented remnants of lowland habitats of north-east NSW. However, there is little evidence to guide practitioners as to which actions are appropriate in particular scenarios. We need to know how far certain plants are able to disperse their genetic material (pollen and seed) and whether there is effective dispersal between remnants.

CONCLUSION

Despite recent advances in restoration theory and practice, there is still much to learn about the roles that animal-plant interactions play in the conservation and restoration of fragmented landscapes. We know that animal-plant interactions are often critical in sustaining or restoring forest health and regeneration. However, we do not always know what components of these interactions are important for certain species or how to manipulate them to advantage restoration or ecological outcomes. There is a clear need for scientific and educational materials pertaining to animal-plant interactions to be disseminated in a format readily digestible to the broader community. This will assist practitioners to deliver outcomes that benefit animal-plant interactions and also assist in the restoration of degraded landscapes.

Animal-plant interactions in tropical restoration: observations and questions from north Queensland

Nigel I. J. Tucker and Tania M. Simmons
Biotropica Australia Pty Ltd

INTRODUCTION

In north Queensland's Wet Tropics, restoration has been undertaken for 20 years in what is a highly fragmented landscape. This paper is based on the authors' observations of pollination, dispersal, herbivory and predation in restoration plantings, and poses research questions that may assist in understanding these interactions.

POLLINATION

Two broad observations can be made regarding pollination of planted stems in restored forests. First, there is marked difference in the reproduction of species from different successional guilds. Pioneer species such as bleeding heart *Omalanthus novo-guineensis*, sarsaparilla *Alphitonia spp.* and some species within the *Glochidion* genus, generally flower and produce viable, regular, abundant fruit crops from three years of age. Some of these species attract large numbers of European honey bees *Apis mellifera*, and an extensive array of exotic and native pollinating insects. For instance, honey bees are a common visitor to *Alphitonia* flowers in restoration plots, but are always accompanied by many native species, belonging to the Hymenoptera (moths and butterflies) and other pollinator groups.
Longer-lived plants, more common in tree-fall gaps and secondary forests, also attract a wide range of invertebrate pollinators and vertebrate pollinators such as honeyeaters (*Meliphagidae*). For example, blue quandong *Elaeocarpus angustifolius* has flowered and set viable fruits from five years of age at Donaghy's Corridor (Tucker 2002), a pattern observed elsewhere in north Queensland. Other gap species such as pink euodia *Melicope elleryana* produce large flower sets on an annual basis, attracting very large numbers of moths and butterflies. Members of the *Lauraceae* within this guild (eg., grey bollywood *Neolitsea dealbata* and three-veined laurel *Cryptocarya triplinervis)* may be pollinated by honey bees, but are also likely to be pollinated by beetles.

That is, the effect of planting pioneer and gap-phase species, which are adapted to disturbance, has been to stimulate what appears to be a generalist group of pollinators, which are themselves tolerant of fragmentation. By comparison, longer-lived trees more typical of intact forest often have yet to reproduce within restoration plots, including plots that are 18 years of age. This may be due to the absence of specialized pollinators. However, the failure of these trees to reproduce may also be due to the effects of competition from neighbouring trees, and this is the second broad observation that can be made.

Fruit-set on isolated trees and trees on the edge of a plot, both planted and naturally established, generally occurs from a younger age and is more regular and abundant, than production on the same species where they occur within a denser aggregation. For example, at Lake Eacham, open planted individuals of Kuranda quandong *Elaeocarpus bancroftii* and bumpy satinash *Syzygium cormiflorum*, two large-fruited, long-lived species, flowered and set fruit at ages 12 and 15, respectively. However, over the same period, neither species has produced flowers or fruit within regularly monitored restoration plots where they have been planted at high densities (at 1.5 m spacings).

Nevertheless, many native species planted outside their normal distribution will flower and fruit on a regular basis. For example, the ability of some rare plants with very restricted distributions within the Wet Tropics (e.g., *Actephila foetida,* fern-leaved Stenocarpus *Stenocarpus davallioides*, and rusty carabeen *Aceratium ferrugineum)* to produce (usually viable) fruits when planted outside their natural range, suggests that pollination of these species is not dependent on highly specialised interactions. Pollination of transplants may be effected by animals which feed on closely related local taxa, and/ or by selfing, where this occurs.

DISPERSAL

While the effects of isolation and time since restoration on pollination are complex and very poorly known, the effects of these factors on seed dispersal are better understood.
First, a number of studies have shown that seed dispersal tends to increase the richness of restoration plots over time (Tucker and Murphy 1997; Tucker 2001, 2002). For example, the richness of seedling recruits in restoration plots established in 1989/90 adjacent to forest at Lake Barrine increased from 49 species in 1996 (Tucker and Murphy 1997) to 123 species in 2000 (White *et al.,* in press). Some of the new recruits included seedlings of large-fruited species such as hairy walnut *Endiandra insignis*, as well as epiphytes such as basket fern *Drynaria rigida*.

Second, seed dispersal declines with increasing distance from intact forest (McKenna 2001; White *et al.,* in press). For example, total species recruitment at a replanted site of the same age and size at the Lake Barrine plot mentioned above, but isolated from intact forest by 600 m, did not increase between 1996 and 2001 (the plot had 23 species of recruits in both surveys).

