



Weeds of Rainforests and Associated Ecosystems

Edited by A.C. Grice
and M.J. Setter



Rainforest CRC



WEEDS OF RAINFORESTS AND ASSOCIATED ECOSYSTEMS

Workshop Proceedings
6-7 November 2002

Edited by
A.C. Grice and M.J. Setter



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CONTENTS

PREFACE v
EXECUTIVE SUMMARY vi
INTRODUCTION 1
SECTION 1 — Workshop Methodology 3
SECTION 2 — Invited Papers	..... 7
A bioregional perspective of weed invasion of rainforests and associated ecosystems: Focus on the Wet Tropics of north-east Queensland <i>Garry L. Werren</i>	..... 9
The ecology of seed dispersal in rainforests: implications for weed spread and a framework for weed management <i>David A. Westcott and Andrew J. Dennis</i>	..... 19
Landscape processes relevant to weed invasion in Australian rainforests and associated ecosystems <i>Steve Goosem</i>	..... 24
Rainforest weeds: detecting and managing new incursions <i>Barbara M. Waterhouse</i>	..... 34
Managing weeds relevant to Australian rainforests and associated ecosystems <i>Melissa J. Setter and Joseph S. Vitellii</i>	..... 39
SECTION 3 — Current Research and Developmental Activities	..... 51
Biological control of <i>Lantana camara</i> <i>Michael Day</i>	..... 52
Best practice natural resource management on protected areas <i>Leasie Felderhof</i>	..... 54
Southeast Queensland Rainforest Recovery Plan <i>Catherine Hulm</i>	..... 56
Update on Cape York Weeds and Feral Animals project <i>Peter James</i>	..... 57
Frugivorous vertebrates and rainforest seed dispersal in subtropical eastern Australia: Interactions in forested and fragmented landscapes <i>Cath Moran</i>	..... 59
Ecology of Wet Tropics Weeds project summary <i>Melissa Setter</i>	..... 61

Ecology of bird-dispersed weeds: identifying plant functional groups and associated bird-dispersal syndromes <i>Chris Stansbury</i>	..... 63
The dynamics of <i>Lantana camara</i> invasion of subtropical rainforest in Southeast Queensland <i>Daniel Stock</i>	..... 66
Remote sensing for mapping weeds: An example from the Wet Tropics (pond apple) <i>Catherine Ticehurst, Stuart Phinn, Tim Edmonds and Alex Held</i>	..... 68
Weeds of linear clearings through rainforest <i>Steve Turton and Miriam Goosem</i>	..... 70
Invasive vine dispersal: Going with the flow? <i>Gabrielle Vivian-smith</i>	..... 72
Weeds in rainforest restoration: Research in Project 5.2 of the Rainforest CRC <i>Grant Wardell-Johnson</i>	..... 74
New Wet Tropics Natural Resource Management Plan <i>Nigel Weston</i>	..... 76
SECTION 4 — Workshop Outcomes	
Research and development needs	..... 78
Research and development priorities	..... 80
Research and development recommendations	..... 96
REFERENCES	..... 98
APPENDICES	
A1 Weed species list	..... 103
A2 Workshop program	..... 105
A3 List of workshop attendees	..... 107

PREFACE

These are the Proceedings of a workshop on weeds of rainforests and associated ecosystems. The workshop was held in Cairns, Queensland, Australia in November 2002 and was organised as a joint effort of the Cooperative Research Centre (CRC) for Tropical Rainforest Ecology and Management and the Cooperative Research Centre for Australian Weed Management. Weeds are a significant threat to Australian rainforests and associated ecosystems and yet there has been relatively little research directed at this issue. A primary purpose of the workshop was to identify research needs in relation to weeds as a precursor to developing a research program as a collaboration between the two CRCs.

The organising committee for the workshop consisted of:

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EXECUTIVE SUMMARY

- Australian rainforests and associated ecosystems are important for the biodiversity they contain, the ecosystem services they provide and the industries that they support. Invasion by weeds, however, constitutes a serious threat to the integrity and sustainable use of rainforests.
- These Proceedings derive from a workshop organized jointly by the CRC for Tropical Rainforest Ecology and Management (Rainforest CRC) and the CRC for Australian Weed Management (Weeds CRC). The objectives of the workshop were to:
 - 1) review current knowledge of weeds of Australian rainforests and associated ecosystems;
 - 2) identify important research gaps in relation to weeds of Australian rainforests and associated ecosystems;
 - 3) propose priority research and development (R and D) actions in relation to weed issues for Australian rainforests and associated ecosystems.
- About 510 exotic plant species are naturalized within the Wet Tropics Bioregion. This constitutes around 10% of the total flora of the region. The exotic flora includes a great variety of growth forms including ferns, grasses, sedges, forbs, aquatic and semi-aquatic plants, vines, shrubs and trees. In terms of numbers of species naturalized forbs, grasses, shrubs, vines and trees are the most important groups. Invasive vines are prominent for their impacts on Australian rainforests.
- A weed risk assessment system for the Wet Tropics rates weed species for the risk that they pose. Under this system, the highest scoring vine species are *Thunbergia* spp., *Mikania micrantha* and *Turbina corymbosa*. The tree species with the highest weed risk assessment scores are *Annona glabra*, *Leucaena leucocephala* and *Miconia calvescens*. The highest scoring forb and shrub were *Sphagneticola trilobata* and *Chromolaena odorata* respectively.
- Animal dispersal is important for a large proportion of plant species in Australian rainforests. Some important weeds or potential weeds of Australian rainforests are animal-dispersed so knowledge of dispersal processes by this mechanism is important to weed management.
- Land use, disturbance and climate are important driving factors in weed invasion. Most weeds of Australian rainforests are confined to parts of the landscape that are disturbed by humans. Community service corridors and riparian zones represent the primary conduits for spread of weeds in rainforest areas. Global climate change presents a formidable research and management challenge in relation to weeds of rainforests.
- Surveillance for weeds is critical for the prevention of new weed incursions and for detecting invasions in their early stages. The Northern Australia Quarantine Strategy of the Australian Quarantine and Inspection Service provides a key surveillance function. The Weeds CRC includes a program that is conducting research to improve predictive capacity and risk assessment in relation to new weed incursions.
- There are many “new” weeds threatening rainforests and associated ecosystems. A high proportion of these were deliberately introduced as garden plants for tropical areas.
- Management of weeds in rainforest areas must be based on an understanding of the physical, social and economic characteristics of these areas. Ecological information that would be useful for management is lacking for particular weed species.

- Fire, mechanical and chemical treatments and biological control are available as weed management tools for rainforest weeds but the nature of rainforests often limits the ways and extents to which these tools can be used. Integrated long-term strategies are vital. Community involvement is important for the management of weeds in rainforests.
- Issues in relation to the research and development needs for weeds of rainforests and associated systems were canvassed during the workshop using a “brain-storming” technique. The research and development needs identified relate to:
 - (i) understanding weeds and invasions;
 - (ii) detection weeds, managing new incursions and eradication;
 - (iii) prioritizing weed problems;
 - (iv) weed impacts;
 - (v) engaging communities;
 - (vi) practical solutions to existing problems; and
 - (vii) resources for weed research and development.
- Ideas in relation to five priority areas were developed in more detail. These were:
 - (i) development of a database to capture current knowledge and information as regards weeds of rainforest and associated ecosystems;
 - (ii) research on the impacts of weeds on ecological processes in rainforests;
 - (iii) research on disturbance regimes and landscape characteristics in relation to weeds of rainforests;
 - (iv) engagement of people in addressing weed issues at a landscape scale;
 - (v) early detection and response to new weeds.



a



b



c



d



e



f

SOME WEEDS OF AUSTRALIAN RAINFORESTS

This page: **a:** Leaves and flowers of hiptage (*Hiptage benghalensis*); **b:** Fruits of hiptage (*Hiptage benghalensis*); **c:** Venezuelan pokeweed (*Phytolacca rivinoides*); **d:** Fruit of Venezuelan pokeweed (*Phytolacca rivinoides*); **e:** Mikania vine (*Mikania micrantha*); **f:** Leaves and flowers of harungana (*Harungana madagascariensis*).

Over page: **g:** Fruit of pond apple (*Annona glabra*); **h:** Stand of pond apple trees (*Annona glabra*); **i:** Hymenachne (*Hymenachne amplexicaulis*); **j:** Siam weed (*Chromolaena odorata*) **k:** Fruit of Siam weed (*Chromolaena odorata*); **l:** yellow burrhead (*Limnocharis flava*).

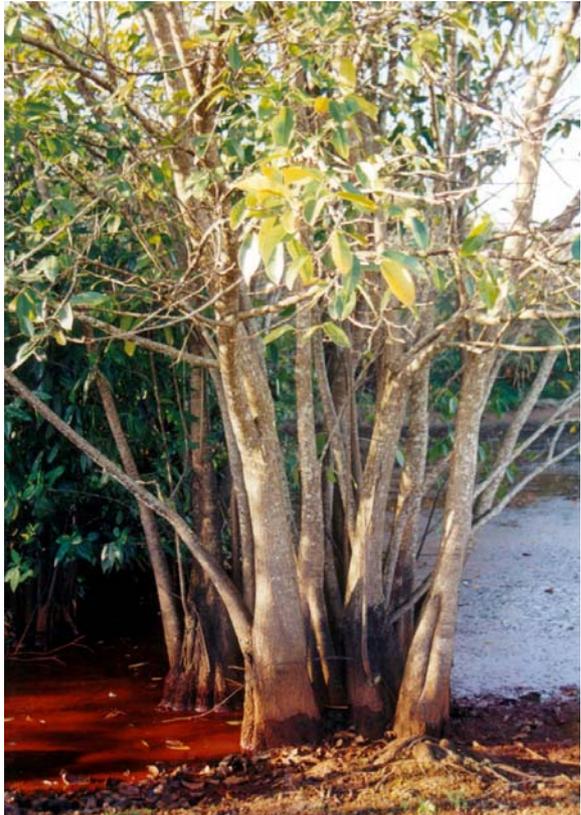
Photographs courtesy of: **a-d** and **l:** Barbara Waterhouse; **e, g** and **h:** Stephen Setter; Photos **f, j** and **k:** Peter van Haaren.



g



j



h



k



i



l

INTRODUCTION

Invasion by alien plant species is an important threatening process for most native Australian plant communities. Alien plants compete directly with native species, and alter the structure, function and composition of the plant communities with consequent effects on higher levels of food webs. Australian rainforests and associated ecosystems are subject to the impacts of invasive plant species (see **Appendix 1**).

Australian rainforests, within which there is considerable structural and floristic variation, are discontinuously spread across coastal and sub-coastal eastern and northern Australia. The distribution of this complex of communities is influenced by climatic, edaphic and topographic factors and by fire regimes. Moreover, large areas of rainforest that existed at the time of the European settlement of Australia have been cleared. Today, an estimated three million hectares of rainforest remain in eastern Australia, this being approximately 70% of the original area. Some types of rainforest have been almost totally cleared with lowland rainforests being most severely depleted.

Rainforests are important for three reasons. They are biologically diverse, they provide critical ecosystem services, and they are of direct economic importance. The Wet Tropics Region of north Queensland, which has a large proportion of Australia's tropical rainforest, is a centre of species richness for plant species and four vertebrate groups (amphibians, reptiles, birds and mammals) and has a high level of endemism for these groups (State of the Environment Advisory Council 1996). Rainforests on the eastern side of the Great Dividing Range in north Queensland also help protect catchments whose rivers flow into the lagoon of the Great Barrier Reef. North Queensland rainforests are also of vital importance to the tourism industries of the region.

To retain these environmental, ecological and economic values, rainforests must be protected from threats that include those posed by alien plant species. However, to date, relatively little research has been done on the weeds of Australian rainforests. These proceedings derive from a workshop organised jointly by two Cooperative Research Centres (CRC), the CRC for Tropical Rainforest Ecology and Management (Rainforest CRC) and the CRC for Australian Weed Management (WEEDS CRC) to begin to address this need. In particular the objectives of the workshop were to:

- (1) Review current knowledge of weeds of Australian rainforests and associated ecosystems.
- (2) Identify important research gaps in relation to weeds of Australian rainforests and associated ecosystems.
- (3) Propose priority research and development (R and D) actions in relation to weed issues for Australian rainforests and associated ecosystems.

The focus of the Rainforest CRC is on the rainforests of Queensland, including both the tropical rainforests of north Queensland, principally located in the Wet Tropics World Heritage Area, and the warm sub-tropical forests of south-east Queensland. The emphasis of this workshop was in keeping with this focus. It did not expressly deal with cool sub-tropical rainforests of northern and central coastal New South Wales, with temperate montane forests further south in NSW, or the warm or cool temperate rainforests of Victoria and Tasmania.

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SECTION 1

Workshop Methodology

WORKSHOP METHODOLOGY

The workshop was held in Cairns, Queensland over a two-day period in November 2002 (see **Appendix 2**). It was attended by 30 individuals with expertise and/or interest in weed and/or rainforest science and management. Together they represented various educational institutions, State and Federal government agencies and other relevant organisations (see **Appendix 3**).

The workshop included three main elements:

1. **A series of five invited papers.** These were presented to workshop participants by relevant authorities in the fields addressed. Written versions of these presentations are provided in Section 2 of this report.
2. **Brief presentations on current research and development activities.** Workshop participants were given 10 minutes to outline any current research and development activities related to weeds of rainforests. Outlines of these presentations are provided in Section 3 of this report. This section of the workshop program was not intended to provide a comprehensive picture of current RandD activities related to weeds of Australian rainforests.
3. **Research and development needs were identified and prioritised.** This was achieved in a three-stage process:
 - (1) A 'brainstorming' approach was used to list research and development needs in relation to weeds of rainforests and associated ecosystems. The list was prepared without consideration of the importance of items that were listed and items were not discussed at this stage.
 - (2) The list prepared during the brainstorming session was analysed. Similar or related items in the list were combined or grouped. Steps (1) and (2) in the process to identify and prioritise R and D issues were completed by all workshop participants in plenary.
 - (3) Five R and D issues that were identified by the group as being of high priority were discussed and developed by five sub-groups of workshop participants. The goal of this step was to outline actions required in relation to the issues.

All material presented at the workshop, along with recommendations derived from it, are summarised in these proceedings.

SECTION 2

Invited Papers

A bioregional perspective of weed invasion of rainforests and associated ecosystems: Focus on the Wet Tropics of north Queensland

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ABSTRACT

Rainforest communities, while arguably resilient to weed invasion when intact, are often naturally and artificially insular within the Australian landscape and thus susceptible to exotic plant incursions. This paper focuses on issues of weed invasion within rainforests and associated ecosystems of the Wet Tropics bioregion of north-east Queensland. More than 510 taxa of exotic (alien) plants have established self-maintaining populations within the bioregion. The paper (i) reports on the trial of a regionally explicit risk assessment system, (ii) explores those functional groups that present the greatest risk to the integrity of rainforests and related communities, and (iii) documents individual species that constitute the greatest threats to maintaining the internationally renowned biological values of Australian wet tropical rainforests. The six highest ranked species comprised *Annona glabra* (a weed of national significance or WONS), the introduced forage legume *Leucaena leucocephala*, the highly invasive *Chromolaena odorata* (a very high priority declared plant), *Miconia calvescens* (similarly classified), *Hymenachne amplexicaulis* (a ponded pasture species now classified as a WONS) and *Sphagnetocola trilobata* (a ground-cover species formerly used as a bank stabiliser but being considered for declaration as a plant requiring control in environmentally sensitive areas under new State legislation). Consideration is also given to weed ingress issues, particularly with respect to the deliberate introduction and promotion of some of the worst environmental weeds, and recommendations for further research are presented.

INTRODUCTION

Rainforest communities are evolutionarily residual mesic communities imbedded in a matrix of open sclerophyll forests and woodlands. They are distributed along almost the entire east coast of Australia with occurrences extending to the Otway Ranges on Victoria's central south coast, to the sheltered gorges of the Kimberley in the northern-most part of W.A., with some extensive areas of western Tasmania supporting cool temperate rainforest. The most significant mainland rainforests occur in the Iron and McIlwraith Ranges of eastern Cape York Peninsula, within the Wet Tropics bioregion between Cooktown to just north of Townsville, along the Central Queensland Coast from the Conway Range to south-west of Eungella (with outliers near Byfield and Shoalwater Bay) and in the Conondale Range to Border Ranges of south-east Queensland and north-eastern N.S.W. It is in the Wet Tropics of north-east Queensland that the most extensive (> 25% of Australia's total; Goosem 2003) rainforests occur, and where, due to their range of intrinsic biological and related values, they have been accorded international significance in the listing of the Wet Tropics World Heritage Area.

Rainforests, by definition, constitute closed canopy vegetation typified by generally high tree densities. This confers a natural resilience to the establishment of plants other than those

that can germinate in the shade of the canopy or that can exploit high light levels occasioned by a tree fall to germinate and grow rapidly within the resultant canopy gap. Despite this, alien plant invasion can and does present major problems for the maintenance of the integrity of these ecosystems. Rapid invasion of similar systems on other islands such as New Guinea (pers. obs.), Guam (Waterhouse, pers. comm.), Tahiti (Csurhes and Edwards, 1998) and Hawaii (Smith, 1989; Teytaud, 1998) provides testimony to the invasion proneness of at least some tropical rainforest communities.

Rainforests are often very naturally insular in the Australian continental context. As well as occurring on the seaward sections of the coastal ranges that intercept rain-bearing air masses, they are found along streams, in gully heads and along the most equable parts of the coastal lowlands. In the lowlands they have been destroyed or heavily fragmented, being replaced or surrounded by sugarcane fields, other cropping systems or residential areas. Therefore, many existing rainforests, including those of the Wet Tropics bioregion, are either naturally or artificially ecosystems with very high perimeter to area ratios, leaving them particularly prone to weed invasion along their extensive edges. Moreover, cyclones are relatively frequent in tropical rainforest areas and are sometimes associated with extensive defoliation and tree-fall. This presents opportunities for alien species to establish beyond forest edges.

The relative paucity of pioneer species within the native rainforest flora (as argued by Goosem 2003), combined with the prominence of animal dispersal vectors (Westcott 2003) provides opportunities for alien species that have naturalised within or close to rainforest environments. This is especially so with respect to species that present fleshy fruits for animal dispersal (zoochory) since animals such as fruit-bats (*Pteropus* spp.) and birds such as fruit-pigeons (e.g. *Ptilinopus* spp. and *Ducula spilorrhoea*), can and do carry fruits long distances from parent plants, thus enhancing the invasion process.

Other factors predispose rainforest environments to weed invasion. Tropical environments (i.e. year-round warm temperatures and generally moist conditions), provide for rapid biogeochemical reactions and long growing seasons that can greatly accelerate the invasion process, along with strong vertical stratification and great opportunities for species packing and niche specialisation. Such factors permit the host environment to accommodate a great range of species, including exotics. These may proliferate and grow, without their natural parasites and predators, at the expense of native species.

Especially in the coastal lowlands, the World Heritage Area embraces areas that are occupied not by rainforest but by more open communities that are frequently associated with rainforests in intricate mosaics. While predominantly rainforest, more than 30% of the World Heritage Area contains non-rainforest communities ranging from montane heathlands to low grassy woodlands. Rainforest associated communities include tall open (wet sclerophyll) forests fringing the western edge of the rainforested massifs of the bioregion. These are mixed forest communities exhibiting a mesic subcanopy or understorey overtopped by sclerophyll emergents (e.g. *Eucalyptus grandis*, *E. resinifera*). They are quite susceptible to invasion by species such as lantana (*Lantana camara*).