Most studies have shown that the majority of dispersal is conducted by birds, and that small-fruited disturbance-adapted plants (<10 mm diameter) are more commonly dispersed than large-fruited species (>30 mm diameter). Nevertheless, in forest adjacent to restoration plots, large fruited species such as *E. insignis,* grey milkwood *Cerbera inflata, S. cormiflorum* and bunya pine *Araucaria bidwillii* have established at distances of 50 – 300 m from the nearest parent tree, clearly due to vertebrate dispersal (Tucker and Simmons, unpublished data). In three of four cases, the seedlings have been located directly at the base of stems, indicating that caching by rodents was a likely cause. Whilst their role as seed predators is well established, it is likely that rodents are also responsible for sporadic, though important, dispersal events.

HERBIVORY AND PREDATION

Herbivore relationships in restoration are limited to a few well known examples. Attacks by pademelons on *Omalanthus spp.* have been recorded in restoration plots in both tropical and subtropical Australia. In north Queensland, pademelons also heavily browse most members of the mahogany family (*Meliaceae*, e.g., *Dysoxylum, Toona* and *Aglaia*), most figs *Ficus spp.*, and selectively browse many other plant taxa. Invertebrate herbivory is usually restricted to defoliation of host plants, after which plants usually recover quickly. Mortality as a result of herbivory is probably outweighed by density-dependent mortality and/ or edge induced climatic fluctuations.

We know little about rodent seed predation in restoration plots but predation is likely to increase as plots mature and become suitable rodent habitat. However, there is likely to be a ‘window of opportunity’ when rodents are not present in plots, but the canopy has closed sufficiently to allow seeds to germinate in a relatively weed-free environment. In restoration plantings in north Queensland, this occurs between 1 – 3 years after establishment. Direct seeding of plantings during this ‘window of opportunity’ may be a cheap way to increase the diversity of plant species that are rare, patchily distributed, large-seeded, produce fruit irregularly or are difficult to propagate.

Interestingly, restoration can also be an important tool in reducing rodent predation in agricultural crops. For example, Storey *et al.* (unpublished data) and Ward *et al.* (in press) show that restoration of matrix habitats can rapidly and sustainably reduce rodent predation in sugar cane and macadamia orchards, respectively.

RESEARCH QUESTIONS

1. Despite the evidence that tolerance of the 'matrix' is a major determinant of persistence in fragmented landscapes for rainforest animals (Laurance 1991), and that improving matrix quality can enhance persistence in remnants (Tucker 2002; Simmons and Tucker 2002; Paetkau *et al.* unpublished data), there have been few studies that address the contribution of restoration plantings to regional conservation at an appropriate scale. Conservation biology is the science of scarcity, restoration ecology is the science of replenishment - for this reason alone there needs to be a marriage of research agendas.

    Question: How can restoration contribute more to the wider persistence of matrix intolerant or fragmentation sensitive species?

2. Ecological restoration is an expensive way to re-establish native rain forest vegetation. Direct seeding is considerably cheaper, yet the outcomes are far more uncertain. However, there are many young (1-3 years old) restoration plots where there is a 'window of opportunity' for conducting direct seeding trials in the absence of a large (seed-predating) rodent population, and the effects evaluated for germination and persistence.

    Question: What is the role of direct seeding in increasing species diversity within young restoration plantings (both monocultures and polycultures)?

3. Our understanding of plant-animal interactions in restoration is limited, but existing knowledge does allow some reliable assumptions to be made, using our ecological knowledge of various indicators to assess and interpret the biological interactions that are occurring. However, there is a need to refine the indicators we study, and to identify a subset of indicators that will provide a more comprehensive picture of restoration success.

    Question: What are the most efficient bioindicators for monitoring restoration success, and what are the best ways to measure them?

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SUMMARY OF WORKSHOP DISCUSSIONS

Group 1: Pollination in rainforest conservation and restoration.

Reporting by **Ros Blanche[1] and Saul Cunningham[2]**
[1] Rainforest CRC at CSIRO Entomology, Atherton, [2] CSIRO Entomology, Canberra

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SUMMARY

Pollination plays a major role in rainforest dynamics, but the consequences of the failure of this interaction may not be immediately apparent
The consequences of pollinator failure may not be apparent until the next generation of a plant species fails to appear (due to zero seed set by parents) or is depauperate or inferior (due to low seed set or inbreeding depression).

Our knowledge of specific plant-pollinator interactions in rainforests is limited
It is dangerous to generalise about the effects of pollinator disruption. Some plant species may be highly resilient (via pollinator substitution) and not require a large management effort. Other plant species may be very vulnerable, even to loss of a single pollinator. We don’t have enough detailed knowledge to predict what the outcome might be for many species.

Management may need to take a risk management approach
Due to our limited knowledge of plant-pollinator interactions, managers need to decide where to focus their management efforts – to develop a prioritised risk management approach. Suggested ways to do this are to target:

- plant species and their pollinators known to be threatened, or
- plant species with highly specialised pollinator relationships, or
- plant species that have a large impact on the rainforest environment (see Fig. 1)

Other management issues
Possible management tactics include:

- landscape modelling,
- better management of pesticides and herbicides,
- use of gardens and agricultural crops as providers of alternative pollinator host plants, and
- increased planting of target species in revegetation areas.

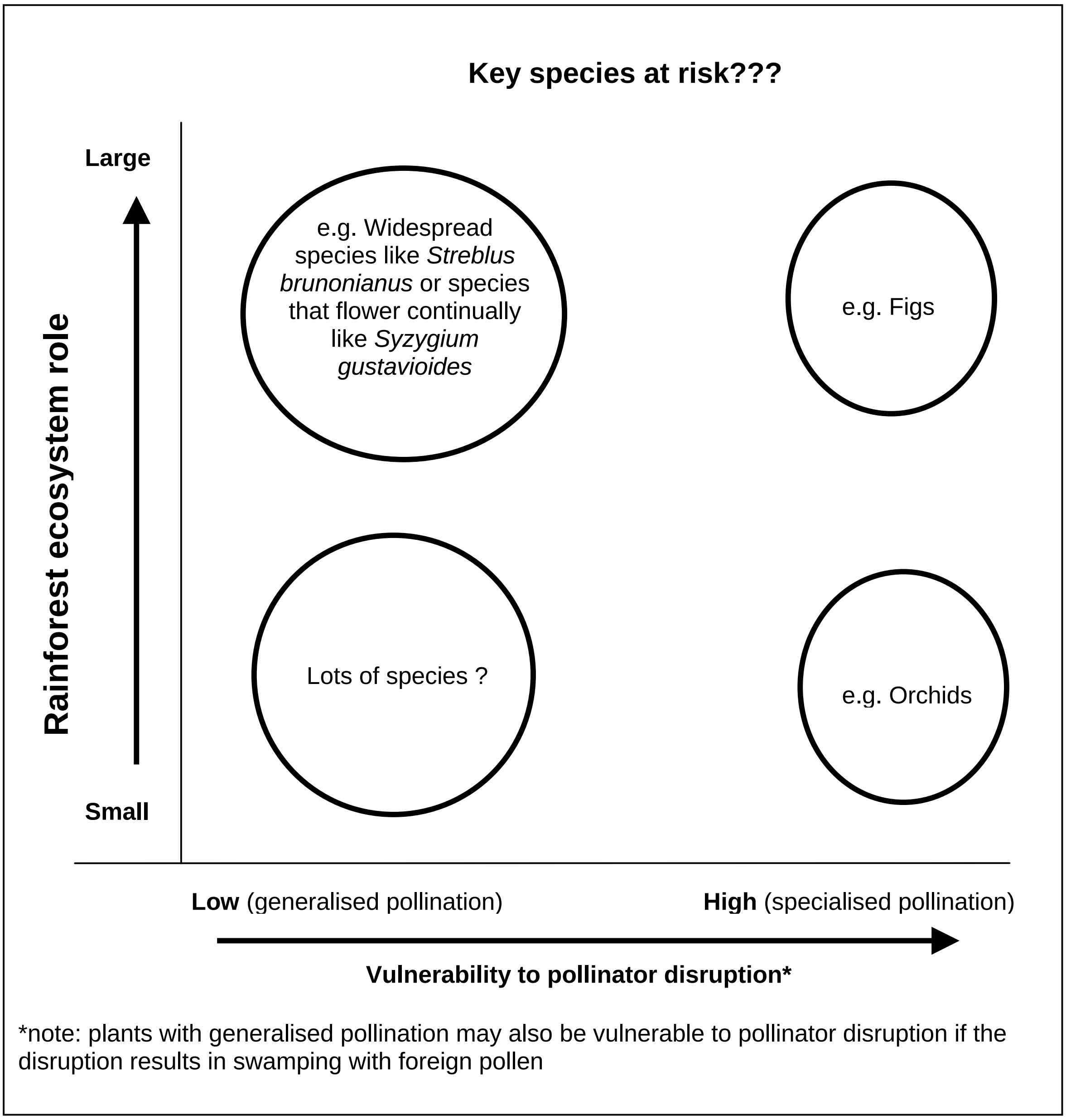

Figure 1. Risk assessment framework for managing pollination interactions in rainforests.

Group 2: Seed dispersal in rainforest conservation and restoration.

Reporting by **Andrew J. Dennis[1], Stephen Garnett[2] and Cath Moran[3]**
[1] Rainforest CRC at CSIRO Sustainable Ecosystems, Atherton, [2] Queensland Parks and Wildlife Service, Cairns, [3]Rainforest CRC at Environmental Sciences, Griffith University, Nathan

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SUMMARY AND INTERPRETATION

The group focussed primarily on the outcomes of forest restoration and the protection of remnants for the re-establishment of seed dispersal services and ecological functioning across the landscape. This is because the loss of biodiversity at a local scale was considered an important conservation issue. The group recognised the importance of understanding natural processes in intact forest as setting benchmarks or goals for the restoration of similar functioning across altered landscapes. A majority of discussion focussed on local communities as the main “management” and user groups of research into these areas. The involvement of government agencies in this process was not a significant part of the discussion. However, the group did suggest that conservation dollars should be directed toward the restoration of ecological functioning in altered landscapes. This was considered particularly important for key species (some threatened) that needed to cross altered landscapes to access particular resources or had to seek resources within altered landscapes in certain seasons (e.g., Coxen’s fig-parrot *Cyclopsitta diophthalma coxeni*).

The group felt that there was a great need for more detailed information in the form of guidelines for restoring ecological functioning by enhancing natural seed dispersal and successional processes. The re-establishment of seed dispersal services for plants with medium and large fruits was also considered an important goal. It was considered preferable that natural processes be used to maintain services to these species where possible but that direct actions by people may be necessary in some locations.

The role of fleshy-fruited weed species in the landscape was of particular interest. Many participants felt that weed species such as camphor laurel *Cinnamomum camphora*, lantana *Lantana camara* and wild tobacco *Solanum mauritianum* provided both opportunity and problems. On the one hand they provided resources that helped to maintain animal populations throughout the landscape. On the other, they created an arrested succession preventing native vegetation from re-establishing. Much interest was expressed in how to best manage existing weed communities to support native seed dispersers while actively driving a succession toward greater native species diversity. Other key questions arising from the discussion related to how to make the most effective use of natural processes. These included (i) identifying key plant species for attracting frugivores into restoration plantings to enhance recruitment, and (ii) identifying strategic locations within the landscape for most efficient application of resources.