Riparian systems and wetlands are also related communities that frequently support a high representation of mesic (rainforest) species. They also have a very high functional significance within the landscape and yet are particularly vulnerable to weed invasion (Rejmánek 1989). In a strongly seasonal climate, floods constitute major disruptions for riparian and near-stream vegetation. This confers a high level of invasibility (Humphries and Stanton 1992). Pysek and Prach (1993) document the high susceptibility of riparian vegetation elsewhere in the world to invasion by exotic plants. Baker (1986) confirms this and other workers such as Décamps *et al.* (1988, 1995) further explore the issue. These authors also report the enhancement of exotic species invasion of such systems when

human-induced disturbances significantly modify the hydrologic regime. In the Mackay district of the Central Queensland coast (often considered a southerly outlier of the Wet Tropics), Batianoff and Franks (1998) specified riparian forest as “the most susceptible vegetation type to environmental weed invasion” and that “disturbed habitats support 95% of the environmental weeds”.

The bioregional approach to landscape management and planning

Thackway and Cressell (1996) devised a system of bioregional subdivisions of Australia that has now gained wide currency as a basic tool in natural resource management and conservation planning. The system delineates natural regions on the basis of coherent biophysical features including climate, landscape and biota that differentiate them from adjacent areas (Figure 1).

This system has been adopted by the State of Queensland to differentiate natural regions and to underpin natural resource management legislation, such as the *Vegetation Management Act (1999)*. Regional ecosystems have been documented for the Wet Tropics Bioregion (Goosem *et al.* 1999) and provide a basis for identifying various levels of endangerment of native ecosystems. This, in turn, may be employed to ascribe levels of risk associated with weed invasion as a threatening process as a statutory component under the *Environmental Protection and Biodiversity Conservation Act (2000)* (EPBC Act) of the Commonwealth Government. Assessments of conservation status, allowing invasion risk to be scored according to communities and/or species at risk from the alien invader (i.e.

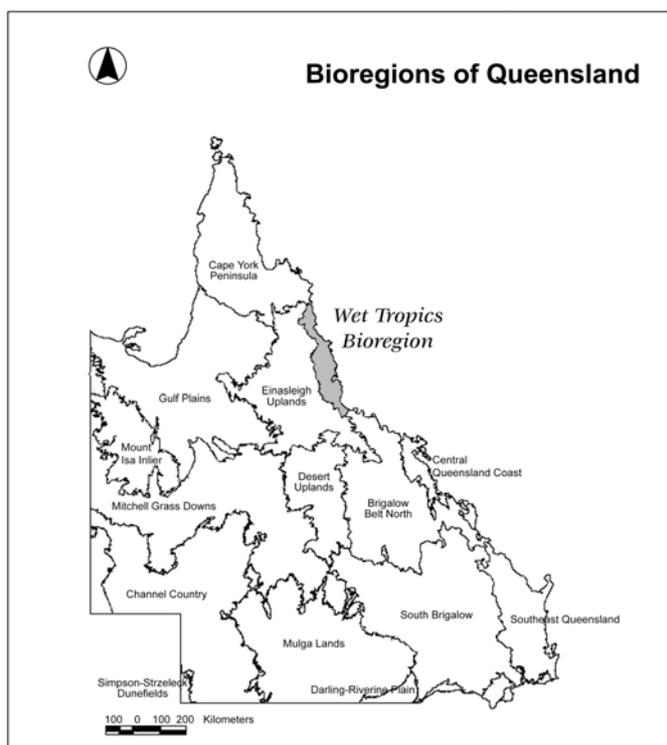


Figure 1. The bioregional subdivision of Queensland showing the location of the Wet Tropics Bioregion.

were drawn from official lists. These are Goosem *et al.* (1999) for communities (Regional Ecosystems) as in the *Vegetation Management Act (1999)* or according to *Wildlife Schedules of the Nature Conservation Act (1994)* for species (Goosem *et al.* 1999).

Values of the host environment at risk

The Wet Tropics bioregion extends from south of Cooktown (15°35'S., 145°20' E.) to just north of Townsville (19°20'S., 146°25' E.). The vascular flora of the Wet Tropics Bioregion is estimated to consist of 4664 species (WTMA 2000) of which almost 25% (1150 species) are endemic. It is the most biodiverse region of the State and is second only to the South-West botanical province of Western Australia in terms of plant species richness on the continent (Boden and Given 1995). Moreover, at a global scale, generic endemism per unit area of the Wet Tropics Bioregion is second only to that New Caledonia (Webb and Tracey 1981, Morat *et al.* 1986). It constitutes one of the world's centres of plant diversity (i.e. Au10; Werren *et al.* 1995).

The region is of particular biological significance since it supports:

- primitive angiosperm families (12 out of 17)
- East Gondwanan plant families, genera, monotypic species
- protoconifers (*Agathis*, *Araucaria*, *Prumnopitys/Sundacarpus*, *Podocarpus*)
- cycads (*Bowenia*, *Cycas*, *Lepidozamia*)
- megaphyllous ferns (*Angiopteris*, *Marattia*)
- tassel 'ferns' (*Lycopodium*, *Huperzia*)
- ancestral forms within a highly biodiverse fauna, and
- many rare/restricted or threatened plants and animals from a range of groups.

In addition, there are many regional ecosystems that are classified as 'endangered' or 'of concern' and at risk from exotic plant invasion. Of particular note, are the freshwater paperbark (*Melaleuca* spp.) swamp communities many of which are being rapidly invaded by pond apple (*Annona glabra*). The integrity of these and related communities within the vegetation mosaic of the coastal lowlands is also reliant upon the maintenance of local hydrological variations which can also be severely disrupted by weed invasion – particularly of ponded pasture species such as para grass (*Brachiaria mutica*) and hymenachne (*Hymenachne amplexicaulis*) which greatly modify the hydraulic conductivity of streams (Bunn *et al.* 1998) as well as out-competing the native graminoids (particularly rare sedges), and of highly flammable African C4 grasses (e.g. *Melinis minutiflorus*, *Panicum maximum* – cf. Wallmer 1994) that carry fires into fire-sensitive rainforest patches.

Naturalised exotic component of the regional flora

Records obtained from the Queensland Herbarium (in Werren, 2001) together with more recent discoveries (Waterhouse, pers. comm.) indicate that over 510 exotic plant species have naturalised within the region (see also **Appendix 1**). This amounts to almost 9.8% of the total flora. This figure is relatively low in comparison to many other parts of Australia and neighbouring countries such as New Zealand (with ca. 45% of its vascular flora comprising naturalised exotics – Landcare Research, 1999). Despite the comparatively low proportion of exotic species in the Wet Tropics region of Queensland, many of these are actually or potentially serious invaders of rainforests and associated ecosystems.

Development of a regionally-explicit weed risk assessment protocol

A weed risk assessment system (RAS) has been designed explicitly to consider alien environmental weed risks to the Wet Tropics bioregion. It incorporated the most appropriate properties of several existing systems, including some currently being developed. The system was specifically designed to take into account weeds documented for tropical areas, inherent invasiveness and significance of systems at risk.

Components of this system include:

- determination of whether a species is a weed elsewhere (particularly in comparable environments) or if it is closely related to proven weeds;
- 'gross invasiveness' (ecesis/establishment in native vegetation, to what extent a species is advantaged by disturbance);
- a range of intrinsic (biological) attributes predisposing species to invasiveness (i.e. reproductive capacity/mode; dispersal capacity; competitive ability and ecesis needs); and
- extrinsic (host environment) factors (important in the context of World Heritage Area management and regional ecosystems/species at risk).

The latter constitutes the basis for 'asset-based' management systems that are employed in other states such as Tasmania (Hall, 1999), South Australia (Virtue, 2001) and elsewhere (e.g. Hiebert and Stubbendieck, 1993). Control feasibility, which is frequently incorporated as a basic element of weed risk assessment systems, was considered secondary to risk

assessment *per se*. Accordingly, it was treated separately as a subsequent management consideration. The RAS allocates relative scores with respect to the above components providing a relative ranking to a maximum of 100, with higher environmental weed risk directly proportional to the numeric score. This will be relevant to the interpretation of scores associated with species listed in tables below.

Results of preliminary screening of the regional RAS

In order to evaluate the proposed RAS all seven alien aquatic species known to have naturalised within the region, and a selected sample of 50 terrestrial species were allocated environmental weed risk scores. Terrestrial taxa comprised those 31 species listed by DNRandM (Land Protection) as requiring research priority. Species were drawn from those identified as priority weed species in the various Local Government Pest Management Plans formulated throughout the region (i.e. from Atherton, Cardwell, Cook, Douglas, Eacham, Herberton, Hinchinbrook, Johnstone, and Mareeba Shires and Cairns City Council LGA) using a MODSS (Multiple Objective Decision-Support System; Bebawi, pers. comm.). Of these, 30 were alien species (including five aquatics), together with itch grass (*Rottboellia cochinchinensis*), that is considered to be a native tropical floodplain species (Godwin, pers. comm.). This sample was supplemented by a further 24 terrestrial species drawn from the list of naturalised exotics chosen to provide a wide representation of various groups [i.e. the single weedy queen palm *Syagrus romanzoffiana*, fruit plants, Navua sedge (*Cyperus aromaticus*), and ornamentals, including peacock fern (*Selaginella vogelii*) - the only lycopod included in the trial]. While this life form group has little bearing on rainforest invasion issues, the RAS was also applied to all seven aquatic macrophytes known to have naturalised within the Wet Tropics at the time of screening. Subsequently, one major and other scattered infestations of an eighth exotic species, *Limnocharis flava*, were discovered (Waterhouse, pers. comm.) in the Cairns region.

What sorts of plants become weeds of rainforests and associated systems?

A great variety of life forms, reproductive systems and places of origin are represented in the exotic flora of rainforests and it is instructive to review such attributes here. The numbers of species and relative proportions of the total exotic component of the regional flora are set out in Table 1. The relative proportions of the different life groups in the alien component are often very different from those of the native flora – for example, there are many more trees and fewer grasses, shrubs and forbs in the native assemblage.

Table 1. Wet Tropics weed species sorted according to life form (after Goosem, unpublished data).

Life form	No. of species	% total exotics
ferns	6	1.2
grasses	79	16.1
sedges	9	1.8
forbs	188	38.4
semi-aquatic macrophytes	6	1.2
aquatic macrophytes	9	1.8
vines	72	14.7
shrubs	74	15.1
trees	47	9.6

The prevalence of invasive vines in rainforests and associated communities

The status and impact of invasive species within Australian wet tropical and sub-tropical rainforests was explicitly addressed by ANPWS (1991). In this publication, it was emphasised that exotic vines are among the most aggressive invaders of these communities since they are:

- a natural growth form of rainforests, and
- well represented in such systems, and particularly so in sub-tropical rainforests.

Of 19 exotic species that are considered particularly invasive of the sub-tropical rainforests of south-eastern Queensland and northern N.S.W., 70 per cent are vines. Examples of what is considered to be the “most destructive life form” (ANPWS, 1991) of rainforests include cats-claw creeper (*Macfadyena unguis-cati*), Madeira vine (*Anredera cordifolia*), balloon vine (*Cardiospermum grandiflorum*), mile-a-minute (*Ipomoea cairica*), morning glory (*I. indica*) and the bridal creepers/asparagus ferns (*Protoasparagus africanus*, *P. plumosus*, *P. densiflorus*). All except for the bridal creepers also invade tropical rainforests, save for the fact that the balloon vine is represented in the tropics by its congener, *C. halacacabum*. Additional species posing a significant environmental weed threat include the trumpet vines (*Thunbergia grandiflora*, *T. laurifolia*), turbine vine (*Turbina corymbosa*), Brazilian nightshade (*Solanum seaforthianum*) and mikania (*Mikania micrantha*). Most of these were introduced as ornamental plants, although mikania appears to have been imported for its medicinal properties. They also originate from various locations, although those originating from the Indian subcontinent and south-east Asia are disproportionately represented.

Results for exotic vines that were screened using the Wet Tropics RAS (Table 2) indicate that:

- there is a moderate representation in the exotic component of the regional flora (14.7%) but a relatively high representation in the sample screened (21.4%) suggesting the recognition of greater relative impacts associated with this life form;
- the sample yielded an intermediate to high mean score (44.3) but with large range (20-76) indicative of a range of impacts that extend to the very high impact categories; and
- there is a need for other predictors within this very variable life form group which is particularly invasive in riparian zones.

Table 2. Results of screening exotic vines of the Wet Tropics region using RAS.

* Mean score of all species.

% total exotics	Species	% sample	Score
	<i>Thunbergia</i> spp.		76
	<i>Mikania micrantha</i>		74
	<i>Turbina corymbosa</i>		68
	<i>Solanum seaforthianum</i>		60
	<i>Syngonium podophyllum</i>		50
	<i>Momordica charantia</i>		42
	<i>Passiflora foetida</i>		40
	<i>Allamanda cathartica</i>		38
	<i>Aristolochia ringens</i>		38
	<i>Cardiospermum halicacabum</i>		20
	<i>Macroptilium atropurpureum</i>		18
	<i>Clitoria ternatea</i>		8
14.7	All vines	21.4	44.3*

Woody invasives of tropical systems

In contrast, Binggeli *et al.* (1998), in a major compendium and review of invasive woody plants in the world's tropics generally, stress the prevalence of woody life forms. These authors emphasise taxonomic, rather than the functional affinities or association with particular host ecosystems, of these woody invasives. They note that the Rosaceae and legume families collectively, and to a lesser extent the Pinaceae and Myrtaceae, contain a

large number of invasive woody plants, while families such as the Asteraceae, Myrtaceae and Melastomaceae have a number of highly invasive species but few possibly/potentially invasive species and are chiefly tropical/sub-tropical species. They further note that irrespective of the degree of invasiveness, the Mimosaceae has contributed the largest number of invasive species in the tropics. Representatives of this family are more likely to be invasive in open communities rather than rainforest *per se*, although there are some exceptions as in the case of *Leucaena leucocephala* (and in the central Queensland coast bioregion mesic riparian forests, *Dalbergia sissoo*) that invades moist forest and coastal wetland communities.

Details of the trees and shrubs represented within the regionally naturalised flora and those scored using the Wet Tropics RAS are set out in Table 3. A significant proportion of shrubs, but not trees, are representatives of the Asteraceae. Species of Myrtaceae are also represented in both components of the woody naturalised flora. The invasive trees, however, are taxonomically diverse, with single species representation from groups as diverse as the Arecaceae (i.e. queen palm, *Syagrus romanzoffiana*), Anacardiaceae (mango, *Mangifera indica*), Annonaceae (pond apple, *Annona glabra*), Bignoniaceae (cucumber tree, *Parmentiera aculeata*) through to members of the legume families (*Leucaena leucocephala*, *Bauhinia monandra*), Melastomataceae (*Miconia calvescens*) and Myrtaceae (*Psidium guajava*).

Table 3. Results of screening woody species of the Wet Tropics region using RAS.

* Mean score of all species.

Life form	% total exotics	Species	% sample	Score
Trees		<i>Annona glabra</i>		90
		<i>Leucaena leucocephala</i>		88
		<i>Miconia calvescens</i>		80
		<i>Psidium guajava</i>		78
		<i>Mangifera indica</i>		64
		<i>Spathodea campanulate</i>		62
		<i>Parmentiera aculeata</i>		62
		<i>Azadirachta indica</i>		58
		<i>Harungana madagascariensis</i>		56
		<i>Bauhinia monandra</i>		46
		<i>Syagrus romanzoffiana</i>		44
		<i>Muntingia calabura</i>		40
		<i>Persea americana</i>		16
		9.6	All trees	17.9	60.4*
Shrubs		<i>Chromolaena odorata</i>		82
		<i>Ageratina riparia</i>		64
		<i>Tithonia diversifolia</i>		62
		<i>Eupatorium catarium</i>		58
		<i>Senna obtusifolia</i>		50
		<i>Duranta erecta</i>		48
		<i>Hyptis</i> spp.		46
		<i>Murraya paniculata</i> cv <i>exotica</i>		40
		<i>Eugenia uniflora</i>		34
	15.1	All shrubs	16.1	53.8*

Trees are moderately well represented in the exotic flora but over-represented within the sample processed (Table 3), suggesting a greater invasive potential. The high mean score is also of concern, although the range is high (from 16-90) but is distorted by the low score of avocado (*Persea americana*) and a more representative range would be from 40-90. It is notable that the two highest scores achieved through application of the RAS were associated with trees. Camphor laurel (*Cinnamomum camphora*) is highly invasive in sub-

tropical rainforests of northern N.S.W. and south-east Queensland (ANPWS 1991). It features as an invader again in the Wet Tropics region where it is spread widely by birds in the cooler parts of the Atherton Tableland.

Shrubs were also among the most invasive types of plants in sub-tropical rainforests in eastern N.S.W. and the Border Ranges of Queensland (ANPWS 1991). Privets (*Ligustrum lucidum*, *L. sinsense*), mist-flower (*Ageratina riparia*) and Crofton weed (*A. adenophora*) are particularly invasive shrubs in these systems. All but the latter species are also invasive of wet tropical rainforests.

Shrubs account for approximately 15% of the regionally naturalised exotic flora and a comparable proportion of the sample screened. The mean score is slightly less than that achieved by the trees within the sample, but at 53.1 and with a range from 34 to 82, there is the strong suggestion of high invasion ability within this group. In some cases this is directly confirmed by observation. Examples include the aggressive spread and persistence of Siam weed (*Chromolaena odorata*), despite intensive control efforts as part of SWEEP (Strategic Weed Eradication and Education Program), and the extent of infestations of this species, along with leuceana and tree pepper (*Piper aduncum*), in comparable environments in Papua New Guinea's northern lowlands (pers. obs.)

The problems of introduced grasses and other graminoids

Non-woody plants are also well represented within the regionally naturalised flora with the grasses and sedges together contributing just under one-fifth of the total number of exotic species (Table 4). This may well be a function of the forage value of even the more invasive of these rather than their comparatively low invasive capacity. There may have been a reticence to include these amongst the Local Government Pest Management Plan lists that contributed the bulk of species that were screened explaining why they are under-represented in the sample. This is supported by the highest mean invasiveness risk score obtained of 66.5 for this rather small sample as compared with that for trees (60.4), shrubs (53.8) and vines (44.3).

Primarily grasses are weeds of rainforest margins and of disturbance corridors such as roads or power-line easements that pass through rainforest blocks. They also proliferate along riparian zones where there are edge effects and where repeated disturbance advantages establishment of certain species. Grasses have the capacity to greatly increase fuel loads thus rendering what are generally fire-sensitive communities more fire-prone. Those that are semi-aquatic also impair ecosystem function, particularly by reducing the hydraulic conductivity of waterways through direct physical blockage and by facilitating sedimentation within them. In many cases they out-compete native species and eventually replace them. Exotic sedges can occur in various parts of the landscape including within wetland sedge swards, along streams, and amongst native grassy understoreys. It is likely, however, that greater risks of invasion by exotic graminoids confront the more open systems rather than rainforest systems.

Table 4. Results of screening graminoid species of the Wet Tropics region using RAS.

*Mean score of all species.

Life form	% total exotics	Species	% sample	Score
Grasses		<i>Hymenachne amplexicaulis</i>		80
		<i>Brachiaria mutica</i>		74
		<i>Panicum maximum</i>		72
		<i>Andropogon gyanus</i>		40
	16.1	All grasses	7.1	66.5*
Sedges	1.8	<i>Cyperus aromaticus</i>	1.8	40

Invasiveness potential of other life forms

Forbs constitute a comparatively high proportion (almost four-fifths; Table 1) of the regionally naturalised exotic flora yet they are only modestly represented (at 12.5% of species) within the sample screened (Table 5). In this case, this may suggest that this group constitutes less of a risk when compared with other life forms. Upon closer informed inspection of Table 5 it can be observed that the scores range greatly from Singapore daisy (*Sphagneticola trilobata*) at 82 to the inconspicuous and relatively benign spider flower (*Cleome aculeata*) at 6. The mean score is nonetheless moderate at 33.3. This can be interpreted as indicating that some forbs such as the aggressive and allelopathic Singapore daisy can and do constitute environmental weed risks, while there are a host of others that, perhaps by virtue of their modest dimensions and/or membership of a subordinate synusium or stratum, are innocuous exotics, constituting only a mild form of biological contamination within conservation areas. Whatever, this group is large, diverse and will require more investigation at the individual species level.

Table 5. Aspects of the forb/herb component of the regional weed flora screened using the RAS.