MAIN POINTS RAISED DURING DISCUSSION:

Understanding seed dispersal processes in intact forests is important.

- As a baseline for understanding their degradation outside continuous forest.
- As a baseline for understanding frugivore responses to resource patchiness within continuous forest compared to patchiness in a landscape of habitat fragments.
- To set a benchmark for goal setting in the restoration of degraded lands and habitat fragments.

Seed dispersal processes provide both services and disservices to humans.

- Seed dispersal maintains and structures natural forests.
- Seed dispersal contributes to forest restoration/ regeneration.
- The spread of weed into regrowth, reforestation, forests and production landscapes provides both services (food resources for frugivores, pioneer or framework species in regrowth and restoration) and disservices (costs of control, arrested succession).

Maintaining ecological services to habitat fragments is a good use of conservation dollars.

- In many places, habitat fragments make up the bulk of the landscape.
- Some habitat types are only present as fragments.
- People lament the loss of biodiversity across altered landscapes.
- Protection of habitat fragments and the biodiversity and processes within them is important because this is where most people interface with the environment.

The restoration of deforested land and protection of habitat remnants are both important.

- Remnants provide a source of resources (seeds and dispersers) that already exist and should be protected or enhanced first.
- Restoration of deforested land will promote re-establishment of seed dispersal services across the landscape by facilitating animal movement.
- Restoration will enhance the ability of remnants to support seed disperser populations, which will in turn provide a positive feedback through the dispersal of more seeds into the landscape.

Prioritising locations for protection or restoration is limited by social factors and unlikely to be ecologically strategic.

- Locations for action are determined by landholder/ manager willingness to participate.
- It is important to identify sites where minimal work will restore ecological functioning.

The aim of actions should be to restore natural processes at a landscape scale but the actual work is done at the property scale.

- It is important to support willing workers and landholders with restoration efforts.
- Need some focus on restoring remnants to maintain the natural resource base across the landscape.

More information on strategic use of plants and locations for restoration is required.

- What keystone fruit resources should be incorporated into restoration plantings to enhance natural processes?
- How should the weedy matrix be managed most effectively to enhance succession toward ecologically functional native vegetation?
- Are corridors along streams the most efficient target for the restoration of ecological functionality across the landscape?
- What additional seed dispersal services are provided by fish in relation to the restoration of streamside vegetation?
- How useful is the planting of single trees or the provision of artificial perches to the re-establishment of forests on cleared land?

Group 3: Seed and seedling predation in rainforest conservation and restoration.

Reporting by **Peter Green[1], Kristen Williams[2] and John Kanowski[3]**
[1] Ecosystem Dynamics Group, Research School of Biological Sciences, Australian National University, Canberra, [2] CSIRO Sustainable Ecosystems, Atherton, [3]Rainforest CRC at Environmental Sciences, Griffith University, Nathan

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SUMMARY

Seed and seedling predators are believed to play an important role in the dynamics of intact rainforest, but their importance is a matter of debate

Seed and seedling predators are believed to have important impacts on the population biology of many plant species, and seed and seedling predator/ plant interactions are vital in determining the dynamics of tropical forests. However, the specific role of seed and seedling predators in maintaining plant diversity is still a matter of debate. Unfortunately, resolving the debate is difficult, as there is a major disparity between the timescales over which we study animal-plant interactions (a few years), and the temporal scales over which these interactions are important for many rainforest plants (e.g., trees that live for hundreds of years).

Seed and seedling predators can have negative impacts on human activities.

Seed and seedling predators may have a negative impact on human activities/ endeavors in 'off-reserve' situations: e.g., herbivory of plantations by wallabies, or seed predation in macadamia plantations by rats.

Seed and seedling predator/ plant interactions are potentially threatened or vulnerable to current human-induced impacts.

Seed and seedling predator interactions are potentially vulnerable to human-induced impacts, such as the introduction of alien species (e.g., as on Christmas Island) or fragmentation. However, in complex systems, it may be difficult to identify key players in seed and seedling predator interactions. The extent of ecological redundancy in these interactions is generally unknown. Can we afford to lose some seed and seedling predators from natural systems, and not have a measurable impact on ecosystem properties?

Processes such as seed and seedling predator/ plant interactions are not often considered problematic by management agencies.

Management agencies generally devote few resources to managing and restoring animal-plant interactions, especially within remnant forest. This is partly because there is a profound mismatch in temporal scales between ecological processes mediated by seed and seedling predators (which may potentially take decades to become evident) and the short time scales by which government agencies operate.

The necessity, feasibility or cost-effectiveness of managing seed and seedling predator/ plant interactions has generally not been established.

Managing seed and seedling predator interactions in remnant forests may not necessarily be a high priority, given other impacts may have potentially greater or more immediate effects on conservation, such as fragment size, isolation and edge effects. However, analyses must be done on a case-by-case basis. There are some situations where management interactions might be critical, such as on Christmas island. In restored forests, it may be necessary to artificially re-establish seed and seedling predator/ plant interactions to facilitate succession and maintain diversity, e.g., by the translocation of ‘missing’ seed predators, or by the control of hyperabundant seedling predators.

There was discussion on pro-active *versus* reactive management, the latter approach often characterising conservation agencies when dealing with complex, long-term issues such as animal-plant interactions. However, pro-active management requires sound information, which we often do not have on seed and seedling predator/ plant interactions.

Canopy herbivores: a forgotten interaction?

Canopy-level herbivores (i.e., possums and insects) may also influence rainforest conservation and restoration. For example, the introduction of brush-tailed possums *Trichosurus vulpecula* to New Zealand has had a huge impact on forest dynamics, but in that situation possums have been introduced to a flora that evolved without arboreal folivores. Whether possums have a similar effect in “native” systems - intact, fragmented or restored - is unknown.

SYNTHESIS

John Kanowski and Carla P. Catterall
Rainforest CRC at Environmental Sciences, Griffith University, Nathan

OVERVIEW OF WORKSHOP

This workshop brought together researchers, conservation managers, restoration practitioners and members of the public to discuss the role of animal-plant interactions in rainforest conservation and restoration. Workshop participants were affiliated with various institutions within and outside the Rainforest CRC and represented interests from both tropical and subtropical Australia.

Most participants agreed that animal-plant interactions play an important role in rainforest dynamics, and therefore that disruptions to these interactions may have negative and possibly far-reaching consequences for rainforest conservation. Such disruptions are most likely in landscapes where rainforest has been extensively cleared, because the population size, distribution, composition and behaviour of animal assemblages are often altered by habitat loss and fragmentation.

For example, fragmentation may disrupt the pollination of some rainforest plants (Blanche, Chapter 1). Plants with highly specialised pollination syndromes are likely to be most vulnerable to fragmentation, although the risk management framework developed in the workshop (Discussion Group 1) suggested that managers should be most concerned with the consequences of pollination failure in the subset of plants which play major ecosystem roles (e.g., figs, which provide a food resource to many frugivorous animals). Interestingly, long-term observations indicate that some mature-phase rainforest trees have yet to reproduce in restoration plots (Tucker and Simmons, Chapter 8). This may be due to pollination failure, but other explanations (e.g., competition with other plants for sunlight and water) may also explain this phenomenon.

There is now clear evidence that fragmentation may severely alter patterns of seed dispersal in former rainforest landscapes. In north Queensland, Dennis *et al.* (Chapter 2) showed that fruit removal rates decline in remnants compared with intact forest, and that within remnants, removal rates decline with decreasing size and increasing distance from intact forest. These trends are strongest for medium and large-seeded species. These results imply that an ecological process fundamental to rainforest dynamics has been degraded in remnant rainforests in north Queensland, with major implications for the conservation of biodiversity in these remnants. Participants in the ensuing discussion (Discussion Group 2) spoke strongly in favour of conserving biodiversity in remnant forests. In some landscapes, remnants comprise a substantial proportion of native forest and often conserve threatened forest types. Participants compiled a list of key issues which needed to be addressed to restore seed dispersal services in fragmented landscapes, including the management of weedy regrowth, the identification of key plants to use in restoration, and prioritising key locations for restoration plantings.

There was more debate on the role of seed and seedling predators in rainforest conservation. Green (Chapter 3) suggested that there is limited evidence to support the long-standing hypothesis that seed and seedling predators play a key role in maintaining rainforest diversity. Further, Green argued that while rainforest clearing and fragmentation might be expected to disrupt seed and seedling predation, there may be little point in trying to manage this interaction in remnants, and that efforts should be directed instead into threatening processes such as broadscale clearing. Some of these ideas were challenged by participants in the ensuing discussion (Discussion Group 3). For example, it is clear that seed and seedling predators can strongly affect regeneration patterns within some rainforest types, particularly within simplified ecosystems such as rainforests on islands, restoration plantings and regrowth. While participants agreed that managing seed and seedling predators in remnant forests may not always be a high priority, there are some situations where management of these interactions might be critical.

Rainforest conservation managers and restoration practitioners voiced two contrasting responses to the threats associated with disruptions to important animal-plant interactions. According to Smith and Garnett (Chapter 4), state agencies responsible for conservation are largely concerned with the planning and day-to-day management of protected areas to enable sustainable use (e.g., visitation). Management is driven by short-term funding and political cycles; in this environment, management of animal-plant interactions is considered a 'luxury' only afforded to highly threatened or problematic species. However, managers clearly have been presented with little reason to believe that disruptions to animal-plant interactions will have important ramifications for the conservation estate and even less information as to how best to intervene, if required.

In contrast, restoration practioners have for some time emphasised the importance of considering animal-plant interactions in the conservation and restoration of cleared rainforest landscapes (e.g., Russell, Chapter 6; Bower, Chapter 7; Tucker and Simmons, Chapter 8). A number of projects have been designed with the explicit purpose of attracting animals, such as seed-dispersing birds, to help restore forest cover to degraded land. However, most restoration projects are in their infancy, and practioners realise that there is still much to learn about the role of animal-plant interactions in restoration. For example, practitioners do not know which interactions are most important to manage in particular sites or to promote or control certain species, or how best to manipulate the interactions for conservation outcomes.

Research on restoration plantings and other forms of reforestation is beginning to address these research gaps (Kanowski *et al.*, Chapter 5). For example, seed and seedling predation can have a major influence on successful establishment of forest cover, while seed dispersal is a major factor affecting the recruitment of plants to reforested sites. Seed dispersal is limited by the proximity of reforested sites to intact rainforest and by habitat quality, particularly the abundance of fleshy-fruited plants in reforested sites. These results suggest that some forms of reforestation, particularly timber plantations, are unlikely to catalyse the restoration of rainforest to cleared land, except perhaps where plantations are located adjacent to intact forest. However, these results also suggest that the inclusion of more fleshy-fruited plants (as timber trees or as 'biodiversity plantings') may attract frugivores and their seed dispersal services to plantations, in cases where plantations are to be managed for their biodiversity values.