*Mean score of all species.

% total exotics	Species	% sample	Score
	<i>Sphagneticola trilobata</i>		82
	<i>Stachytarpheta</i> spp.		54
	<i>Sansevieria trifasciata</i>		48
	<i>Mimosa diplotricha</i> ,		44
	<i>Elephantopus mollis</i>		38
	<i>Salvia coccinea</i>		12
	<i>Ageratum conyzoides</i>		8
	<i>Euphorbia heterophylla</i>		8
	<i>Cleome aculeata</i>		6
38.4	All species	16.1	33.3

SUMMARY AND PROGNOSIS

About 10% of the Wet Tropics regional vascular flora consists of exotic species that have demonstrated an ability to naturalise without the advantages provided by major human disturbance or cultivation. While this is a relatively low proportion compared with other regions of Australia and very low in comparison to those of tropical rainforest island countries such as Tahiti, Hawaii and Papua New Guinea, it constitutes a major threat to the maintenance of the World Heritage Area of Queensland's Wet Tropics. This threat to the maintenance of global biodiversity is comparable to that due to global warming and habitat loss associated with forest clearing (Lovëi 1999).

A range of life forms presently form significant, often rampant, infestations within the rainforests and associated systems of the region. These comprise:

- vines such as blue trumpet vine, passionfruits (*Passiflora* spp.) and turbine vine (*Turbina corymbosa*);
- trees such as African tulip (*Spathodea campanulata*), cucumber tree and mango along with small trees/shrubs such as Siam weed, mist-flower, praxelis (*Eupatorium catarium*) and Japanese sunflower (*Tithonia diversifolia*);
- grasses such as Guinea grass, parã grass and hymenachne;
- forbs/herbs such as Singapore daisy, snakeweed (*Stachytarpheta* spp.), mother-in-law's tongue (*Sansevieria trifasciata*) and giant sensitive plant (*Mimosa diplotricha*).

Some of these are the result of accidental introductions but most are not. Many have been deliberately introduced as ornamentals (e.g. lantana, Japanese sunflower), others were deliberately introduced for cattle fodder (e.g. leucaena, many other mimosaceous shrubs

plus a host of C4 grasses and pasture legumes) while others were imported as timber species (e.g. camphor laurel). Continual promotion of the use of such plants (DPI 1999), along with the future introduction of potentially invasive species bears with it great risks.

A sample of naturalised plants within the Wet Tropics has been screened using a RAS explicitly designed to accommodate risks posed to native communities/ecosystems of the region. Results produced are plausible. They include:

1. confirmation of risk associated with plants with already demonstrated capacities to cause major modification to species richness, abundance or ecosystem function (cf. Waterhouse and Mitchell 1998; Fondation d'Entreprise Total 2001) and
2. identification of other species in early phases of invasion that are potential threats or 'sleeper weeds' (Groves 1999).

Lastly, further work is required to enhance our predictive capability so as to:

- identify plants that are already invasive in neighbouring areas but which have not yet entered Australia; this will help ensure quarantine vigilance to preclude entry and/or facilitate early detection and eradication;
- provide additional autecological information on known weeds in order to refine risk assessment and/or to enhance control measures;
- identify plants that are already present but which have not yet invaded ('sleeper' weeds);
- establish whether individual taxa can become agrestal weeds (i.e. weeds of agriculture versus environmental weeds), ruderals (i.e. those found in a range of human-modified and natural systems that are dependent on disturbance) or 'swampers'/'transformers' (i.e. those environmental weeds that have the capacity to replace native species and/or totally modify the functioning of native systems);
- determine the precise distributional extent of naturalised exotics within the region;
- establish relative risk of demonstrated invasive exotic species that occur as restricted and/or contained infestations; and
- understand the relative risk of widely distributed invasives which can allow effective decision-making with respect to control priorities.

A concerted, appropriately resourced effort is needed to institute strategic weed management. Effective preventative measures are required to guard against further introduction and spread of invasive exotic species. If these steps are not taken, the values for which the region's rainforests and associated communities, along with Australia's international reputation as a signatory nation to the World Heritage Convention, will be distinctly imperilled.

The ecology of seed dispersal in rainforests: implications for weed spread and a framework for weed management

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INTRODUCTION

Of the many ecosystem processes that influence the ability of weeds to establish and persist in rainforest, seed dispersal is of particular importance. Here we provide a brief outline of the ecology of seed dispersal in rainforest. We highlight how seed dispersal in these forests differs from seed dispersal in other habitat types and consider how this might influence the spread and control of weeds. We provide an overview of a framework for describing seed dispersal in complex ecosystems such as rainforests, and then illustrate how this framework could be applied to the development of weed management strategies.

Seed Dispersal

What is seed dispersal? Seed dispersal is the process by which a seed moves from its maternal plant to the site where it establishes or dies. The distance that individual seeds disperse can vary dramatically with some moving no further than directly beneath the parent plant while others may move hundreds or even 1000s of kilometres (van der Pijl 1982). The spatial pattern in which a plant's seed crop is distributed around it is termed its "seed shadow" and is depicted as the proportion of seeds that are moved any particular distance (e.g. Figures 1C and 2).

Plants have evolved a wide variety of seed dispersal strategies, the mechanisms of which range from the sublimely simple to the surprising and complex. The major seed dispersal mechanisms include dispersal by: (i) gravity, where seeds or fruit simply fall to the ground; (ii) wind, where seeds are removed from the plant by wind, (iii) water, where seeds fall into water and move away on currents; (iv) rain, where the impact of raindrops on the fruiting body catapults seeds away from the plant; (v) explosion, where air or mechanical pressure from within the plant drives the seed away from the plant, and (vi) animal dispersal, where fruit or seeds are carried away by animals, either internally or externally. These different dispersal mechanisms tend to be associated with different plant taxa and particular habitat types. However, within any particular ecosystem a variety of dispersal syndromes will be encountered (van der Pijl 1982).

Seed dispersal processes in rainforest

While the full range of seed dispersal mechanisms are represented in rainforest, animal-dispersed species often represent the majority of plant species, e.g. 89% Colombia (Hilty 1980), 75-90% Gabon (White 1994), 72% Panama (Foster 1982), 75 –95 %, Wet Tropics Region of Australia (Webb and Tracey 1981). The reasons underlying this dominance remain unresolved and are almost certainly a response to multiple evolutionary drivers. Irrespective of its causes, this dominance of fleshy fruiting plant species has had significant consequences for evolutionary and ecological processes in these communities.

Since most fleshy-fruited plants rely on vertebrates for their dispersal, it is not surprising that over evolutionary time vertebrates have responded to their abundance. Specialisation on

fruit has resulted in evolution at both physiological and morphological levels, e.g. the evolution of colour vision in New World primates (SurrIDGE and Mundy 2001). Such specialisation has underpinned major radiations in vertebrate taxa throughout humid tropical regions of the world (Snow 1981). Examples of these radiations include the cotingas and manakins of the Neotropics, the hornbills of Asia and Africa, the bowerbirds and birds-of-paradise of Australia and New Guinea, and the monkeys and apes of both the Old and New Worlds. The response to fruit resources has not been just evolutionary. In many tropical forests frugivorous vertebrates represent the majority of vertebrate biomass as well as species richness (Terborgh 1986, Gautier-Hion and Michaloud 1989).

The process of seed dispersal is of fundamental importance to plant communities and impacts at every ecological level (Levey *et al.* 2002; Wang and Smith 2002). For individual plants, it determines the micro-site and conditions they experience during life, a significant influence on survival and performance. Seed dispersal is also influential in plant population level processes such as immigration, emigration and population growth, and contributes to determining plant population genetic structure and diversity. Dispersal contributes to the determination of the dispersed species' range, its distribution, genetic structure and evolutionary trajectory. Finally, seed dispersal plays a fundamental role in determining community diversity, structure and trajectories (Harms *et al.* 2000). Nearly all of these effects are exerted through the role that seed dispersal plays in determining the "recruitment surface" for subsequent generations.

Rainforest seed dispersal and weeds

The nature of seed dispersal processes in humid tropical forests will impact on the kinds of weeds that are likely to be successful in these ecosystems, their patterns of spread and management strategies used against them. Survival to establishment in these forest types often requires significant nutrient stores, favouring fleshy fruits and large seeds. Weeds with such diaspores will find a large suite of dispersers eager to consume and move their seeds, potentially over very large distances and against ecological and physical gradients that might not otherwise be overcome. This is not to suggest that weeds utilising other dispersal modes will not be successful; they can be and they are. Instead it is to indicate that in tropical humid forests there will be a shift in emphasis towards fleshy-fruited weeds.

This shift in emphasis to animal-dispersed weeds has implications for the patterns of weed spread and for the management strategies used to combat and contain both agricultural and environmental weeds. The development of an understanding of the existing dispersal processes into which weed species insert themselves will provide the advantage of a framework for the development of weed control strategies. In the following sections we describe work in which we are currently developing a predictive model of seed dispersal processes within tropical humid forests and provide an illustration of how this framework can be used in weed management.

Describing community-wide patterns of seed dispersal

Our research sets out to describe seed dispersal in rainforests and adjacent agricultural landscapes, at scales appropriate to the process, i.e. the community scale (all plants and all vertebrates) and the landscape scale. While funding cycles have not permitted us to conduct the study on the appropriate temporal scales, we have designed the study to enable us to use modelling to extrapolate to times scales of hundreds of years.

In our framework we simplify seed dispersal to a process with a several components. We assume that the distance a seed is dispersed is a function of (i) which animals process it, (ii) how long the animal retains it, and, (iii) how far the animal travels during that time. The seed shadow of a tree is the sum of the interactions between its seeds and their dispersers,

making relative rates of removal by dispersers important. The spatial pattern of seed rain for the entire community is the sum of the seed shadows of each tree.

In the Wet Tropics Region, depending on the definitions used, there are about 45 dispersers (Dennis 1997) and 1500 fleshy-fruited plants (Hyland *et al.* 1999). There are too many potential interactions to document them individually. Consequently we simplify the matrix of interactions to a set of 8-10 disperser functional groups (DFGs) and 6 fruit functional groups (FFGs). DFGs are defined on the traits that influence the kind of dispersal that frugivores provide, e.g. handling and scale of movement. FFGs are defined using the traits that influence which frugivores eat them, e.g. size and structural defences.

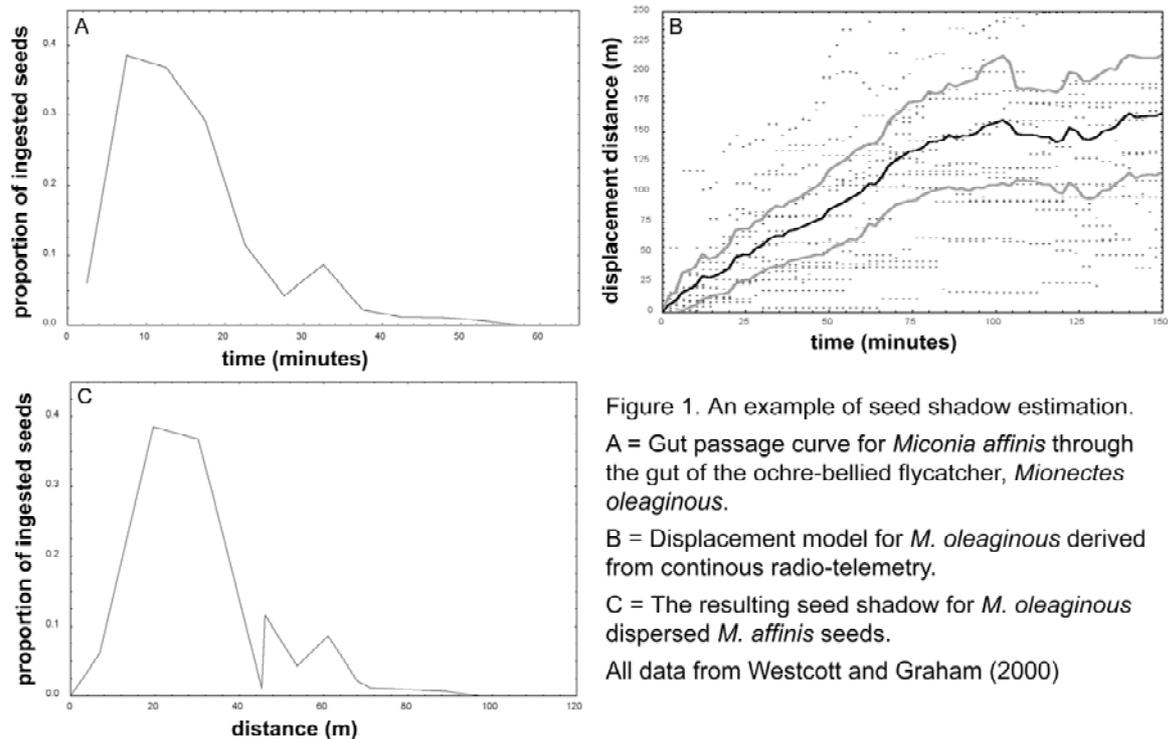


Figure 1. An example of seed shadow estimation.

A = Gut passage curve for *Miconia affinis* through the gut of the ochre-bellied flycatcher, *Mionectes oleaginous*.

B = Displacement model for *M. oleaginous* derived from continuous radio-telemetry.

C = The resulting seed shadow for *M. oleaginous* dispersed *M. affinis* seeds.

All data from Westcott and Graham (2000)

The next phase of the work is to describe the seed shadows produced for each FFG x DFG interaction. This is done in two phases. In the first, gut passage times through each DFG are obtained for representatives of each FFG in captive feeding trials. These data are expressed as the proportion of viable seeds excreted as a function of time since ingestion (Figure 1A). In the second phase, continuous radio-telemetry is used to produce displacement models for each DFG. The data produced are expressed as distance moved from a randomly chosen point in space as a function of time (Figure 1B). Combining these two curves gives us the seed shadow for the DFG x FFG interaction (Figure 1C).

To construct a complete seed shadow for a particular FFG requires combining the seed shadows for each of the DFGs relevant to that FFG. The relevant DFG and the relative proportion of the crop they remove are determined during observations at fruiting trees of each FFG.

The landscape context in which a tree occurs is a particularly important consideration in estimating its seed shadow. Because dispersers respond differently to changes in landscape structure, such as fragmentation of native vegetation into isolated patches surrounded by agricultural land (Warburton 1997), different suites of dispersers will visit trees in fragmented and continuous forests (Table 1). These differences may also result in changes in the relative proportion of the crop removed by each DFG in different landscape contexts. Fragmentation may also alter the pattern and scale of disperser movement. Consequently,

both DFG movement patterns and FFG utilisation must to be examined in the relevant landscape contexts.

Table 1. Comparison of the frugivores feeding at two rainforest trees in different landscape contexts, rainforest fragments and continuous rainforest

<i>Elaeocarpus angustifolius</i>		<i>Polyscias murrayi</i>	
Fragment	Continuous	Fragment	Continuous
Wompoo pigeon	Wompoo	Victoria's riflebird	Victoria's riflebird
Spotted catbird	Spotted catbird	Lewin's honeyeater	Lewin's honeyeater
Tooth-billed bowerbird	Tooth-billed bowerbird	Silvereye	Satin bowerbird
Lewin's honeyeater	Lewin's honeyeater		Tooth-billed bowerbird
Victoria's riflebird	Satin bowerbird		Spotted catbird
Pied currawong	Topknot pigeon		Brown cuckoo-dove
Satin bowerbird	Rose-crown fruit-dove		Bridled honeyeater
	Yellow-eyed cuckoo-shrike		Sulphur-crested cockatoo
	Brown cuckoo-dove		Emerald dove

The process of data collection outlined above provides a description of seed dispersal at community and landscape scales. It also provides the basic parameters necessary for spatially-explicit modelling of seed dispersal at a landscape scale and on appropriate time-frames on real or simulated landscapes. Because the spread of a particular weed is simply a specific case of seed dispersal, this modelling can be used to predict patterns of spread and to optimise management actions. To do this, the weed's characteristics can be used to assign it to a FFG and from this a seed shadow can be estimated.

Estimating scale of vertebrate dispersal: a case study of Pond Apple

Pond apple (*Annona glabra*) is a woody weed that has been declared a Weed of National Significance (Agriculture and Resource Management Council 2000). It is one of the most threatening environmental weeds of the Wet Tropics Region (Werren 2001). With buoyant fruit and seeds, it is well adapted to water dispersal and this dispersal mode, particularly on ocean currents, has been assumed by managers to be the critical one. However, pond apple produces a fleshy fruit that is attractive to vertebrate frugivores, some of which are potential dispersers. Because both the fruit and the seeds are relatively large and the flesh is soft, most dispersers readily separate the flesh from seeds prior to swallowing them. Two species, the southern cassowary, *Casuarius casuarius*, and the feral pig, *Sus scrofa*, consume large quantities of pond apple and excrete whole seeds, 100% and 23% of those ingested respectively (Setter *et al.* 2002).

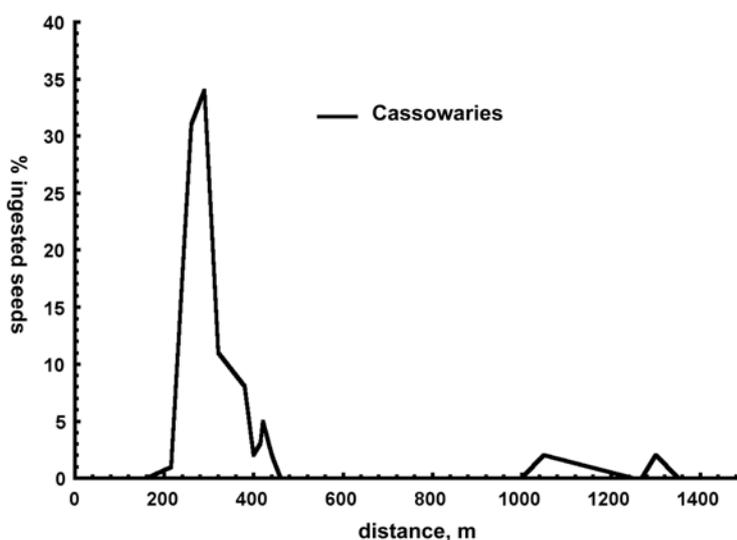


Figure 2. Seed shadow produced by cassowaries for pond apple (*Annona glabra*)

Combining data on gut passage of pond apple seeds through cassowaries (Setter *et al.* 2002, Setter *et al.*, in prep.) with cassowary movement data (Westcott and Bradford, in prep) provides an estimate of the seed shadow produced by the cassowary (Figure 2). This

indicates that cassowaries are capable of providing long distance dispersal to pond apple. Other species that consume pond apple, such as musky rat-kangaroos and native rodents which carry and bury seeds or flying foxes that may carry entire fruit, do so over only short distances. Because cassowaries consume large quantities of pond apple (mean # seeds/dung = 200, range 3-842), all of which are intact (Setter *et al.* 2002, Setter *et al.* in prep.) they are likely to be the most effective dispersers of pond apple. Most importantly for management, they will disperse seeds both upstream and between drainages. This has significant consequences for the design of control strategies as it means that the spread of pond apple will not necessarily simply follow currents to the sea and then north along the coast (Setter *et al.* 2002, Setter *et al.* in prep.).

SUMMARY AND CONCLUSIONS

A solid understanding of seed dispersal processes in rainforest provides a number of advantages in the design and implementation of control strategies for both agricultural and environmental weeds. First, the ability to classify weeds into fruit functional groups allows prediction of probable dispersers and disperser functional groups for that weed. Combined with data on patterns of movement of the relevant DFG and their processing times, this information also allows for estimation of seed shadows and the consequences for this of landscape structure. Combining a functional group approach with an understanding of seed shadows opens the door for spatially explicit modelling of weed spread and so for optimising weed control measures. The approach outlined above will help address a variety of questions relating to the spread of both agricultural and environmental vertebrate-dispersed weeds, such as: How far should searches be conducted for escaped weeds? What are potential rates of spread for a weed species? What are the types of landscapes dispersal will occur across? Where in the landscape will control efforts be most effective?