ANIMAL-PLANT INTERACTIONS: CHALLENGES FOR RESEARCHERS, MANAGERS AND PRACTITIONERS

With a few notable exceptions, we still have only a superficial knowledge of the roles that animals play in rainforest conservation and restoration. In large part, this is attributable to the difficulty of studying complex interactions in such a diverse and heterogeneous ecosystem as rainforest, where the dominant organisms (trees) live for centuries and many recruit episodically or irregularly. Studying rainforest ecology is a major challenge in terms of methodologies and logistics. In some cases, advances in technology are required before some processes can be studied in detail. For example, the recent siting of large construction cranes within rainforests has greatly facilitated pollination studies (Ozanne *et al.* 2003). However, in many cases, research on animal-plant interactions in rainforests requires the application of a large amount of effort, over considerable areas, for a sufficiently long period of time. For example, the study of fruit removal rates in north Queensland rainforests by Dennis *et al.* (Chapter 2) has been made possible through the use of teams of volunteers making observations over several years. Studies of the effects of seed and seedling predators on rainforest dynamics reported by Green (Chapter 3) have involved repeated surveys of natural experiments or exclusion plots, whose affects may not be apparent for several years. Similarly, the detailed study of the biodiversity values of reforestation reported by Kanowski *et al.* (Chapter 5) has entailed the collection of data from a large number of sites and collaboration amongst experts in various fields over several years.

Unfortunately, there is a profound mismatch between the time-scale over which disruptions to animal-plant interactions are likely to become evident in rainforests, and the prevailing short-term concerns of management agencies. In the absence of information to the contrary, conservation managers have largely relegated potential problems associated with disruptions to animal-plant interactions to a low-risk (i.e., do nothing) category. However, if animal-plant interactions do play key roles in rainforest dynamics, then this approach may result in the need for expensive reactive management in the future. For example, the absence of native rodents in some remnant rainforests in northern New South Wales appears to have released the large-seeded tree black bean *Castanospermum australe* from predation. Seedlings of this species now dominate the understorey in some remnants and will presumably dominate the canopy in the future, at the expense of other species (Lott and Duggin 1993). If this scenario is correct, then the maintenance of diversity in these remnants may require the culling of millions of black bean seedlings, and perhaps the reintroduction of rodents to remnants for long-term regulation of the species. On the other hand, it is possible that the flush of recruitment observed by Lott and Duggin (1993) is a natural event, or at least falls within the variability inherent in rainforest dynamics. In this case, intervention would be not only a waste of money but perhaps detrimental to the biodiversity of the remnants.

Clearly, a much better understanding is required of the roles played by animal-plant interactions in rainforest conservation and restoration. Managers may be wise to devote some of their scanty resources to supporting research into large-scale, long-term processes, such as key animal-plant interactions, that may fundamentally affect the viability of protected areas. Research that may be useful may include studies of:

- the basic ecology of pollination, seed dispersal, and seed and seedling predation in remnant and restored rainforests;
- the effects of major anthopogenic impacts (e.g., habitat fragmentation, impacts of exotic species and climate change) on animal-plant interactions; and
- ways of mitigating these impacts.

However, it will be a real challenge for researchers, managers and practitioners to work towards the better understanding and management of animal-plant interactions in rainforest conservation and restoration (and similar large-scale, long-term issues). For example, researchers are often most interested in longer-term questions whose relevance may not be immediately obvious to managers or practitioners. On the other hand, managers and practitioners want information to address their immediate concerns, and are often willing to accept ‘interim guidelines’ or ‘work in progress’, an approach contrary to the training of most scientists.

Advances in both ecological knowledge and useful information are possible if researchers, managers and practitioners work jointly to initiate and conduct research projects. For example, a better understanding of the potential for fleshy-fruited plants to attract frugivores to timber plantations could be gained if a suite of plantations were explicitly designed to include varying proportions of fleshy-fruited plants as timber trees, and the use of these plantations by frugivores was monitored over time. There is also much scope for using existing landscapes as 'natural experiments' to examine the consequences of fragmentation, regrowth and restoration for animal-plant interactions. This approach would require scientists to compromise on research questions, and managers and practitioners to try some approaches about which they may initially be sceptical. The production of 'interim guidelines' based on the best available knowledge will also require some cultural changes, including a willingness on the part of scientists to provide advice in the face of uncertainty. There will also need to be a willingness on the part of managers and practitioners to accept that such advice is temporary and conditional, and to continue to support a research effort aimed at improving the quality of advice.

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Ozanne, C. M., Anhuf, D., Boulter, S. L., Keller, M., Kitching, R. L., Körner, C., Meinzer, F. C., Mitchell, A. W., Nakashizuka, T., Silva Dias, P. L.. Stork, N. E., Wright, S. J. and Yoshimura, M. (2003) Forest canopies: understanding global ecosystems. *Science* 301, 183-186.

APPENDIX 1
Workshop format

The workshop ran for two 1.5 hour sessions. The first session comprised presentations from invited speakers. In the second session, the workshop broke into groups to discuss key questions on selected topics, followed by a plenary session.

SESSION 1

Chair: Carla Catterall
Welcome and general introduction to workshop.

Presentations

Fruit removal rates across a landscape. Andrew Dennis, David Westcott, Adam McKeown, Matt Bradford and Graham Harrington.

The role of seed and seedling predators in rainforest dynamics. Peter Green

Insect pollinators from tropical rainforests: their role in native forests, forest fragments and agricultural environments. Ros Blanche

Are studies into animal-plant interactions of any practical use for rainforest conservation managers? Keith Smith and Stephen Garnett

Animal-plant interactions in rainforest restoration in tropical and subtropical Australia. John Kanowski, Carla Catterall, Terry Reis and Grant Wardell-Johnson

Animal-plant interactions and restoration practice in south-east Queensland. Marc Russell

Animal-plant interactions and restoration practice in north-east New South Wales. Hank Bower

SESSION 2

Opening plenary

Facilitator: Carla Catterall
Brief outline of structure and goals of session, and introduction to topics for discussion.

Group work

1. Pollination in rainforest conservation and restoration.
2. Seed dispersal in rainforest conservation and restoration.
3. Seed and seedling predation in rainforest conservation and restoration.

Discussion centred around key questions:

1. In what ways is this interaction (i.e., pollination, seed dispersal or seed and seedling predation) important in intact rainforest?
2. What services or disservices to human activities come from this interaction (either on- or off-reserve)?
3. In what ways is this interaction threatened or vulnerable to current human-induced impacts?
4. What are the main issues in restoring this interaction: (1) within remnant forest, (2) in forest reinstatement, (3) as elements in production systems?
5. Is it necessary, feasible or cost-effective to manage aspects of this interaction?
6. Identify any priority locations or taxa for management of this type of interaction.

Concluding plenary

APPENDIX 2
Workshop questions nominated by the organising committee.

The list of questions nominated for consideration at the workshop by the organising committee are presented here, grouped by broad themes. Note some questions are applicable to more than one theme. The list was distilled into the six key questions discussed at the workshop (Appendix 1).
RB = Ros Blanche; CC = Carla Catterall; AD = Andrew Dennis; SG = Stephen Garnett; PG = Peter Green; JK = John Kanowski; KS = Keith Smith; DW = David Westcott.

Pollination
- Is pollinator biodiversity important in maintaining pollination services (in crops/ forest/ revegetation/ remnants)? RB
- Are 'organic' farming practices more likely to attract the services of rainforest insect pollinators than 'convential' farming practices? RB

Seed dispersal
- Our research is demonstrating that for some rainforest plants there is a significant loss of dispersal services in fragments that may affect long term community dynamics and increase the likelihood of extinctions. What would be the critical thresholds at which either the re-introduction of dispersers or the replacement of lost services by human intervention be undertaken? AD
- Seed dispersal services by vertebrates are a double edged sword. They control natural vegetation dynamics and the spread of numerous weed species. How should their dual role be viewed and acted upon in a multi-use landscape where weed control is Australia's highest farming cost and a serious ecological and restoration cost? AD

Seedling predation
- How important are pre- and post-dispersal seed predators, and seedling predators, in determining the abundance and diversity of seedlings in intact rain forest? PG

Fragmentation
- Is habitat connectivity essential to maintain abundant and diverse rainforest pollinator communities and plant/ pollinator interactions (in crops/ forest/ revegetation/ remnants)? RB
- How does fragmentation affect the role played by pre- and post-dispersal seed predators in remnant vegetation? PG
- In what ways does forest fragmentation affect animal-plant interactions, and are some types of interaction more vulnerable than others? CC

Restoration
- What aspects of animal-plant interactions are most critical to establish/ manage during rainforest restoration? JK
- How do we re-establish important animal-plant interactions in reforested sites? Is it simply a matter of planting the right trees, or does more need to be done? JK
- Can weed-dominated regrowth be viewed as a form of secondary rainforest succession, and be managed as the basis for rainforest restoration over large areas? CC

- If herbivores are important in natural forest systems, at what stage should we encourage their re-introduction to recovering or reconstituted systems? PG
- Do plants with large diaspores deserve special attention in rainforest restoration? CC

Management - why and what

- Can we manage animal-plant interactions? If so what are the interaction types that will be most effectively manipulated? DW
- Is it important to manage animal-plant interactions in rainforest landscapes, and can they be managed? CC
- What do conservation managers want to know about animal-plant interactions? KS
- Threatened species and problem species management: what elements of animal-plant interaction can be managed to promote recovery or minimise social and economic impact? KS
- What (and why) are the rainforest animal-plant interactions that are: particularly threatened by human impacts; important in reforestation; economically important; important in forest dynamics? CC
- What elements of animal-plant interactions need active management and which will happen passively? SG

Management – how, where and at what scale?