ACKNOWLEDGEMENTS

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Landscape processes relevant to weed invasion in Australian rainforests and associated ecosystems

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ABSTRACT

Environmental weed research within rainforest landscapes is particularly important because rainforests often contain a highly endemic and diverse flora that could be especially sensitive to weed invasions.

Although the Wet Tropics is a very small biogeographic region, it is characterised by a wide range of climates (encompassing tropical, sub-tropical, temperate and monsoon climatic zones), a wide range of geologies and soil types and a long and favourable growing season, making the region susceptible to invasion by a very broad range of weeds originating from a large range of climate zones and environmental conditions.

To better understand the susceptibility of rainforest landscapes to invasion it is necessary to understand the role of land use and the spatial arrangement of disturbance (landscape context) in determining patterns of distribution of weed species. It is also important to understand the mechanisms of weed dispersal and to assess the degree of percolation of weed species into more pristine environments.

Land use, disturbance and climate are driving factors in weed invasion, and most weeds in rainforest areas are confined to parts of the landscape that are disturbed by humans. Pristine rainforest environments however, are not immune from the threat of weed invasion. Community services corridors, such as power-line clearings and roads, represent the primary conduits for the introduction of weed species into protected areas and for flow of weed propagules through these landscapes. Fortunately, most generalist weed species are incapable of colonising less disturbed rainforest environments and confine themselves to the gross disturbance footprint of the clearing. Even so, this network of linear community infrastructure may still serve as the source of propagules that progressively percolate into disturbed rainforest edges or are liberated into interiors of pristine rainforest following natural disturbance events. The rapidly colonising weed species along these networks of linear infrastructure could also potentially act as vectors and reservoirs of plant diseases and insect pests that could affect pristine rainforest areas.

Global change phenomena, such as climate change, present a formidable research and management challenge. The range and seasonality of rapidly changing environmental factors such as temperature and precipitation; the intensity and frequency of severe episodic events such as cyclones, storms, floods, drought and fires; and the demographic, economic and social pressures related to human activities are likely to interact in ways that will greatly favour the introduction, naturalisation, spread, establishment and impact of weeds within rainforest environments.

INTRODUCTION

Undisturbed rainforest is generally resistant to invasion by weeds and large stands of rainforest are generally devoid of introduced plants except around their perimeters. Unfortunately, rainforest regeneration cycles are driven by disturbance that creates gaps in the canopy. At any point in time, rainforests are a mosaic of patches at different stages of maturity. The nature of the stage in the cycle (and the inherent susceptibility of rainforest to weed invasion) depends on the size of the gap and the environment within it, which in turn is related to the intensity, scale, and frequency of disturbance.

Although recovery of rainforest following disturbance is usually treated as an example of secondary succession, and although various categorisations of species into successional response groups have been proposed, there are basically only two qualitatively distinct groups – pioneer and non-pioneer species. Pioneers have seeds that germinate only in gaps large enough for sunlight to reach the ground for at least part of the day, and require high irradiance levels for seedling establishment and growth. Seedlings and young plants of these species are never found under a closed canopy. This behaviour contrasts dramatically with non-pioneer species that have seeds which can germinate and whose seedlings can establish in shade. Some are capable of persisting in shade for prolonged periods, although most require alleviation of shade conditions through gap formation for their longer-term survival. Non-pioneer species are not restricted to below a closed canopy and may co-exist with pioneers in large gaps. Within both groups there is variation in the response of species to a number of environmental factors. However, pioneer and non-pioneer species are distinguished absolutely on the basis of their germination and seedling characteristics. Another distinguishing characteristic is that pioneers tend to form seed banks whereas non-pioneers form seedling banks.

Similarly, there are two basic ecological categories of rainforest weeds: those that behave like rainforest pioneers and the smaller group that act like non-pioneers.

There are only about 20 species of native rainforest pioneer trees in the Wet Tropics, most of which have very wide geographic distributions. The low number of pioneer tree species is a general feature of tropical rainforests which are generally very resilient to small scale natural disturbances but are not well equipped to handle large scale artificial disturbances, having a generally impoverished pioneer flora that is able to respond.

Two other quintessential characteristics of rainforests that are relevant to the movement of weed species across rainforest landscapes are:

- the high proportion of native fleshy fruited plant species reliant on animals for dispersal; and
- the general lack of wind below intact rainforest canopies.

These features have important implications for both the mechanisms and patterns of weed invasion of rainforest landscapes. An understanding of the behaviour of the native and feral seed dispersal guilds and their spatial and temporal interactions with the disturbed and intact parts of the landscape is important. Similarly, it is important to gain an understanding of how air movement patterns and intensities are influenced by the configuration and intensity of clearing. It is especially important to understand how air movement along cleared linear infrastructure corridors through rainforest affects the spread of wind dispersed weeds (and perhaps the flight patterns of birds and bats).

The relative susceptibility of rainforest landscapes to invasion by weed species is therefore not only closely aligned to the pattern, extent, frequency and history of rainforest disturbance and land use but also to the demographics and behaviour of rainforest seed dispersers.

The discussion that follows examines some of these issues at three spatial scales:

- continental scale (land area of Australia – 768,230,000 ha)
- regional scale (Wet Tropics biogeographic region – 1,976,000 ha)
- sub-regional scale (Wet Tropics of Queensland World Heritage Area (WHA) – 894,000 ha)

The general landscape processes that will be briefly described relate to:

- landscape pattern (clearing, fragmentation)
- landscape alterations (land use)
- landscape health (modified forest systems)
- global influences (climate change).

Australian Rainforest Distribution – Present and Past

Only about 20% or 156 million hectares of Australia has a native forest cover of which just over 3.0 million hectares is rainforest (Table 1). Rainforests are located in 31 of Australia's 80 IBRA biogeographic regions (Thackway and Cresswell 1995).

Table 1. Area of present day and estimated pre-European rainforest in Australia (km²).

	State						Continent	Region
	Vic	WA	NSW	NT	Tas	Qld	Australia	Wet Tropics
Present	407	16	2218	977	7055	19558	30231	8340
Pre-European	445	18	4836	978	7161	30055	43493	10974
Percent remaining	91.5	88.9	45.9	99.9	98.5	65.1	69.5	76

Source: National Land and Water Resources Audit 2001; WTMA 2002

The largest area of remaining rainforest in Australia (27.6% of the total) is located in the Wet Tropics region where most of the larger blocks are contained within the boundaries of the World Heritage Area (Table 2).

Table 2. Percent contribution to Australia's present day extent of rainforest.

ACT	SA	Vic	WA	State				Continent Australia	Region Wet Tropics	Subregion WHA
				NSW	NT	Tas	Qld			
0	0	13%	0.1%	7.3%	3.2%	23.3%	64.7%	100%	27.6%	22.1and

Source: National Land and Water Resources Audit 2001; WTMA 2002

In Australia, rainforests are scattered across cool temperate, warm temperate, sub-tropical and tropical areas of Queensland, New South Wales, Victoria and Tasmania with small patches also found in north coastal Northern Territory and the Kimberley region of Western Australia. Rainforests occur from sea level to high altitudes, normally within 100 km of the coast and normally in areas receiving more than 1200 mm of rainfall or else within climatic and fire proof refuges. Drier, semi-deciduous vine thickets are also found in the Brigalow Belt and monsoonal vine thickets are scattered over parts of the seasonal tropics of northern Australia (Figure 1).

It is estimated that about 30% (approximately 13,000 km²) of the pre-European extent of rainforests has been cleared (National Land and Water Resources Audit 2001). Most accessible lowland and tableland rainforests have been cleared and/or have become highly fragmented, while most remaining larger blocks of rainforest are on steep or rugged terrains. Historically, rainforests were among the earliest Australian native vegetation communities to be exploited for timber and agriculture. Examples of extensive past rainforests clearing include:

- the decimation of the 'Big Scrub' rainforests in northern New South Wales (Frith 1977; Floyd 1987);
- the Illawarra (NSW) rainforests (Strom 1977);
- the hoop pine scrubs of south-east Queensland (Young and McDonald 1987);
- the rainforests of the Atherton and Eungella Tablelands
- the coastal floodplain rainforests of the Daintree, Barron, Johnstone, Tully - Murray, Herbert, Proserpine and Pioneer rivers in north-east Queensland; and
- extensive areas of Brigalow Belt vine thickets in Queensland and New South Wales (Sattler and Williams 1999).

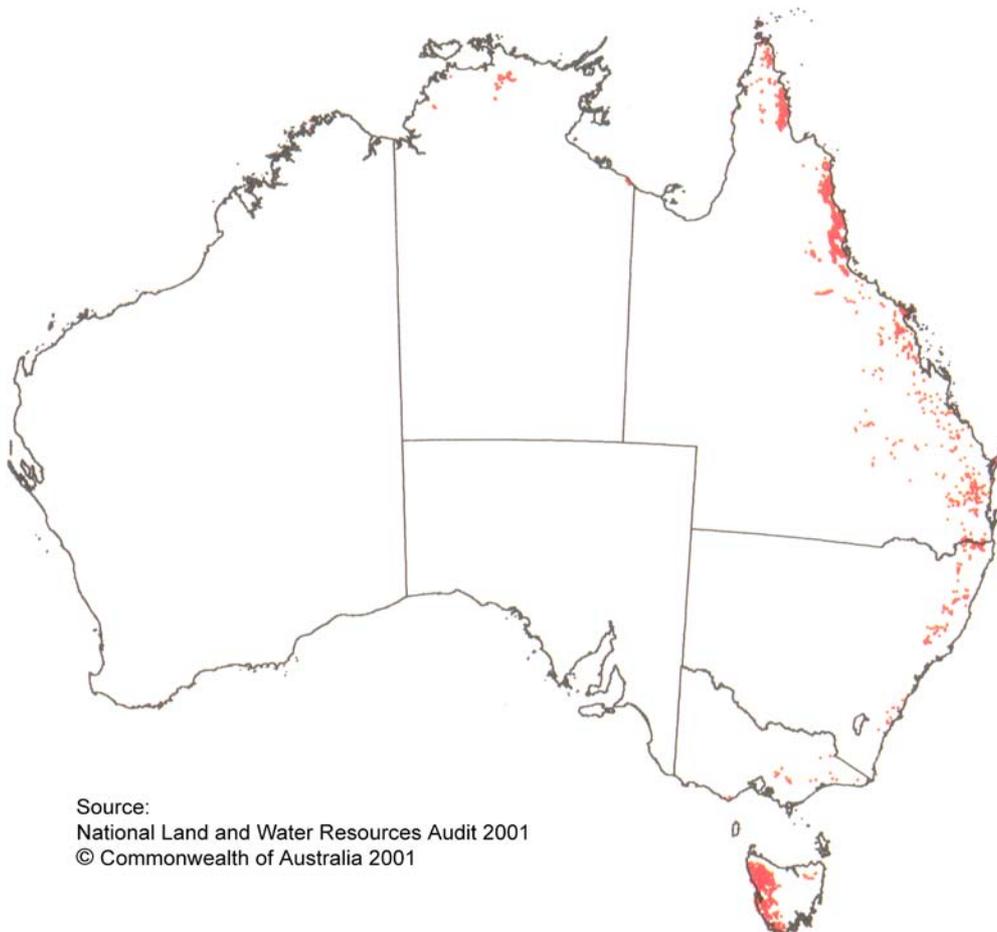


Figure 1. Current distribution of rainforest in Australia

The broad range of ecological community types classified under the umbrella term 'rainforest' masks the level of regional depletion of some rainforest and vine thicket types. In the Wet Tropics, for example, the escarpment and highland rainforest communities remain largely intact, whereas the coastal lowland and tableland rainforest communities have been severely depleted. Of 24 endangered Wet Tropics regional ecosystems 18 occur on the coastal lowlands as fragmented remnants while a further five are from basalt landscapes on the Atherton Tableland (Goosem *et al.* 1999). "Endangered" status, in general, applies to those regional ecosystems that have been reduced to less than 10% of their pre-European extent (Sattler and Williams 1999).

Mabi forest – a regional example of rainforest depletion

An extreme example of selective regional rainforest clearing and fragmentation is the Type 5b rainforest on the Atherton Tableland, lately called Mabi Forest after the Lumholtz's tree-kangaroo (Figure 2).

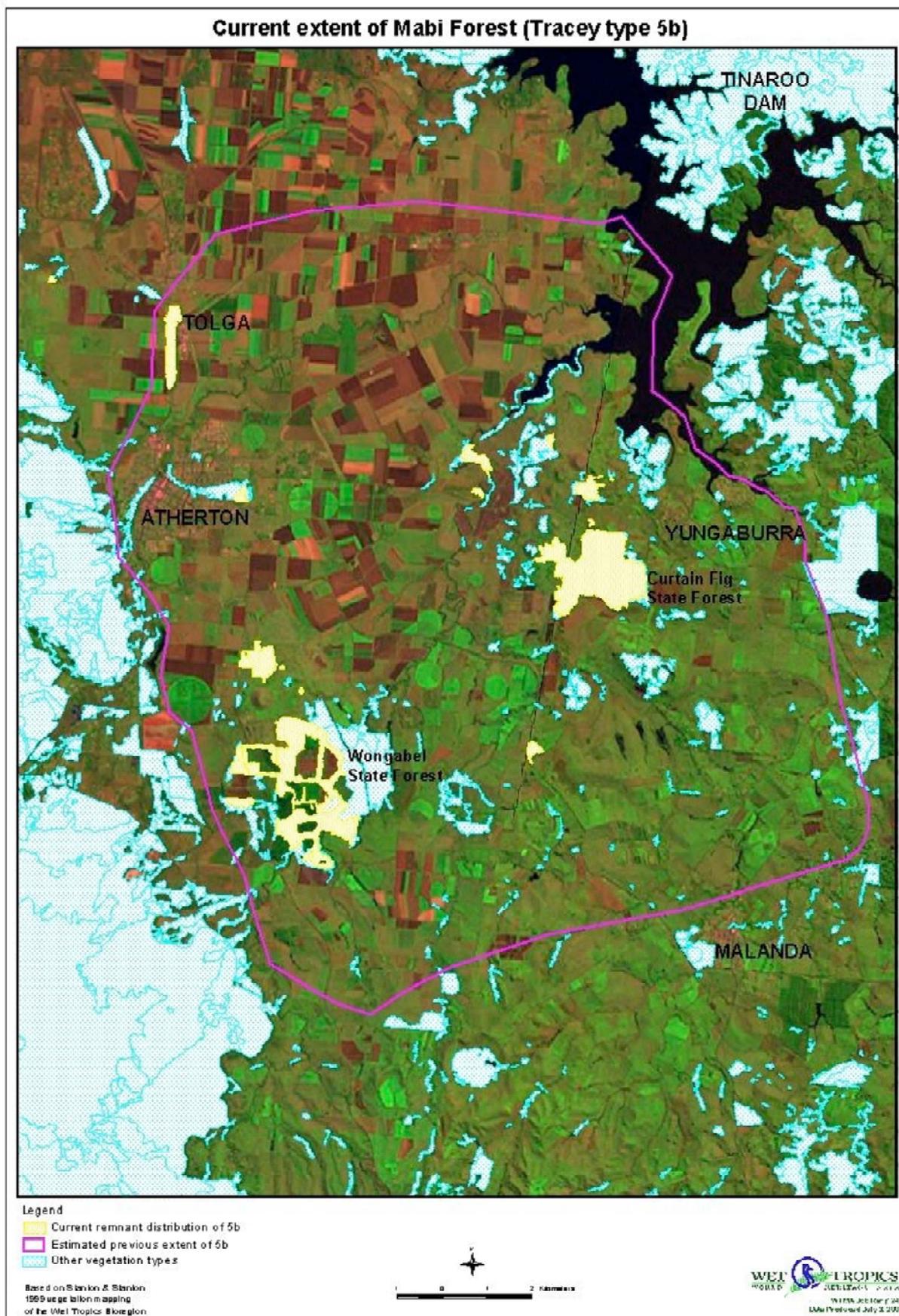


Figure 2. Current and past extent of Mabi rainforest.

It has been estimated that it formally occupied about 20,700 ha – so it was never an extensive rainforest community. It currently only occupies about 671 ha or 3% of its past extent and is spread over 19 remnant patches ranging in size from less than half a hectare to about 260 ha (Table 3). The remnants also have a poor size to shape ratio with a total of 67 km of edge-affected boundary.

All the remaining 19 patches display continuing deterioration of their ecological integrity evidenced by wind damaged, moribund open canopies and weed invasion of both the patch edges and their interiors. The small size of the remnant patches and their relatively large distance from any major blocks of rainforest has apparently resulted in the total loss of fauna such as the cassowary and musky rat kangaroo that are important as dispersers of the seeds of rainforest trees.

Table 3. Current extent of remnant Mabi rainforest (number, size and perimeter of each patch).

Patch No.	Area (ha)	Perimeter (m)
1	0.38	368
2	0.44	281
3	0.59	295
4	1.15	439
5	1.35	542
6	1.78	567
7	3.02	762
8	3.09	871
9	5.40	1154
10	8.59	1490
11	9.14	1497
12	12.03	1923
13	16.45	2520
14	18.93	2801
15	21.17	4619
16	38.55	4338
17	41.24	3771
18	228.00	27494
19	260.11	11229
Total	671.421	
Total area of inferred past extent: 20,741 ha		
Estimated percentage remaining: 3.2%		

Temporal pattern of plant naturalisations within the Wet Tropics region

Queensland has been invaded by around 1,300 vascular plant taxa that have established breeding populations and become naturalised in the wild (EPA 1999). The EPA estimates that 50 to 100 new plant species are imported into Queensland each year (EPA 1999). Within the Wet Tropics, Werren (2001, 2003) identified over 500 exotic plant taxa that have become naturalised, which amounts to around 10% of the region's native flora and represents almost 40% of Queensland's naturalised alien plant species total.

The magnitude of the trend in plant naturalisations within the Wet Tropics over the last century (Figure 3) is very concerning even if it could be argued that the majority do not pose an environmental risk to natural plant communities.

In recent times there has been rapid population growth within the region, the establishment of an international airport, vastly increased national and international trade has occurred, and land uses have greatly diversified. These factors will very likely ensure that the rate of new naturalisations and the probability of major environmental weed invasions will continue to increase.

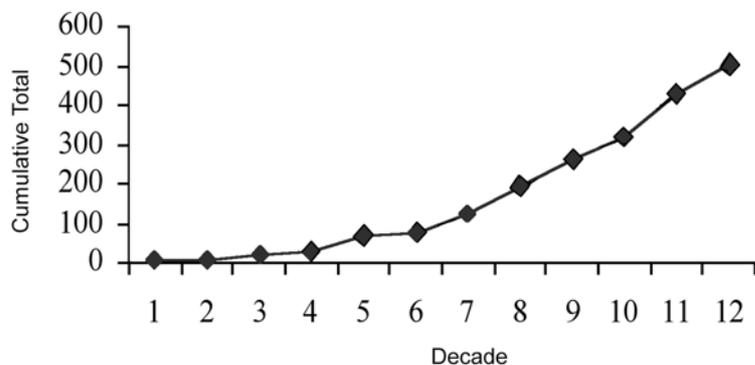
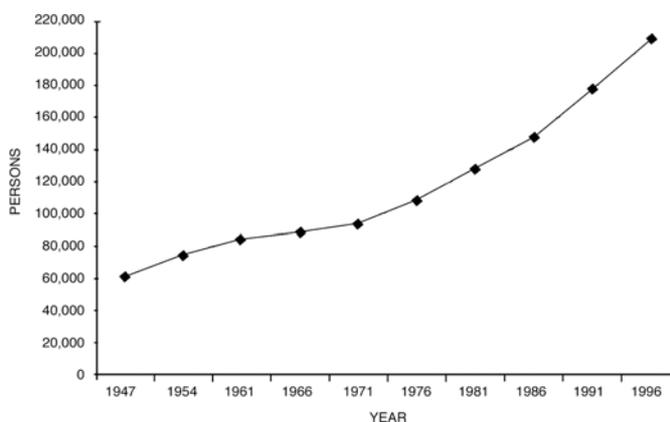


Figure 3. Cumulative total number of alien plant species recorded as naturalised in the Wet Tropics region during 10 year increments where Decade: 1 = pre 1900; 2 = 1900-09; 3 = 1910-19; 4 = 1920-29; 5= 1930-39; 6 = 1940-49; 7 = 1950-59; 8 = 1960-69; 9 = 1970-79; 10 = 1980-89; 11 = 1990-99; 12 = additional unofficial records for the region compiled by Werren (2001). Source: WTMA 2002

Regional population growth

The growth of the human population within the region can be seen in Figure 4. This shows data for a subregion containing the seven local government areas of Cairns, Atherton, Cardwell, Douglas, Eacham, Johnstone and Mareeba that collectively cover most of the major population centres of the Wet Tropics. Population increased from 60,620 persons in 1947 to 208,637 persons in 1996. Most growth has occurred since the early 1970s and the population has more than doubled since 1971.