- When does the degradation of ecological processes that maintain and structure ecosystems become a conservation management issue (i.e., at what spatial scale)? For example, if a region will suffer no net loss of biodiversity despite a loss or decline of biodiversity in fragments, does it matter? AD
- Are the resources required for active management of animal-plant interactions ever likely to be sufficient to make significant biodiversity gains? SG
- Can locations for active management be prioritised for the Wet Tropics? SG
- How do threats associated with/ driven by animal-plant interactions compare spatially and temporally with other threats to the integrity of rainforest landscapes? SG
- Can critical animal-plant dependencies and areas of animal-plant interaction dysfunction, be identified for species under threat in the Wet Tropics rainforests? KS
- At what spatial and temporal scales is management of animal-plant interactions most likely to be effected or will this be highly variable? DW
- Is managing interactors sufficient? DW

Indicators and triggers for action

- Should the development and maintenance of important animal-plant interactions to reforested sites be considered a key indicator of restoration success? JK
- What are the best ways to detect and monitor effects of environmental change on interactions between animals and plants (and what particular challenges are involved)? CC
- What is an appropriate historical benchmark in rainforest restoration? For example, might all Australian rainforests still be experiencing an extinction debt following the loss of megafauna? If so, would it be desirable to (?re-) introduce interactors such as cassowaries and folivorous marsupials (possums, tree-kangaroos) from north Queensland to subtropical rainforests regions, or should we re-set the benchmark to acknowledge irreversible contemporary fragmentation? CC

Appendix 3
Addresses of presenters and convenors

Dr K. Rosalind Blanche
CSIRO Entomology
PO Box 780
ATHERTON QLD 4883
Phone (07) 4091 8800
Email Ros.Blanche@csiro.au

Hank Bower
Environmental Planner (Ecology)
Byron Shire Council
PO Box 219
MULLUMBIMBY NSW 2482
Phone (02) 6626 7135
Email Hank.Bower@byron.nsw.gov.au

Dr Carla Catterall
Environmental Sciences
Griffith University
NATHAN QLD 4111
Phone (07) 3875 7499
Email C.Catterall@griffith.edu.au

Dr Andrew Dennis
CSIRO Sustainable Ecosystems
PO Box 780
ATHERTON QLD 4883
Phone (07) 4091 8800
Email Andrew.Dennis@csiro.au

Dr Stephen Garnett
A/Manager
Conservation Services
Queensland Parks and Wildlife Service
PO Box 2066
CAIRNS QLD 4870
Phone: (07) 4046 6644
Email stephen.garnett@epa.qld.gov.au

Dr Peter T. Green
Ecosystem Dynamics Group, Research
School of Biological Sciences
Australian National University
c/- CSIRO
PO Box 780
ATHERTON QLD 4883.
Email Drpeter.green@csiro.au

Dr John Kanowski
Environmental Sciences
Griffith University
NATHAN QLD 4111
Phone (07) 3875 7499
Email J.Kanowski@griffith.edu.au

Marc Russell
Revegetation and Habitat Officer
Barung Landcare
17 Bicentenary Lane
MALENY QLD 4552
Phone (07) 5494 3151
Email barung@sun.big.net.au

Tania M. Simmons
Biotropica Australia P/L
PO Box 866
MALANDA QLD 4885
Phone (07) 4095 1116
Email kanuka.creek@bigpond.com

Keith Smith
Regional Extension Officer
Conservation Services
Queensland Parks and Wildlife Service
PO Box 975
ATHERTON QLD 4883
Phone (07) 4091 7763
Email keith.smith@epa.qld.gov.au

Nigel I. J. Tucker
Biotropica Australia P/L
P.O. Box 866
MALANDA QLD 4885
Phone (07) 4095 1116
Email biotropica@bigpond.com

Dr David Westcott
CSIRO Sustainable Ecosystems
PO Box 780
ATHERTON QLD 4883
Phone (07) 4091 8800
Email David.Westcott@csiro.au

APPENDIX 4
List of known workshop participants.

Pollination group
Ros Blanche – CSIRO, Entomology
Frederic Beaulieu – University of Queensland
Sarah Boulter - Griffith University
Saul Cunningham – CSIRO, Entomology
Kylie Goodall – Rainforest CRC
Peter Grimbacher - Griffith University
Gitte Kragh – Aarhus University, Denmark
Andrew Lowe –University of Queensland
Katie Pritchard – James Cook University

Seed dispersal group
Joanne Arlukiewicz – School for International Training
Marcus Balstrode – Landcare, Johnson Ecological Society
Hank Bower – Big Scrub Landcare/Byron Shire Council NSW
Paul Bray – Local Resident
Lee Curtis – Writer
Andrew Dennis – CSIRO, Sustainable Ecosystems
Nicola Dowding – James Cook University
Ceinwyn Edwards – Independent Field Biologist
Jenny Maclean – Tolga Bat Rescue and Research
Stephen Garnett – Queensland Environmental Protection Agency
Miriam Goosem – James Cook University
Cath Moran – Griffith University
Tom Rayner – James Cook University
Bronwyn Robertson – Wet Tropics Tree Planting Scheme
Marc Russell – Barung Landcare
Elinor Scambler – Birds Australia
Damon Sydes – Cardwell Shire Council
Sarah Townsent – James Cook University
Grant Wardell-Johnson – University of Queensland
Jessie Wells – University of Queensland/CSIRO
Mary Wenzel – Volunteer bat carer

Seed and seedling predation group
Andrew Ford - CSIRO, Sustainable Ecosystems
Peter Green – Australian National University/CSIRO
Deborah Harrison – Rainforest CRC
Bob Hewett - CSIRO, Sustainable Ecosystems
David Hilbert - CSIRO, Sustainable Ecosystems
John Kanowski - Griffith University
Darryl Killen – Queensland Department of Primary Industries
Melinda Laidlaw – University of Queensland
Trevor Parker - CSIRO, Sustainable Ecosystems
John Peters – Ergon Energy
Catherine Pohlman – James Cook University
Anna Richards - University of Queensland
Keith Smith – Queensland Parks and Wildlife Service
Daniel Stock - Griffith University
Kristen Williams - CSIRO, Sustainable Ecosystems
John Winter – Freelance Zoologist