Population growth inevitably leads to greater demands for clearing and development, energy supplies and their distribution networks, telecommunication facilities, and the upgrading and duplication of transport corridors. Population growth and increased trade also inevitably leads to increases in the number and distribution of invasive weed species.



SOURCE: Australian Bureau of Statistics, Census of Population and Housing between 1947 and 1996

Figure 4. Cairns subregion human population between 1947 and 1996

Linked to increased levels of trade, the region is becoming increasingly urban with the vast majority of population growth occurring in the Cairns area. Many invasive species are most prolific in high density urban and urban-fringe environments where residents seek climatically suitable exotic ornamental plants from a wide range of sources. Settlements also involve transportation links, and the distributions of many invasive species in the region seem to follow transportation corridors. In recent years, urbanisation and housing development are also tending to encroach more and more upon rainforests and other natural areas.

Regional land use

Land use directly affects invasion processes by modifying disturbance regimes and environmental conditions. Land use also affects the invasion process indirectly by creating sources of propagules from which species may invade more pristine environments.

The region's land uses are predominantly agricultural. In coastal areas the main crops have been, and remain, sugarcane and bananas. Agricultural land uses on the Atherton Tableland are rapidly changing especially with the expansion of irrigated crops such as sugarcane. Production of mangos, avocados and other tropical fruits is increasing (DPI 2000). Most of these tropical fruits originate from overseas rainforest environments, are attractive to our native seed disperser fauna and many have a high potential to invade natural areas.

Sandwiched between the largely cleared coastal lowlands and upland tablelands is the protected World Heritage Area (WHA) which is traversed by essential community service facilities and infrastructure. Essential services supplied by community infrastructure are important for regional development but the construction and maintenance of infrastructure within an otherwise protected area has significant impacts due to habitat fragmentation, the creation and exposure of edges, extreme micro-climatic and micro-hydrological alterations and the intrusion into closed canopied forests of a myriad of introduced weed species.

Power lines and roads represent the primary conduits for the introduction of most weed species into the WHA, especially for generalist species with rapid life cycles and high reproduction. Fortunately, most weed species growing in disturbed roadsides and power line corridors are incapable of colonising less disturbed natural environments. Even so, these disturbance corridors still may serve as starting points for some species to percolate from the edges into the interiors of pristine or naturally disturbed environments. Roadsides and power line clearings may also act as reservoirs of weed propagules that can be liberated in disturbance events.

Habitat alteration/degradation

So far the examples have focused on the landscape-transforming processes associated with clearing, its configuration and subsequent use. Habitat alteration occurs when the broad structure of the habitat remains the same but components are lost or modified. Invasion of rainforest landscapes by weeds may be assisted by large-scale degradation of habitat. Three processes that are responsible for widespread habitat alteration within and adjacent to rainforests are past logging, forest dieback in rainforest areas, and changes to historic fire regimes in non-rainforest ecosystems. Widespread structural damage resulting from natural cyclonic events either alone or in interaction with other disturbances may also provide conditions suitable for weed invasion.

Logging

The most pervasive past human use of much of Australia's rainforests, including the Wet Tropics was logging. Up until World Heritage listing in 1988, for example, most of the region's rainforests had been available for selective removal of commercial timber species for 70 years. Long-term average yields from the region, prior to listing, were 63,000 cubic metres of rainforest timber per annum from a productive area of 158,000 ha. Although the intensity, frequency and impact of logging over the region is highly variable, much of the present rainforest has been severely disturbed in the recent past and canopy damage is still widespread.

Forest Dieback

Dying and dead patches of rainforest associated with the root-rot fungus *Phytophthora cinnamomi* were first recorded in north Queensland in 1975 (Brown, in Gadek 1999). Subsequent soil surveys showed the fungus was widespread and associated with serious disease in two widely separated rainforest areas in north Queensland, one of them in the Wet Tropics, the other the Eungella Tableland near Mackay.

In 1999, lots of patches of dead rainforest canopies were again noted in parts of the Wet Tropics, initially in the Tully Falls-Koombooloomba area, but subsequently also in several other localities extending from the Carbine Tableland in the north to Kirrama in the south (Gadek *et al.* 2001, Worboys and Gadek 2002).

The effects of *P. cinnamomi* on the region's rainforests vary from no visible impact to slight loss of canopy leaves in susceptible species to the death of all plants in virulent outbreaks. The opening of the canopy, the disruption to community structure, the death or reduced fitness of established native species due to the dieback phenomenon are all impacts which increase the risk of invasion by *Phytophthora* resistant and/or light requiring weed species.

Cyclones

High intensity winds associated with cyclones are a frequent natural phenomenon across tropical Australia. Webb (1958), for example, suggested that in north Queensland few areas of rainforest would escape some major cyclone damage for more than 40 years, so that cyclones are a major widespread and intensive natural disturbance agent that could aid in the spread and establishment of weeds. The invasion of parts of the steep inaccessible eastern slopes of the Bellenden Ker Range by *Harungana madagascariensis*, for example, has been attributed to structural damage to the rainforests caused by cyclone Winifred.

As cyclones move across the coast and decline, they may become intense rain bearing depressions responsible for astonishingly intense rainfalls. For example, Cyclone Peter dumped 1947 mm on Mt Bellenden Ker over a 48 hour period on 4-5 January 1979 (Adam 1994). Such high intensity rainfall also results in high velocity flows, erosion and flooding disturbance. High velocity flow and flooding disturbance to stream and riparian communities in the region is another common entry point for the establishment and spread of many weeds.

Climate Change

Climatic conditions in the Wet Tropics are subject to a degree of natural variability with cyclic phenomena like El Nino exerting an important influence. On top of this, the build-up of greenhouse gases from human activities is contributing to the present accelerated rate of climate change. The current concentrations of carbon dioxide, methane and nitrous oxide are unprecedented during at least the last 400,000 years (IPCC 2001).

In comparison to 1990 temperatures, it is predicted that coastal north Queensland will be between 1.4-5.8°C warmer by 2100 with an associated +4% to -10% change in rainfall per degree of warming (Walsh *et al.* 2000). More El Niño-like conditions are expected and tropical cyclone intensity and frequency may increase (Walsh and Ryan 2000). Due to this predicted rapid climate change and the increasing frequency of severe climatic events such as cyclones, floods and droughts, natural ecological systems will undoubtedly be under severe and increasing stress over the next few decades. Preliminary analyses by CSIRO (Hilbert *et al.* 2001) suggest that the rainforests of the Wet Tropics are extremely sensitive to climate change. The possible magnitude of impact is immense with preliminary modelling results indicating that it is possible that up to 66% of all the Wet Tropics endemic vertebrate faunal species may be lost over the next 50 to 100 years (Hilbert and Williams).

Climate change could well promote the interests of invasive weed species. For example, if the species that are dominant in the native vegetation are no longer adapted to the environmental conditions of their habitat, what species will replace them? It may well be that exotic species will find these "new" habitats especially attractive. It seems highly likely that invasive species are going to have far more opportunities in the future than they have at present.

Global change phenomena, such as climate change, present a formidable research and management challenge. Regions, such as the Wet Tropics are being subjected to changes in land use, atmospheric composition and climate of an unprecedented magnitude. Of the interacting driving forces of ecological change, the most important for determining the stresses on natural ecosystems and conversely for determining the likely distribution and performance of environmental weed species are the range and seasonality of environmental factors such as temperature and precipitation; the intensity and frequency of severe episodic events such as cyclones, storms, floods, drought and fires; and the group of demographic, economic and social pressures related to human activities.

Rainforest Weeds: detecting and managing new incursions

Barbara M. Waterhouse

Australian Quarantine and Inspection Service and Weed CRC

INTRODUCTION

The direct cost of weeds to Australian agriculture has been estimated to be more than \$3,300 million annually (Groves 1998; WWF Australia 2003). The environmental cost of weeds is difficult to assess in monetary terms although it is now widely recognised that invasive species pose one of the greatest threats to biodiversity in Australia (Williams *et al.* 2001; WWF Australia 2003).

Rainforests and associated ecosystems in northern Australia contain a relatively small proportion of naturalised weeds when compared with other ecosystems and regions elsewhere in Australia (Werren 2003). However, fragmentation and disturbance caused by agriculture, urbanisation and infrastructure (eg. road networks and powerlines) renders rainforests more susceptible to weed invasion. Early recognition, and intervention before new weeds become widely established is thus essential for reducing the impact of weeds.

A primary goal of the Cooperative Research Centre for Australian Weed Management (Weeds CRC) is to enhance capacity for early detection and response to new weed incursions at national, state and regional levels. This paper summarises surveillance conducted as part of the Northern Australia Quarantine Strategy, which although limited in its geographic coverage and focused on a broad range of 'quarantine pests' including weeds, provides a good example of a pre-existing, successful early warning program. Several recently discovered weeds that threaten rainforests or associated ecosystems in northern Australia are discussed.

Why is early detection and response to new weeds important?

- To minimise further environmental damage and economic costs.
- Many potential or 'sleeping' weeds are lurking in gardens or in early stages of naturalisation but remain unrecognised.
- The probability of successful eradication decreases with increasing size, distribution, and duration of infestations (Groves and Panetta 2002).

Requirements for early detection and response

- Active searching for invasive or potentially invasive plant species and curiosity about unfamiliar taxa.
- Collection and formal identification or verification of voucher specimens.
- Co-ordinated mechanism for notification of significant detections and a consultative process to determine appropriate response.
- Prompt, adequately resourced response, co-ordinated nationally and/or regionally.

Current status

- Nationally, the capacity for early detection and response to new weeds is improving but has tended to be *ad hoc*.
- Mechanisms include national, state and local government weed strategies for example the National Weeds Strategy (ARMCANZ and ANZECC 1999); Northern Australia Quarantine Strategy; Queensland Natural Resources and Mines Strategic

Weed Eradication and Education Program [SWEEP] and Victorian Weed Spotters Network.

- Better co-ordination is being sought through activities of the Weeds CRC (eg. Program 1: Weed Incursion and Risk Management; Program 4: Community Empowerment) and publication of the Worldwide Fund for Nature Position Paper on Weeds and Pests (WWF Australia 2003).
- Adequate and guaranteed resources are vital for success.

The Northern Australia Quarantine Strategy (NAQS)

The Northern Australia Quarantine Strategy (NAQS) is a sub-program of the Australian Quarantine and Inspection Service and has scientific, operational and public awareness components. It was established in 1989 after a review of Quarantine in northern Australia highlighted the special quarantine risks faced by that region. This risk relates to the region's geographic proximity to neighbouring countries, relatively free movement of traditional inhabitants, prevailing winds from the north-west from December to March; and the sparsely inhabited northern coastline of Australia. The principal relevant activities of NAQS are:

- Surveillance and monitoring for new pests, diseases and weeds primarily focused on a narrow coastal zone from Broome to Cairns, including offshore islands. Overseas surveys in Indonesia, East Timor and Papua New Guinea (PNG) provide early warning of movement of new pests towards northern Australia.
- The NAQS zone is subdivided into 'risk areas' such as Torres Strait Islands, Northern Peninsula Area etc. Changing risk factors are reviewed regularly. Survey frequency is determined by perceived threats to the individual risk areas within the NAQS zone. For example, in Queensland, the inhabited Torres Strait Islands face the highest risk of incursion due to proximity to PNG (Saibai Island is <5 kilometres from PNG) while the southern coastline of the Gulf of Carpentaria is considered to be the lowest risk.
- 'Target lists' of pests not known from Australia (e.g. Waterhouse and Mitchell 1998) help focus survey activities, but all new detections are reported. Voucher specimens are collected for verification and permanent record. Landholders and the general public are encouraged to submit specimens of unknown weeds for identification by NAQS botanists. Federal and State authorities are formally notified of significant findings through an agreed protocol. Significant detections usually lead to response activities (eradication and/or containment programs) managed by the relevant State authority (in Queensland, the Queensland Department of Natural Resources and Mines [QNRM] for weeds). NAQS personnel often participate in the initial response to incursions and/or provide ongoing technical advice in the area of their expertise.
- Public awareness activities and products (e.g. calendars, leaflets, children's books) are used to draw attention to pest species found in adjacent regions but not yet known from, or with limited distribution in Australia.
- Serious new weeds detected for the first time in Australia through NAQS activities include *Chromolaena odorata*, *Mikania micrantha*, *Limnocharis flava*, *Clidemia hirta* and *Miconia racemosa*. Eradication efforts are in progress for these species.

"NEW" WEEDS THREATENING NORTH QUEENSLAND RAINFORESTS AND ASSOCIATED ECOSYSTEMS

1. Species with pre-emptive declaration status under federal or state legislation

- *Chromolaena odorata* (L.) King and Robinson (Asteraceae): chromolaena or Siam weed. Origin: tropical America. Naturalised and a serious weed in Africa, Asia, Philippines, Indonesia, PNG and Micronesia. Scandent shrub to c. 3m tall in open sites but climbing to c. 8m along forest margins; propagates vegetatively from stem and root fragments; produces huge numbers of wind-borne seeds that are readily

spread as contaminants of vehicles, machinery, animals and floodwaters (Smith 2002); forms dense smothering stands; invades agricultural land, pastures, woodlands, forest gaps and stream banks; often spreading away from roadsides; inhibits forest regeneration, fire tolerant and fire promoting. First detected in Bingil Bay – Tully region of north Queensland in July 1994 with numerous infestations found scattered throughout lower Tully River valley and adjacent catchment. Nationally funded eradication campaign managed by QNRM, commenced in August 1994 and still continuing; cost to date approximately \$1.4 million; excellent progress toward eradication has been made but location of isolated plants and persistent seed bank are problematic (Waterhouse and Zeimer, in 2002).

- *Mikania micrantha* Kunth (Asteraceae) mile-a-minute or mikania vine. Origin: tropical America. Naturalised and a serious weed throughout Asia, Indonesia and the Pacific Islands. Perennial, twining vine climbing to the forest canopy; propagates vegetatively from stem fragments; prolific wind-borne seed; forms dense tangled infestations in pastures, plantations and disturbed forests; suppresses underlying vegetation. Small infestations first detected at Bingil Bay, Mission Beach and Forrest Beach in June 1998 and Speewah and Ingham in 2001 (Smith 2002; Waterhouse submitted paper); total known infested area less than 10 hectares. Eradication campaign managed by QNRM, Mareeba and Hinchinbrook Shire councils in progress; national funding being sought.
- *Clidemia hirta* (L) D. Don (Melastomataceae): Koster's curse or soap bush. Origin: tropical America. Naturalised and a serious weed in Malaysia, Indonesia, Fiji and Hawaii. Much-branched, shade-tolerant shrub 1-5m tall; fruits prolifically; seeds dispersed by birds, mammals and floodwaters; forms dense infestations in forest understoreys, along stream banks and in pastures; displaces native species. Tiny infestation discovered along an ephemeral stream at Julatten, north Queensland in August 2001 (Smith 2002; Waterhouse 2003); eradication effort currently managed by Mareeba Shire Council and QNRM; national funding being sought.
- *Miconia calvescens* DC. (Melastomataceae): miconia or velvet leaf. Origin: tropical America. Relatively uncommon throughout its native range, but cultivated elsewhere for its attractive foliage; naturalised and a serious weed in French Polynesia and Hawaii. Shade tolerant shallow-rooted tree to 15m tall; fruits prolifically; tiny seeds dispersed by birds, mammals, running water and as contaminants of footwear, tyres; forms dense monospecific stands excluding understorey species and leading to soil erosion on steep sites. Formerly planted as an ornamental in north Queensland; small naturalised populations found in Miallo, Julatten, Kuranda and Cairns districts; now a prohibited species and eradication in progress, managed by QNRM and local councils; national funding being sought.
- *Miconia racemosa* (Aubl.) DC. (Melastomataceae): camasey felpa. Origin: tropical America. Reported to be weedy throughout its native range; never previously recorded outside its native range. Straggling, shade-tolerant shrub to 5m tall; fruits prolifically; tiny seeds dispersed by birds, mammals, floodwaters. Small infestation discovered near Kuranda in June 2002; growing along an ephemeral stream; identifying botanist (in USA) warned of potential major weed status and recommended eradication before becomes widespread; eradication program managed by QNRM and Mareeba Shire Council in progress (linked with *M. calvescens* eradication campaign).
- *Limnocharis flava* (L.) Buchenau (Limnocharitaceae): limnocharis or yellow burrhead. Origin: tropical America. Naturalised and invasive in USA, Sri Lanka, India and southeast Asia including Indonesia. Clumped aquatic to semi-aquatic perennial herb to 1m tall; rooting in muddy substrate; prolific reproduction via seeds and vegetative shoots; seeds and plantlets waterborne, moved by humans as an ornamental or

green vegetable (Smith 2002); waterfowl might also spread seeds; forms dense infestations in wetlands, slow-moving streams, shallow lakes and dams. Infestations arising from cultivated plants detected in Cairns (June 2001), Black River (September 2001) and Townsville (September 2002); also found in several suburban ponds (Waterhouse 2003); wild plants found in Mulgrave River near Babinda are cause for concern (source remains unidentified); target of eradication program managed by QNRM and local councils; national funding being sought.

2. Species without pre-emptive declaration status

- *Phytolacca rivinoides* Kunth and Bouche (Phytolaccaceae): Venezuelan pokeweed. Origin: tropical America. Weedy in native range; probably toxic to livestock; spreading shrub to 3m tall; attractive flowering and fruiting racemes, probably introduced for ornamental purposes; prolific seed production; seeds dispersed by birds and floodwaters. Tiny infestation discovered in Miallo area in April 2002; native silveryeyes and honeyeaters have been observed feeding on fruit; eradication being attempted by Douglas Shire Council with support from QNRM.
- *Brillantaisia lamium* Benth. (Acanthaceae): brillantaisia. Origin: tropical West Africa. Probably introduced as ornamental for candelabra-like inflorescences and attractive purple flowers; not known to be invasive elsewhere. Much-branched perennial herb or sub-shrub to 2m tall, shade tolerant; vegetative propagation and prolific seed production; seeds dispersed locally by explosive rupture of capsules; further by waterborne spread and as contaminant of vehicles, machinery and nursery stock. First recorded from Japoonvale area in 1996, but origin traced to Miallo area where it is now a serious weed of stream banks and understorey of forest margins; other localised infestations have been found at Julatten, Speewah and near Cape Tribulation, but may be more widespread; target of local control in Douglas Shire but likely to get away; eradication of known populations in Mareeba Shire Council is being attempted.
- *Hiptage benghalensis* (L.) Kurz (Malpighiaceae): hiptage. Origin: southern Asia. Invasive in La Reunion, Mauritius, Hawaii, robust woody vine climbing to canopy of riparian forest; winged 'seeds' (fruit) probably aid local dispersal into forest gaps but seeds also waterborne; seedlings and saplings difficult to distinguish from native vegetation; forms impenetrable thickets; weight of vines cause breakage of supporting trees; cultivated for attractive, sweet-scented flowers and unusual seeds, possibly widespread; serious infestation along several kilometres of South Mossman River and also reported to have naturalised in southeast Queensland; not currently target of co-ordinated control efforts.

FURTHER WORK REQUIRED AND POTENTIAL AREAS FOR RESEARCH

- **Eco-climatic modelling** for all species recorded as 'newly naturalised' (includes new incursions as well as escaped introductions) to determine potential distribution and habitats/ecosystems likely to be affected.
- **Genetic studies to determine origin of weeds** where accidental or multiple introductions are suspected (eg. *Mikania micrantha*). These studies might assist development of enhanced preventative strategies and are also important in cases where biological control may be contemplated as a long-term management strategy.
- **Collection of base-line ecological data** for invasive species without a 'history' elsewhere (eg. *Brillantaisia lamium*, *Miconia racemosa*).
- **Life history studies and acquisition of ecological data under 'local' conditions** (i.e. in Australian rainforests or associated habitats) to supplement data from native

range (and naturalised range elsewhere). Scope and longevity of these studies may be limited for species that are subject to formal eradication efforts; but should be an integral component of any eradication program.

- **Interactions between recently naturalised species and native fauna.** Effective early response requires detection of all occurrences of the new invader, a problematic task when plant numbers are low and the terrain difficult. The establishment and spread of potentially invasive species with fruit adapted for avian or mammalian dispersal (eg. *Clidemia hirta*, *Phytolacca rivinoides*) is likely to be enhanced due to frugivore diversity in Australian rainforests, particularly in the Wet Tropics bioregion. Fruit characteristics could be used to predict disperser functional groups and potential dispersal distance from infestation foci (Westcott 2003). This information would aid delimitation of minimum search area.
- **Studies to determine weed potential under Australian conditions** of species with a history of weediness overseas and already in cultivation here, but not yet known to be naturalised (e.g. *Rhodomyrtus tomentosa* (Aiton) Hassk.).

Managing weeds relevant to Australian rainforests and associated ecosystems

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INTRODUCTION

This paper deals with the practical challenges of managing weeds of rainforests and associated ecosystems. It focuses mainly on northern rainforests and associated ecosystems, where the authors have most experience and knowledge. It can be expected that many of the issues and insights that we discuss are common to other areas of Australian rainforests. The major questions relating to weed management in northern rainforests are:

- Who manages these areas?
- How are they managing weeds?
- What can we do to help them manage weeds better?
- How do we measure success?

CHARACTERISTICS OF RAINFORESTS AND ASSOCIATED ECOSYSTEMS

In order to develop the best possible weed management strategies for rainforests and associated ecosystems, it is important to understand the physical, social and economic characteristics of these areas, and their implications for weed management.

Social Environment

Northern Australian rainforest areas are inhabited by a diverse mix of people who use their land in a variety of ways (Figure 1). Cultivation of both traditional crops as well as 'new' or 'alternative' species is widespread. Some people conduct commercial or hobby-farm type operations, others have nurseries, and others are simply looking for a 'lifestyle' block of land. There are at least a dozen substantial horticultural crops being grown commercially in the Wet Tropics, with many more species being grown on a domestic or small scale. Other important land uses include farming, defence training, communication facilities, mining, grazing, electricity infrastructure, beekeeping, water storage, diversion and extraction, roads and access corridors, eco-tourism, traditional land use (indigenous culture), aquaculture, forestry, recreation and conservation. This diversity can lead to an increased number of exotic species that are potentially weedy. It can also make extension and awareness activities more difficult, as there is not one common goal or common 'grower group'. The situation in the northern rainforest region can be compared, for example, with that in the Desert Uplands where most landowners are graziers, and can be reached through publications/field days aimed at graziers. By contrast, where there are heliconia farmers, paw-paw farmers, and private aquaculture ventures, for example, living side-by-side, it is not so easy to reach them all through one communication channel. Another challenge involves extension for indigenous groups that manage land. Traditional extension methods may not always be the most effective in communicating with these groups.

In the northern rainforest areas, there are many small lots of land. The managers of these small lots may not have the resources that may be required for mechanical and chemical control of the weeds. Also, there is a large number of gardening enthusiasts, and people

pursuing 'alternative' lifestyles. Both of these factors are likely to increase the number of exotic species in an area as plants are grown for ornamental and herbal/medicinal uses. Pursuits such as organic farming and permaculture are also common, and can limit some avenues of weed control, for example, the use of herbicides. There is also a relatively high proportion of absentee landholders in the northern rainforest areas. This can mean the land management is inadequate and be conducive to weed invasions. On the other hand, a large portion of the people who live in the northern rainforest region have chosen to do so because they enjoy the natural environment. This engenders a high level of environmental awareness and respect, a factor that should contribute to a desire to counter the detrimental effects of invasive plants. Unfortunately this attitude does not always extend to surrounding associated ecosystems.

In recent years, the majority of 'new' weeds in the Wet Tropics rainforest areas have been escapees from gardens and plant collections. This has become increasingly evident in the number of new P1/P2 plants (that is plants requiring immediate destruction) that have recently been discovered in north Queensland. The growing use of the Internet for plant trading has also exacerbated the problem of introduced plants.

Land tenure is another issue relevant to weed management. Much of Australia's remaining rainforest occurs within state forests and national parks. In Queensland in general, more than 80% of the land associated with rainforests is owned or managed by either State or Federal government. A similar situation exists in other states and territories, where the major land managers responsible for managing rainforests are state or federal governments (Table 1). National Park and Forest Reserves together occupy about 60% of the Wet Tropics World Heritage Area (WTWHA) (Figure 1). The importance of land tenure for weed management in this region is compounded by the fact that more than 2500 individual blocks of land, of mixed tenure, abut the WTWHA along its 3000km boundary.

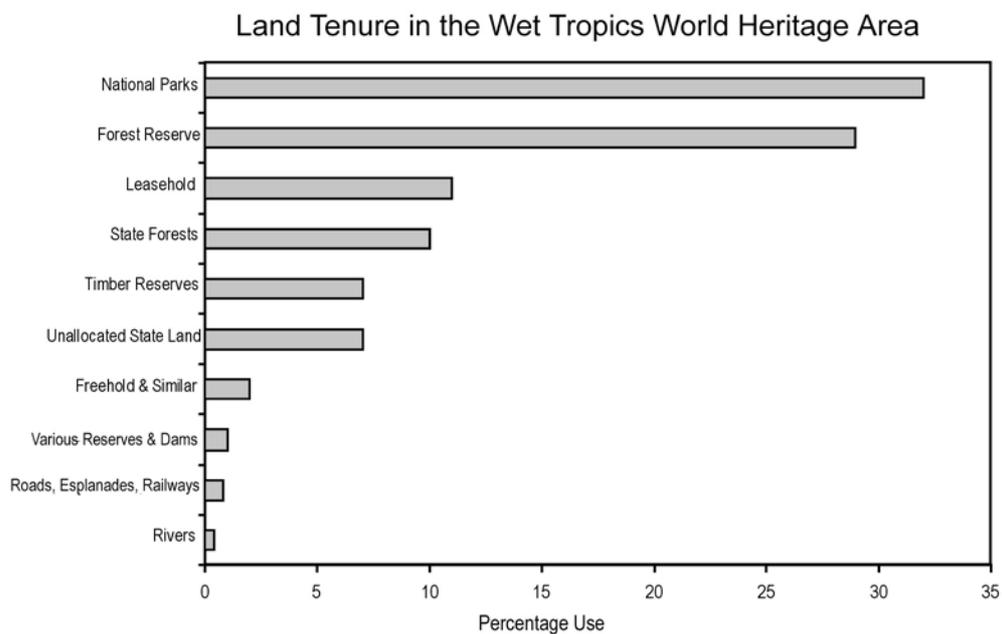


Figure 1. Land use within the Wet Tropics World Heritage Area.
Source: WTMA 2000 Wet Tropics Management Authority Annual Report 1999-2000

Table 1. Summary of land tenure responsibilities for rainforests in each state of Australia.**Source: Australian Native Vegetation Assessment 2001**

New South Wales	protected areas, state forests; little on freehold land
Northern Territory	most on freehold land; some in protected areas
Queensland	state forests, protected areas, some freehold land and leasehold land, many isolated areas on freehold land
Tasmania	protected areas, state forests, vacant crown land
Victoria	mainly state forests; some in protected areas and little on freehold land
Western Australia:	mainly in Aboriginal reserves

Physical Environment

In considering the physical environment in which rainforests and associated ecosystems occur, it is important to recognise that, although we have grouped them together in describing the relevant management issues, there are many different ecosystems and communities to consider. For example, the Queensland Regional Ecosystem System lists 13 broad categories in north east Queensland that are further divided into 27 communities. In this paper we have taken a generic approach, but there are some elements of weed management that may not be transferable across all ecosystems, and so management should be tailored for specific situations.

One of the greatest attributes of rainforests, their high biodiversity, can also create a difficulty in relation to weed management. The large number of species makes it very difficult to identify weeds and to describe the non-target species in a given area. The density of vegetation can also make it very difficult to notice weeds, because they are hidden by other vegetation. Also it is a lot easier to develop a species list for a low-diversity area, such as a Mitchell Grass community, than for a high-diversity and structurally complex rainforest. For example, rubber vine growing in a riparian habitat in the dry tropics is much easier to locate than mikania growing in a rainforest environment. This applies to both on-ground and aerial detection of weeds generally. Furthermore, the density of vegetation can make it difficult to access areas in order to destroy weeds once found.

Rainforests have a high diversity of fauna as well as flora. It would be very time-consuming to develop a full picture of the effect of weed invasion on an area of rainforest and it would require considerable expertise. For example, in a study of rainforest biodiversity led by Roger Kitching (Griffith University and the Rainforest CRC) a fully survey of the biodiversity of one hectare of rainforest takes 15-20 workers two weeks. This means that when resources are limited, research tends to concentrate more on work directly related to controlling weeds rather than to documenting their effects on biodiversity. The high faunal diversity of rainforests also means that there are many potential dispersal vectors and pollinators. A large proportion of rainforest plants are known to be dispersed by animals, notably, birds, bats and terrestrial mammals.

The high growth rates of plants in the Wet Tropics and sub-tropics can also make weed management more difficult. A weed species can very quickly grow, reproduce and spread and may establish a substantial seed bank in a very short space of time. The threat that this poses is compounded with the difficulties in detecting and accessing weeds in dense structurally complex vegetation.

The rugged terrain of much of the Wet Tropics also adds to the difficulties of detecting and managing weeds. Many areas are only accessible by foot, or in some cases, four wheel drive motorbikes, or even canoes and small boats. For example, to control infestations of the vine harungana, staff of the Queensland Parks and Wildlife Service have recorded climbing up to 6km into the mountains inland of Babinda to reach individual plants. Around Tully, the team responsible for controlling Siam weed regularly spend whole days tramping through

thick vegetation in order to monitor sites and destroy re-growth. In some cases, the forest is so impenetrable that access to riparian infestations is by canoes. These demands make weed management expensive and time-consuming. It can also involve serious safety issues, such as increased risk of snakebite, crocodile attack, heat stroke, or simply getting lost, as well as lesser problems such as mosquitoes, leaches and scrub itch.

Disturbance due to cyclones and floods are common in the Wet Tropics rainforests and associated ecosystems. Fires also can occur in some areas, and are particularly relevant to the margins of rainforests. These natural disturbances can create ideal conditions for weed invasion. Sometimes the natural disturbances combine with 'man-made' problems/disturbances, to ideal conditions for the establishment and growth of weeds. For example increased nutrient deposition after flood events can create suitable habitats for riparian weeds.

Economic environment

Due to their physical characteristics, weed management in rainforests and associated ecosystems often requires more labour-intensive, and therefore more costly, methods of control. In some cases, the most appropriate control techniques may be hand-pulling or stem-injection, rather than the broad-scale control methods such as aerial spraying or bulldozing that can be used in other environments. This will be covered in more depth later in this paper.

The limited availability of usable figures for the costs of controlling environmental weeds and of revegetating or rehabilitating areas that have been treated can make it difficult for managers to make good decisions. On the other hand, the high economic value of land in many areas in or near rainforests, does help make land management (including weed management) more viable than it is in areas of lower-land value.

ECOLOGICAL KNOWLEDGE TO HELP MANAGE WEEDS BETTER

An understanding of the ecology of a weed and of the ecosystem that is being invaded can assist in the development of the most appropriate management strategies. Some simple examples include information on:

- **Distribution.** Information on where a weed is found overseas can provide clues as to where it is likely to invade in Australia.
- **Dispersal.** Information on how a weed is spread (eg by birds, other animals, water, wind, machinery) helps when determining where plants are likely to be found.
- **Age to reproduction.** This information can be crucial when developing strategic plans, particularly in regards to timing of search and control operations. For example, if we know we have killed all miconia in a given area, but we know that seed still exists in the soil, and we know it takes 4 years for seedlings to reach reproductive age, we may conserve resources by only treating again every 3 years instead of every year.
- **Seed banks.** Information on how long seeds remain viable in the soil can help determine the length of time for which monitoring for seedling emergence will be needed once initial infestations have been treated. It can help land managers make realistic projections as to the time commitment required for a control program, and allocate resources accordingly.
- **Growth requirements.** If the environmental conditions under which a plant will/will not grow have been determined, substantial time can be saved when undertaking

surveillance programmes, by focusing on the localities where plants are most likely to be found growing.

Areas where information is lacking and suggestions for improvement

Ecological Information

- Ecological information useful to weed management is lacking for many weed species already invading rainforests and associated ecosystems, and for potential weeds. This is the case even though this sort of information is an important basis for better weed management. Ecological research is being undertaken on some of these weeds (e.g. pond apple in the Wet Tropics).
- Information about the effects of weeds on biodiversity, and in turn, of weed management activities, on biodiversity is poor. This is due largely to difficulties and expense of obtaining these data. Simple indices of biodiversity, for example the use of key indicator species, may be valuable.
- Dispersal – dispersal methods of weeds, particularly animal dispersal, are starting to receive more attention, but it is still an area requiring more work.

New species

There are few resources available to work on ‘new’ weed species until at least some invasion has taken place. This applies to both ecological and control information. It means that recommendations and control programs that are put in place when a plant is finally recognised as a weed may not be the most effective. In some cases, a lag time occurs until information is gathered on how great a threat the weed is likely to pose, whether it can be controlled and how best to control it. Pro-active gathering of information about these ‘new’ or potential weeds before they become problems would be beneficial.

Existing data not available/shared

Often, a lot of useful information does exist but only in people’s heads, or other unpublished forms, that are generally unavailable to weed researchers, managers, and on-the-ground weed-control operators. A concerted effort to document such information, and make it easily accessible, could save considerable research efforts, and lead to the use of more efficient control methods.

Lack of data for cost predictions

Information about the costs of control efforts is often not documented and generally available. Synthesis and documentation of such information could facilitate more efficient management of weeds.

How to measure success of weed management

To some extent, researchers have documented the success of weed management practices and programs, but much additional valuable information could be gleaned from increasing monitoring and documentation of on-ground control efforts.

KILLING THE WEEDS – CONTEMPORARY METHODS

Weeds are one of the most serious threats to biodiversity within rainforests and their impact can range from a minor problem to almost total destruction. Development of control options that are effective, and yet selective, seems like an insurmountable challenge. Conventional weed control methods such as fire, bulldozing, chain pulling or large-scale herbicide spraying in a rainforest environment would normally be considered inappropriate. Generally, simpler methods of weed control, such as hand-pulling or spot spraying, are employed. These methods are usually more labour-intensive, and therefore more costly, than broad-scale mechanical or chemical techniques. However in areas with weed monocultures, such as those heavily invaded by pond apple (*Annona glabra*), the use of contemporary methods may be appropriate forms of control.

Prevention and early intervention

The timing of control options can be critical to effective weed management. One of the keys to successful weed management is prevention and early intervention. It is the most cost-effective method of dealing with weed incursions. Unfortunately plants are generally considered innocent until proven guilty. Most do not view a solitary plant or a small group of similar plants as potential invaders. By the time a weed problem is so obvious that it cannot be ignored, actions that will be effective against the problem are usually very costly.

Siam weed - An example of early intervention in the Wet Tropics

- The case of Siam weed (*Chromolaena odorata*) illustrates the resources required for locating and eradicating a weed in the Wet Tropics (Evans et al. 2002)
- Siam weed grows as a dense tangling bush up to 3 m high, out in the open, but when trees are available it scrambles up to a height of 20m.
- Barbara Waterhouse first discovered Siam weed in 1994 at Bingil Bay. Additional infestations were subsequently found along several kilometres of the banks of the Tully River and Echo Creek. One plant was found at Mt. Garnet.
- Initial surveys revealed that Siam weed had been in Queensland for at least 20 years, probably originating as a contaminant of pasture seed.
- Siam weed was targeted for eradication in 1994, funding was sought and a SWEEP (Strategic Weed Eradication and Education Program) team employed to eradicate the infestation. During this period up to 20 staff were involved in surveying and eradicating the plant at any one time. Surveys to locate Siam weed have involved accessing areas on foot, and in motor vehicles, boats and helicopters. To assist plant identification the main surveys were undertaken from May to July, during the plant's peak flowering period
- The eradication program is in its eighth year and new infestations are still being found in the Tully area with recent plant discoveries estimated to be at least 8 years old.
- The program to date has cost ~\$2 million and involved almost 50 FTE during this period (1994-2002) to treat infestations within 50-60 km radius of Bingil Bay.
- The amount of chemical used by the program and the number of new infestations have declined each year. Staff are still employed for on-ground detection and control.
- In spite of the commitment by QNRM the eradication of Siam weed from the Wet Tropics is still some years away.
- The main hurdles to the eradication of Siam weed have been: knowing where the plant is, ownership of the weed problem (though this attitude is changing) and reluctance of some members of the community to come forward with information on its distribution.

Fire

Managed correctly, fire has a role in weed management but it can be a threat to rainforests. Regular or intense fires can open the rainforest canopy and so alter the temperature and moisture regimes within the forest. This affects suitability of the environment for the regeneration and persistence of some rainforest and vine thicket species.

It can be appropriate to burn before any other weed control is undertaken. The rainforest edge is often smothered in vines and invaded by non-rainforest species. Strategic burning at the commencement of a weed control program in these areas may reduce the overall cost as the fire will remove surface weed seeds, stimulate many of the remaining weed seeds to germinate, and kill many of the established weed plants. For example, fire has been effective in controlling pond apple regrowth and seedlings.

In the absence of fire, rainforest species will invade wet sclerophyll forests, to the detriment of flora and fauna that inhabits these forests. A regime of appropriately-timed fires of the right frequency and intensity will control this invasion.

Hand held burners (for example the Atarus® Ranger) are effective at controlling woody weeds in sensitive or riparian areas where traditional methods such as chemical or mechanical control have limited usefulness (Vitelli and Madigan 2003). The hand held burner applies direct heat to the stem base of a woody weed and the duration of exposure (10 to 60 seconds) can be adjusted to suit particular species. The heat rapidly raises the temperature of the moisture in the plant without combustion of the plant itself. The expansion of the liquid in the plant cells causes cell walls to rupture, leading to plant death. Efficacy varies amongst species with weeds that have a low capacity for root suckering, thin bark, high bark moisture content, and low bark density being the most susceptible.

Mechanical control

Mechanical control may be an option where weeds such as pond apple form a monoculture. The use of a brush-cutter in combination with a herbicide may be effective against scattered weed infestations.

Otherwise, mechanical techniques are of limited use but may be considered where the cost of control would have been prohibitive, or where it is necessary to remove contaminated soil.

Chemical control

The application of herbicides dominated weed control from the late 1940s to the 1980s. In recent years there has been increasing pressure from public and private organisations to reduce the amount of chemicals being applied to the environment. Generally herbicides are applied only to weeds that are at low to medium density. The ultimate aims of chemical application are to select an efficient herbicide and an economically optimum dose for each weed species.

Concerns about damage to non-target species and the ecosystem in general has often been an issue for the use of herbicides in rainforests. Lack of registered herbicides to control weeds of rainforests has, in the past, led to extensive use of glyphosate, irrespective of efficacy. To widen the range of herbicides and increase efficacy a minor use permit PER5385 was recently issued for the control of environmental weeds (see below). New products such as Vigilant (picloram in a gel formulation) are now becoming available. These can be applied to the cut stem of plants with no on-ground contamination of product (Ward *et al.* 2002). With caution, herbicides can be used to control large weed infestations provided there are appropriate follow-up actions.

A Permit to Control Environmental Weeds - Minor Use Permit PER 5385

- A permit (PER5385 - <http://permits.nra.gov.au/PER5385.PDF>) was recently granted to control environmental weeds growing in non-agricultural areas, bushland, forests, wetlands, coastal and adjacent areas within Queensland.
- It covers most situations and environmental weeds that will be encountered when managing weeds of rainforests.
- Persons covered by the permit are pest control operators, members of environmental groups such as Bushcare, Catchment Care, Coast Care and people employed as or working under supervision of Local and State government officers.
- The permit allows the use of twenty herbicides including glyphosate, metsulfuron, 2,4-D, dicamba, MCPA, fluroxypyr, haloxyfop, and triclopyr/picloram formulations to be applied by ground based application equipment. A broad array of weeds are covered under this permit, including annual and perennial grasses, broadleaf weeds, bulbs, shrubs, woody

weeds, trees, vines, and weeds in the following plant families: Anacardiaceae, Asclepiadaceae, Basellaceae, Bignoniaceae, Chinchinchee, Convolvulaceae, Euphorbiaceae, Fabaceae, Geraniaceae, Lauraceae, Malpighiaceae, Ochnaceae, Polygonaceae, and Solanaceae.

- Persons wishing to use this permit must read the permit, particularly the information included in DETAILS OF PERMIT and CONDITIONS OF PERMIT.
- The permit is in force until June 30, 2004.

CASE STUDIES ON WEED CONTROL IN RAINFORESTS

Though there is limited published information on weed control in rainforests, a lot of knowledge has been acquired during restoration projects funded by Environment Australia. In the three case studies described below provide examples where one of the main activities in rainforest restoration was weed control.

Case Study 1. Wet Tropics Vegetation Management Program

- This program was funded by Environment Australia through the Natural Heritage Trust's Bushcare component. North Queensland Afforestation Inc. coordinated the program with the assistance of the 10 Shires of north Queensland.
 - Its aim was to implement on-ground tree planting activities through the Wet Tropics Tree Planting Scheme.
 - In 1997-98, the NQ Joint Board and Wet Tropics Tree Planting Scheme undertook major revegetation and rehabilitation works covering some 125 ha of riparian forests, wildlife corridors and other remnant vegetation areas, revegetating the riparian zone for several kilometres along the Johnstone River.
(http://www.nqtrees.org.au/nqaff/pages/general/tree_planting.html).
 - Trees were planted as a step toward producing a mature forest similar to that which was originally there and to create conditions under which other species could germinate and establish. Some species were chosen because their fruits and flowers attract birds, bats and other animals that in turn bring to the site the seeds of other plants which are deposited in their droppings.
 - Projects within the revegetation component included:
 - Mission Beach Corridor Project
 - Bromfield Swamp Revegetation Project
 - Tolga Scrub Rehabilitation Project
 - Clump Point Grasslands Restoration Project
 - Daintree River Revegetation Project
 - Priors Creek Revegetation Project
 - North Cedar Creek Fluffy Glider Habitat Project
 - Barron River Rehabilitation Project
 - Freshwater Creek Revegetation Project
 - Herbert Floodplain Wetlands Rehabilitation Project
 - Wallaby Creek Revegetation Project
 - Babinda Creek Revegetation Project
 - Cattle Creek Wildlife Corridor Project
 - Keating's Gap Rehabilitation Project
- Green Corps and ACV (Australian Trust for Conservation Volunteers) provided the majority of the labor with weed control (using physical control (hand pulling) and chemical control (use of glyphosate)) taking up the most of the group's time.

Case Study 2. Regeneration of Wingham Brush, NSW

- The aim of this project was to restore an area of degraded rainforest to a weed-free state with a closed canopy.
- The restoration of Wingham Brush (9 ha of lowland tropical rainforest) near Taree, N.S.W., began in 1980 (Stockard 1996 http://www.npws.nsw.gov.au/news/exhibition/POM/draft/pom_draft_wingham.pdf).
- A team of 6 worked 4 hours per week for ~ 20 years (0.75 FTE per year)
- Continual weeding was required to ensure succession to a native forest.
- Glyphosate was the predominate herbicide used to treat exotic weeds.

Case Study 3. Lansdowne Reserve, northern NSW

- The aim of this project was to restore a highly degraded lowland sub-tropical rainforest with associated vegetation in the Lansdowne Reserve, near Taree in northern N.S.W.
- The project to restore 'Lansdowne Brush,' a 4 ha floodplain rainforest remnant, began in August 1992 (<http://www.midcoast.com.au/~klye/repb.HTML>).
- Between 1992 and 1997, the project team committed a minimum of 700 hours (0.5 FTE) per year to restoration.
- Glyphosate was the predominate herbicide used to treat exotic weeds

Commonalities among the three Case Studies

The general theme in the case studies outlined above is that rainforest restoration requires an integrated approach based on a thorough understanding of the rainforest ecosystem. The condition of each of the rainforests had steadily deteriorated over the years due to human impacts and invasion by exotic weed species that spread rapidly throughout the rainforest and associated ecosystems. Exotic weeds smothered native plants, seriously degrading the forest structure and arrested natural regeneration. Without effective weed control the rainforest remnant's health and viability declined and restoration required an enormous amount of resources. While weed control is a vital component, the aim was to replace all weeds with native species in such a way that the process of natural regeneration and succession is sustainable (Leys, 1996).

Many weed species were responsible for the degradation, including thunbergia (*Thunbergia grandiflora*), Madeira vine (*Anredera cordifolia*), large- and small-leaved privet (*Ligustrum lucidum*, *Ligustrum sinense*), morning glory (*Ipomoea purpurea*), harungana (*Harungana madagascariensis*), cat's claw creeper (*Macfadyena unguis-cati*) and wandering Jew (*Tradescantia fluminensis*). Vines such as madiera vine, cat's claw creeper and thunbergia were the most destructive due to their extremely efficient reproductive systems, very rapid growth, height above-ground biomass and capacity to smother all layers of a rainforest from the canopy to the forest floor. The vines reduced healthy rainforests to a stand of vine-draped poles within one to two decades. Privet invaded the understorey, dominated the mid-storey, and covered the forest floor, displacing native species. Wandering Jew formed a thick mat, effectively inhibiting the germination of rainforest seedlings. Harungana was a pioneer species in secondary regrowth areas with annual rainfall exceeding 1300 mm. It invaded cyclone-damaged forest, forest fringes, roadsides and drains, forming dense thickets excluding other species (Vitelli and van Haaren 2000)

Controlling weeds was a long and slow process. For example Madeira vine tubers in the ground were still sprouting after 10 years of intensive spraying.

OTHER APPROACHES TO HELP MANAGE WEEDS IN RAINFORESTS

Agroforestry to control weeds

Rainforest edges become smothered in vines and are invaded by non-rainforest species. The aim of using agro forestry in this context is to develop buffer zones around rainforest, where appropriate, to help close the canopy and so reduce the area's suitability as habitat for weeds. Under natural conditions, rainforest will invade wet sclerophyll forests or retreat depending on many factors such as the frequency of fires. Agroforestry plantations between a rainforest and a wet sclerophyll may reduce the encroachment.

Increasing the number of operators to control weeds

Volunteers must be skilled but volunteers are only as valuable as the technical advice that is provided to them. Ecotourism organisations could be approached to offer free accommodation to volunteers for weed control.

Targeting specific weeds

If resources are limited, targeting fruiting plants and leaving immature weeds may be the most effective approach. This may mean that less follow-up action may be ultimately required, and more fruiting plants are removed sooner than they otherwise might have been. Targeting fruiting plants is not the only criterion. The amount of follow-up that is required must be considered when planning initial control. Follow-up control can be more resource demanding than initial control. Follow-up action must be undertaken before the next generation of weeds reaches the fruiting stage. The extent of some infestations may be such that adequate follow up cannot be provided.

Improved surveillance methods for locating weeds

Tools are required to help locate weeds in the natural rainforest environment, thereby reducing the enormous number of hours currently required to detect individual plants. This may include the use of technologies such as remote sensing and computer modelling and utilise existing knowledge on the distribution and ecology of each weed species.

Improved road designs

The current practice in road construction is to clear along roads to form grassy verges. Maintaining roadside trees would give canopy cover over roads that may retard invasion by weeds and feral animals into the adjacent rainforest. However, there would be safety concerns with such an approach with the risk of collision with trees and trees falling on vehicles. Research currently being undertaken by Professor Steve Turton and Dr Miriam Goosem in association with the Department of Main Roads, aims to improve road design and assess the effectiveness of a wildlife underpass and a revegetation program on the East Evelyn road upgrade (<http://www.rainforest-crc.jcu.edu.au/research/project4.2.htm>).

Other methods

- Incentives such as land for wildlife Johnstone Shire Council rate reductions, environmental levies and a rainforest tax.
- Developing best practice for rainforest management from existing work. For example collation of information from revegetation projects that were funded by Environment Australia and involved weed control.
- Re-educate groups that there are weed control techniques besides hand pulling and use of glyphosate.

SUMMARY

Rainforests and associated ecosystems present many distinctive challenges for weed management. Many are due to the diversity of land uses, the actual physical environment (making weed detection and control difficult and more costly), and a lack of resources. These challenges need to be considered when allocating resources and devising management strategies for these areas. Ecological information can reduce the effort, and thereby resource requirements for on-ground control if incorporated into Best Practice management plans. Early consideration of new or potential weeds is critical.

SECTION 3

Current Research and Development Activities

Biological Control of *Lantana camara*

Michael Day

Alan Fletcher Research Centre, QNRM and Weeds CRC

PROJECT BEING PRESENTED

A summary of a project on the biological control of *Lantana camara*.

Aim of project

To improve the level of control of *L. camara* through the introduction of effective biological control agents. Research is focused on overcoming the factors that have hindered the achievement of successful biocontrol to date.

Location of project

The project is based at the Alan Fletcher Research Station, Brisbane but research and release of agents are being conducted throughout coastal and sub-coastal eastern Australia, from Cairns to the Victorian border.

Methodology / Process

The project involves conducting host specificity testing of new agents and mass rearing, releasing and monitoring approved agents in suitable areas.

Status of Project

The project is continuing. There are two new agents in quarantine and two agents (a sap-sucking bug and a pathogen) currently being released. The release program has been curtailed in some regions due to drought.

Results / Conclusions

Biological control of lantana is a long-term project. Some agents have established and are slowly spreading from release sites and damaging plants. Monitoring of these agents will continue. Host testing of two new agents is yet to commence.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

Successful biocontrol of lantana would assist land managers in the management of lantana throughout eastern Australia and reduce the cost of and dependency on herbicides and other conventional control techniques.

Sponsors / Supporters / Collaborators

The project is primarily funded by QDNRM. Significant contributions also come from the NSW Lantana Taskforce and Landcare or Catchment Groups. The CRC for Australian Weed Management and Weeds of National Significance are funding specific research projects on lantana. The project collaborates with Plant Protection Research Institute, South Africa, Botanical Research Institute of Texas, USA, CRC for Australian Weed Management, CSIRO, University of Queensland, Queensland National Parks and Wildlife Service, NSW National Parks and Wildlife Service, NSW Agriculture, Australian Centre for International Agricultural Research (ACIAR), Wet Tropics Management Authority, Queensland and NSW Local Councils and Landcare Groups.

Possible future directions / recommendations / related future work

Biocontrol of lantana has not been achieved and research activities are addressing the issues that have hindered it. These issues are the taxonomy, biology and ecology of the weed, and the effectiveness of potential agents in terms of host plant and climate suitability.

Best Practice Natural Resource Management on Protected Areas

Leasie Felderhof

Queensland Parks and Wildlife Service

WORK BEING PRESENTED:

A framework that QPWS is using to improve natural resource management practices on the protected area estate. The framework emphasises the interface between research and management, and some of the issues associated with applying research on the ground.

Aim of work:

The aim of the work is to apply 'best practice' and 'adaptive management' when undertaking NRM activities on protected areas and to institutionalise these approaches. These activities relate primarily to fire, weed and feral animal control.

Location of work:

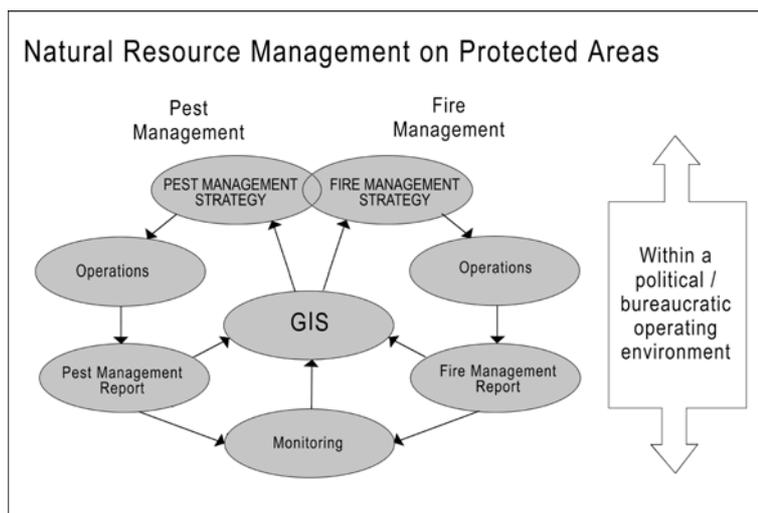
North Queensland, including west to the NT border and south to Ayr.

Methodology / Process:

The process uses the model shown adjacent:

Each element of the system requires information / knowledge and has associated 'best practice' with respect to methods and approach.

For effective operation, the system needs to draw upon ecological, applied, social and tactical research.



Status of work:

Continuing. Fire management components are well developed; version 1 of GIS tool, Parkinfo, is being adopted; initial planning has commenced on pest management components.

Results / Conclusions

Key elements are in place for fire management and the challenge now is to make them work, that is, strategic planning linked to on-ground operations, monitoring and feedback.

BENEFITS OF WORK TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The key benefits are that:

- Natural resource management effort is directed at strategic outcomes.
- Increased documentation at different stages will help capture corporate knowledge and save duplication of effort.

- The system focuses on learning by doing, and a cycle of continuing improvement.

Sponsors / Supporters / Collaborators

Majority of the work is funded by QPWS. Some money for 'systems analysis' has been provided by the Tropical Savanna Management CRC. Collaboration occurring across Northern Australia (WA, NT, Qld) is facilitated by the TSM CRC.

Possible future directions / recommendations / related future work

Key direction is to continue to develop the various elements (particularly GIS functions and Pest system), provide training to staff for implementation, and co-ordination to ensure feedback to management.

Southeast Queensland Rainforest Recovery Project

Catherine Hulm

World Wide Fund for Nature

PROJECT BEING PRESENTED:

Southeast Queensland Rainforest Recovery Plan.

Aim of project

To develop a multi-ecosystem recovery plan for the 32 regional rainforest ecosystems within the Southeast Queensland Bioregion.

Location of project

Southeast Queensland Bioregion.

Methodology / Process

The Southeast Queensland Rainforest Recovery Plan aligns to the regional planning framework. It consists of a 5-year recovery plan, investment strategy, implementation plan and communication/consultation plan. It is the first recovery plan of its type in Australia in that it addresses threatening processes for multiple rainforest ecosystems over a bioregional area.

Status of project

Plan is due for completion in February 2003

Results / Conclusions

The plan highlights that weed infestation is the major threatening process impinging on the long-term conservation of rainforest ecosystems in Southeast Queensland.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The plan will present both the Rainforest and Weed CRCs with prioritised actions for addressing the impacts of weeds in SEQ rainforest ecosystems. It provides a framework for a strategic approach to research within rainforest ecosystems and opportunities to access funding for weed management and research.

Sponsors / Supporters / Collaborators

Queensland Environmental Protection Agency, Queensland Herbarium, Greening Australia, Community Groups, and Local Government.

Possible future outcomes / recommendations / related future work

The plan presents an opportunity for both the Weed and Rainforest CRCs to become involved in rainforest recovery activities within Southeast Queensland.

Update on Cape York Weeds and Feral Animals project

Peter James

Cape York Weeds and Feral Animals Project

PROJECT BEING PRESENTED:

Cape York Weeds and Feral Animals Project

Aim of project

This project will bridge between the first Cape York Weeds and Feral Animals project (CYWAFAP) and subsequent developments. These developments should include the community-based pest management plans of all local Governments (including Community Councils) in the region, landholder's property pest management plans, and a Peninsula-wide strategy and their implementation by each responsible authority. The project will:

- facilitate property and Indigenous Pest Planning, and a Peninsula-wide Pest Management Strategy,
- maintain and support the Cape York Peninsula Pest Advisory Committee (CYPPAC) as the lead consultative group for pests in the region,
- continue on-ground weed and feral animal management in conjunction with landholders throughout the Peninsula,
- provide training and extension targeting landholders and all indigenous communities in the region,
- improve weed seed hygiene awareness and measures in CYP,
- maintain and improve a Peninsula-wide GIS data base, and
- develop income-earning control programs for pests – including a feasibility study on the commercial exploitation feral pigs.

Location of project

Principally Cape York Peninsula.

Methodology / Process

This project will consolidate and enhance the substantial progress made by the Cape York Weeds and Feral Animals project in addressing the strategic weed and feral animal populations threatening conservation and production areas of Cape York Peninsula, and build partnerships with the CYP community. It provides for:

- continuation of the community-based decision-making structures and processes,
- maintenance and enhancement of control works initiated through the previous project,
- GIS support to landholders, this project, Indigenous land and sea management offices and other appropriate CYNHT projects, and
- continuing communication and dialogue with the CYP community regarding pest initiatives and their outcomes

Status of project

Project should continue until Sept 2003

Results / Conclusions

Detailed report of the first 3 years of the project currently being written up.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The CYWAFAP will set the priorities for weed management on the Cape.

Sponsors / Supporters / Collaborators

This project is primarily funded from the Natural Heritage Trust from the \$40M allocated specifically for Cape York. Another major contributor/collaborator is the Cook Shire Council. An in-kind contribution is received from the QDNRM and considerable in-kind contributions from the many stakeholders of the Cape York Peninsula region.

Possible future directions / recommendations / related future work

The CYWAFAP will need continuing support, albeit in a modified form because of its strategic location and the limited population of the area.

Frugivorous vertebrates and rainforest seed dispersal in sub-tropical eastern Australia: interactions in forested and fragmented landscapes

Cath Moran

Rainforest CRC and Griffith University

WORK BEING PRESENTED

PhD Outline.

Aim of work

To investigate the consequences for seed dispersal of changed abundance of frugivorous birds and bats in fragmented rainforest landscapes.

Location of work

Southeast Queensland (SEQ) ('Sunshine Coast' area).

Methodology / Process

- Compare frugivorous bird and bat abundances between extensive forest, remnants and regrowth (sixteen replicate sites of each type) throughout a 4000 ha. region;
- Compare frugivorous bird species abundance among remnant or regrowth sites that differ in isolation
- Compile a database of the plant species eaten by SEQ frugivores, by means of literature review and a network of field observers to identify functional groups.
- Assess the implications of differences in frugivorous bird species, in fragmented or regenerating areas, for the dispersal of fruits and seeds

Status of work

- Fieldwork for stage 1 completed and some data analysed and presented (one draft manuscript submitted; second manuscript in preparation); identifying species' responses to vegetation change.
- Bat surveys and bird surveys in additional remnant sites underway
- The frugivore diet database contains close to 2000 records (60 frugivore species and over 200 plant species). Analyses of these data have commenced.

Results / Conclusions

- Three patterns of change in abundance in fragments and regrowth patches were detected: 'decreaser', 'increaser' and unchanged.
- Species comprising the 'decreaser' group tend to be fruit specialists, considered to be the principal dispersers of many large-seed plant species.

BENEFITS OF WORK TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

- Contributes to an understanding of changed seed dispersal ecology, and regeneration potential, between forested and disturbed parts of the landscape.
- Identifies groups of dispersers of plants with particular fruit/seed characteristics, which may be applied to both native and introduced flora.

Sponsors / Supporters / Collaborators

Rainforest CRC and Griffith University

Carla Catterall, Ronda Green, Mike Olsen (academic supervisors)

Possible future directions / recommendations / related future work

- This project is complementary to studies of frugivore movement patterns and diet in tropical Queensland rainforests that are being undertaken by David Westcott and Andrew Dennis (CSIRO Atherton), and work on fruit choice at QDNR and the Weeds CRC by Chris Stansbury.
- Frugivore movement patterns in the more highly fragmented sub-tropical landscapes are yet to be studied.
- The utility of weedy vegetation as wildlife habitat, and the wildlife conservation risks (and their mitigation) associated with removal of patches of fruiting weeds, need further study.

Ecology of Wet Tropics Weeds project summary

Melissa Setter

Rainforest CRC and Tropical Weeds Research Centre, QNRM

PROJECT BEING PRESENTED:

The 'Ecology of Wet Tropics Weeds' project, which is one of many weed research projects being undertaken by the Queensland Department of Natural Resources and Mines' Tropical Weeds Research Centre.

Aim of project

To investigate the ecology of Wet Tropics weeds in both short and long-term experiments in the field, glasshouse and laboratory. Research is focused on species regarded as high priorities by stakeholders, and ecological knowledge that is highly relevant to control strategies, such as reproductive ability, seed viability and seed bank longevity.

Location of project

Field studies done in Wet Tropics Region of Far North Queensland, office and laboratory work based at South Johnstone.

Methodology / Process

The project consists of various experiments being carried out in the laboratory, shade-house and field. Species being studied include pond apple (*Annona glabra*), hymenachne (*Hymenachne amplexicaulis*), Siam weed (*Chromolaena odorata*), harungana (*Harungana madagascariensis*), tobacco weed (*Elephantopus mollis*), sicklepod (*Senna obtusifolia*), and hairy senna (*Senna hirsuta*).

A few of the major studies include:

- seed longevity and seedling emergence of all species listed above;
- pond apple dispersal by cassowaries and feral pigs
- the effect of shade on hymenachne

Status of project

The project is continuing, some specific experiments have been completed.

Results / Conclusions

Results are available for some experiments. Other work is continuing. Seed longevity studies in particular, take considerable time.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

Our work is designed to find out specific information about the weeds that will help in developing best practice management strategies. For example, as information about seed longevity of pond apple becomes available, managers will be able to more accurately determine what resources are required for follow-up control.

Sponsors / Supporters / Collaborators

The project is primarily funded by the QDNRM. Significant funding also comes from the Rainforest CRC. Some components have received funding from the Weeds of National Significance funds. Collaborators on specific components of work include CSIRO, Cape York

Weeds and Feral Animals Project, Cardwell Shire Council, Cairns Urban Landcare and the University of Queensland.

Possible future directions / recommendations / related future work

Most of these weeds still require considerable ecological research, as do a number of 'new' weeds, recently found invading the Wet Tropics, such as miconia, mikania, clidemia and limnocharis. An understanding of the ecology of these weeds is often essential in order to control them effectively.

Ecology of bird-dispersed weeds: identifying plant functional groups and associated bird-dispersal syndromes

Chris Stansbury.

Weeds CRC and Alan Fletcher Research Centre, QNRM

WORK BEING PRESENTED

Ecology of bird-dispersed weeds.

Aim of work

Bird-dispersed weeds represent a major challenge to weed managers. The dispersal process is complex and difficult to manage, often resulting in seeds being spread over long distances into isolated areas of native vegetation.

This project aims to gain a better understanding of how birds spread environmental weeds by:

1. identifying the main bird species involved
2. determining feeding preferences and behaviour in different habitats and seasons
3. examining patterns of weed spread (whether dispersal is random or directed, scattered or clumped) and potential rates of spread

This information will be used to:

1. investigate the concept of 'plant functional groups' and associated 'dispersal syndromes' and
2. better manage bird-dispersed weeds in SEQ.

What are *plant functional groups*?

Plant functional group refers to a group of plants that share the same traits or attributes that have functional significance. In terms of invasive weed species, plant functional groups may be defined by fruit traits such as fruit size and quality. The time of the year that the weeds produce fruits and how this differs from native fruit-bearing plant species may also play an important role in weed invasiveness.

What is a *dispersal syndrome*?

Dispersal syndrome refers to particular fruit types that are dispersed by certain groups of frugivorous birds, bats or other mammals. Successful dispersal may also depend on whether suitable dispersal agents (e.g. migratory flocking species) are nearby during the fruiting period.

Location of work

Alan Fletcher Research Station, Sherwood, Queensland. Study sites throughout SEQ.

Methodology / Process

Initially, a questionnaire will be sent to bird observers in southeast Queensland and surrounding areas (and later to other bird observer groups across Australia), to determine existing knowledge on bird-dispersed weed species.

Once the main dispersal agents have been identified, several sites in southeast Queensland will be chosen for more structured bird observations. Such observations will focus on bird

species, feeding behaviour, fruit handling techniques, frequency of visitation and bird movements in and out of weedy areas.

Bird characteristics will then be related to fruit traits such as colour, size, nutritional quality, fruit and plant density and fruiting phenology, to determine whether plant fruit functional groups and associated bird-dispersal syndromes can be identified.

Data obtained through structured bird observations and data on fruit characteristics will be supplemented with published information and used to compile a database on bird species and the fruits they consume. In light of the development of similar databases by Rainforest CRC researchers, it is anticipated that this work will focus on contributing to these existing databases.

Other research methods include:

- The use of radio tracking as a means to quantify potential dispersal distributions (e.g., small versus large frugivorous birds). In light of the research presented by David Westcott at the workshop, this work is currently on hold. We are rethinking how the Weeds CRC can contribute to better understanding the dispersal process. This includes looking at how we can potentially manipulate the dispersal process to better manage weed spread and recruitment of natives. Refer to 4th dot point below.
- Aviary trials to monitor gut retention times, the effects of gut passage on seed viability and germination rates, and to provide a guide to estimate maximum potential dispersal distances.
- Seed trapping and/or mapping of key weed species to determine whether dispersal is random or directed, scattered or clumped.
- Monitor bird movement into weedy areas to determine what weed or native plant species are potentially being introduced/recruited. Seed trapping under favoured perches such as wild tobacco. Manipulating perches to encourage native seed recruitment.
- The information will be used to develop Integrated Weed Management strategies that target bird-dispersed weeds, and to identify which recent plant introductions are at risk of being dispersed by birds, potentially becoming invasive.

Status of work

- The project has been underway for 9 months.
- The questionnaire has been completed (January 2003).
- Aviary trials commenced in December 2002 (initially focusing on *Ochna serrulata* and *Lantana camara*). These will take place at Brisbane Forest Park and Currumbin Sanctuary and will continue for approximately 12 months.
- Structured observations are due to start in Autumn 2003.

Results / Conclusions

No yet available.

BENEFITS OF WORK TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

Weed patch size may be important with respect to frugivore attractiveness. If the research can establish whether there is a critical patch size for attractiveness of fruit bearing weed species to frugivorous birds, then appropriate management strategies can be implemented. For example, if small fruiting weed patches are shown to attract fewer avian frugivores, contributing proportionally less to spread, resources could be directed to focus on control of larger patches that are more attractive.

There is also potential for some weed species, especially pioneer species such as *Solanum mauritianum* (wild tobacco), to act as recruitment perches for native plant species. The research conducted as a part of the ecology of bird-dispersed weeds post-doctoral project will identify some of these associations.

Sponsors / supporters / collaborators

QDNRM, Rainforest CRC.

Possible future directions / recommendations / related future work

Questions raised at the workshop

Q. What is the potential for birds in the Torres Straits introducing new weeds into northern Queensland?

A. Birds embarking on long distance migratory flights are likely to get rid of any excess ballast prior to embarking on the flight. However, due to the many islands in the Torres Straits, migratory flights are likely to be a series of short hops, potentially increasing the risk of new weed species coming through this avenue. Potential bird-dispersal related projects could focus on trapping and or collecting faeces for seed identification under known perches of birds that are regular island hoppers in the region.

The dynamics of *Lantana camara* invasion of sub-tropical rainforest in Southeast Queensland

Daniel Stock

Rainforest CRC and Griffith University

WORK BEING PRESENTED:

PhD Outline.

Aim of work

There is much conjecture amongst weed biologists/researchers as to what influences the success of lantana infestations, especially in sub-tropical rainforest. The future of hinterland rainforests is unclear in the face of invasion by lantana. Will the lantana displace the rainforest and turn the rainforest into a monospecific stand of lantana? Will the rainforest reclaim space that has been lost to lantana? Or is there a permanent stand-off between lantana and rainforest?

The aims of this research are to determine whether lantana can displace rainforest; whether rainforest can reclaim space lost to lantana; and to identify the processes involved.

Location of work

Field studies are being/have been conducted in the MacPherson Ranges of southeast Queensland, centred on Springbrook, and also in Lamington National Park

Methodology / Process

This project consists of field-based experiments and studies asking the following questions:

- What limits lantana expansion?
- Which conditions suppress lantana health and aggressiveness?
- Which rainforest species can grow through lantana patches and are able to suppress the growth of lantana?
- What is the maximum canopy gap that can be closed by the expansion of the canopy of the existing trees surrounding the gap?

Status of work

The PhD is currently in its third year with many experiments currently on going

Results / Conclusions

The project is in progress.

BENEFITS OF WORK TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The resources for weed control in national parks in southeast Queensland are very limited. This project expects to aid rainforest weed management strategies by identifying key factors driving lantana invasions and thus helping determine where the limited resources should be spent in managing lantana.

Sponsors / Supporters / Collaborators

This project is primarily funded by Griffith University, Gold Coast Campus.

Possible future directions / recommendations / related future work

This project is mainly directed at lantana ecology in sub-tropical rainforest. Further work is required to determine the ecology of the rainforest in regards to lantana and how the rainforest copes with lantana and other weeds.

Remote Sensing for mapping weeds: an example from the Wet Tropics (pond apple)

Catherine Ticehurst¹, Stuart Phinn², Tim Edmonds² and Alex Held¹

¹Rainforest CRC and CSIRO Land and Water

²Rainforest CRC and University of Queensland

PROJECT BEING PRESENTED:

The Environment Australia – National Weeds Program project ‘Mapping current infestations: developing remote sensing procedures for early detection of new pond apple infestations’.

Aim of project

The main aim of this project was to examine the usefulness of different types of remote sensing data for mapping Pond Apple infestations and to collate existing information about the distribution of pond apple in the Wet Tropics region.

Location of project

Wet Tropics region of Far North Queensland.

Methodology / Process

The project involved a field campaign where the spectral signature of pond apple was measured at a number of sites in the Wet Tropics region. Measurements were taken of individual yellow and green leaves, as well as from above the canopies. The Pond Apple locations and field spectral signatures were used to map possible pond apple locations using various remote sensing data of different spatial and spectral scales (satellite Landsat Enhanced Thematic Mapper – whole Wet Tropics, satellite Hyperion – Cape Tribulation/Daintree River, and airborne Hymap – Cape Tribulation-Noah Creek). Digital Elevation Model (DEM) and hydrology layers were used to model where pond apple is likely (and unlikely) to occur, enabling us to exclude from the analysis those areas unable to support pond apple.

Status of project

Project was completed in October 2002 and a report submitted to Environment Australia and the Rainforest CRC.

Results / Conclusions

Although it was not investigated in this project, colour aerial photography should be an operational system for mapping emergent canopy dominant stands with yellow leaves. High spatial resolution (pixel size < 1.0m) airborne and satellite multi-spectral imaging systems should be partially operational for mapping stands with emergent canopies and yellow leaves. Satellite multi-spectral and hyperspectral imaging systems combined with predictive vegetation modelling is feasible for mapping large patches (> 100m x 100m) with emergent canopies and yellow leaves.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The remote sensing techniques evaluated in this project enable mapping of pond apple in large, canopy emergent stands and provides a basis for mapping the extent of its infestation and potentially monitoring weed control programs in the Wet Tropics and beyond. To be sufficiently accurate and remove false-positives, the mapping process should incorporate

DEM/hydrology modelling with medium spatial resolution imagery (e.g. Landsat), to map the local environments (e.g. soil moisture, vegetation density) where pond apple is likely to occur. Small scale and sub-canopy occurrences of pond apple may only be identified from high spatial resolution aerial photography captured at the time of maximum pond apple leaf yellowing.

Sponsors / Supporters / Collaborators

The industry contact for the project is Melissa Setter. This project was part of the Environment Australia – National Weeds Program, and was completed through the Rainforest CRC.

Possible future directions / recommendations / related future work

The imaging sensor, image processing and field data collection routines applied in this project could also be tested for mapping other types of weeds in the wet-dry tropics. For the pond apple work, a combined aerial photography and moderate spatial resolution image acquisition at the appropriate time of year could be used to develop an integrated multi-scale mapping approach. In addition, high spatial-resolution aerial photography and satellite images could be processed automatically for detection of particular weed species.

Weeds of linear clearings through rainforest

Steve Turton and Miriam Goosem

Rainforest CRC and TESAG, James Cook University, Cairns

PROJECT BEING PRESENTED

Weeds of Linear Clearings project.

Aim of project

- To provide an understanding of the distribution of weed species and relative ecological condition of selected road verges, power-line corridors and walking tracks in the WTQWHA;
- To determine whether satellite or airborne imagery could discriminate individual weed species in these linear clearings and the degree of spatial resolution possible; and
- To examine the penetration of weeds into rainforests from linear clearings and
- To determine the success of restoration plantings across power-line clearings and canopy closure over roads in prevention of weed germination and reduction of weed penetration into the rainforest edge.

Location of project

Field studies in Wet Tropics Region of Far North Queensland, particularly the Palmerston and Bridle Creek/Lake Morris areas; walking tracks across the Wet Tropics; office and laboratory work based at James Cook University, Cairns.

Methodology / Process

- Field survey along transects running parallel to linear clearings (roads, power-line corridors and walking tracks);
- Field survey along transects perpendicular to clearings from centre of clearing to within 100m of rainforest (10m for walking tracks including sites with 3 year restoration plantings); and
- Field survey using hand-held radiometer; remote sensing analysis using Airborne Data Acquisition and Registration system (ADAR) imagery and IKONOS satellite imagery.

Status of project

Project is continuing; remote sensing analysis and vegetation surveys within and perpendicular to selected linear clearings and restoration plantings have been completed.

Results / Conclusions

- Results suggest that although the remote sensing imagery examined did not provide either adequate spatial or spectral resolution for detection of weeds, other sensors presently available or satellite imagery coming on-line in the next two years should be useful for weed monitoring within power-line clearings.
- Restoration plantings only three years old are already demonstrating success in reducing weed germination in otherwise completely weed-infested linear clearings.
- Weeds penetrate further into rainforest edges (to approximately 7 metres) from wider linear clearings than from areas where canopy closure above narrow roads reduces light levels.
- Surveys have uncovered a new weed in the WTQWHA – the orchid *Arundina bambusaefolia* along a narrow management road in the WTQWHA.
- Surveys have demonstrated the success of weed control strategies undertaken by QDNR within the Palmerston road network.

- Weed invasion is occurring along walking tracks in the Wet Tropics, and appears to be a problem alongside some undesignated walking tracks.
- A library of spectral signatures of selected weeds has been developed and a herbarium of weed specimens from linear clearings is being compiled.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The project is providing baseline data on weed infestations along linear clearings and the degree of penetration by weeds from such linear features into the rainforest. The potential of remote sensing as a relatively cheap means of monitoring weed infestations in larger clearings has been examined. Best practice management strategies that reduce weed infestations include rehabilitation plantings, reduction in width of linear clearings and maintenance of canopy closure above linear clearings.

Sponsors / supporters / collaborators

The project is funded by the Rainforest CRC and the Wet Tropics Management Authority, the Rainforest CRC providing research personnel and equipment, whilst WTMA provided funding for a project surveying weeds in selected linear clearings (roads, power-line corridors and walking tracks) within the World Heritage Area and examining the potential for remote sensing to monitor weed infestations in powerline corridors. Significant input comes from James Cook University through student research and funding.

Possible future directions / recommendations / related future work

New remote sensing imagery should be examined as it becomes available. Field surveys could be extended.

Invasive vine dispersal: going with the flow?

Gabrielle Vivian-Smith

Weeds CRC and Alan Fletcher Research Centre, QNRM

WORK BEING PRESENTED:

Research focusing on dispersal characteristics of high impact weedy vines in riparian and creek corridors.

Aim of work

To determine dispersal (spatial and temporal patterns and phenology) and propagule bank characteristics of high impact weedy vine species (primarily *Anredera cordifolia*, *Macfadyena unguis-cati*, *Cardiospermum grandiflorum*) along riparian corridors.

Location of work

Southeast Queensland

Methodology / Process

A series of field and controlled experiments including seed trapping (gravity and in-stream), propagule longevity and emergence under different conditions, propagule buoyancy, *in situ* seed banks, and germination requirements.

Status of work

In progress (Year 1 of 3).

Results / Conclusions

Preliminary results only just becoming available, but suggest species behave quite differently from one another.

BENEFITS OF WORK TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

- Improved understanding of the role of stream corridors in moving invasive plants through the landscape (including into rainforests and associated ecosystems).
- Knowledge of the recolonisation potential of the study species, from both dormant propagule banks and dispersal from upstream environments (to inform surveillance intervals after control efforts are undertaken).
- Providing a basic ecological understanding of high impact weedy vine species that are capable of invading and transforming rainforest edges and gaps, and facilitating further invasion.
- A more informed basis for determining when top-down approaches to catchment-wide weed management strategies are most appropriate.

Sponsors / Supporters / Collaborators

Project is supported by QDNRM and is undertaken in collaboration with Dane Panetta (QNRM).

Possible future directions / recommendations / related future work

- Impacts and ability of vine species to invade and transform rainforest edges, gaps and intact canopies.
- Test techniques that aim to reduce invasibility (eg. Does edge sealing work?).
- Functional trait analysis to determine which species are likely to become major rainforest weeds

Weeds in rainforest restoration: research in Project 5.2 of the Rainforest CRC

Grant Wardell-Johnson

Rainforest CRC and University of Queensland

PROJECT BEING PRESENTED

Weeds in rainforest restoration: research in Project 5.2 of the Rainforest CRC

Aim of project

One component of Project 5.2 of the Rainforest CRC seeks to understand patterns of change in biotic assemblages following different approaches to the re-acquisition of tree cover in tropical and sub-tropical rainforest in eastern Australia.

Location of project

During the first two years of the project we have established and surveyed quadrats in a network of 104 sites, spanning a range of land cover types in the Atherton Tablelands region of northern Queensland (50 sites) and the Border Region of NSW and Queensland (54 sites). Quadrats were in patches of least 4 ha that are at least 5 years since establishment.

Methodology / Process

Plant assemblages (and other components not discussed during this workshop) were sampled in quadrats using frequency counts in three strata in each of the 104 quadrats. Species were identified and categorised under several codes including whether native or introduced.

Status of project

We have commenced the analysis, interpretation and presentation of the data derived from these 104 quadrats to understand patterns and process in land cover change at different scales including that of the landscape level (Catterall *et al.* in press, Tucker *et al.* in press and Wardell-Johnson *et al.* 2002).

Results / Conclusions

The following table summarises the numbers of species in each category in each region. More species of introduced taxa were encountered in the quadrats in the subtropics than in the tropics.

Region (quadrats)	Native species	Introduced species	Total
Subtropics (54 quadrats)	522	102	624
Tropics (50 quadrats)	565	59	624
Total: 104 quadrats (spp. in common)	963 (124)	125 (36)	1088 (160)

Multivariate pattern analysis (MDS ordination, cluster analysis and network analysis in the software program WinPATN - Belbin *et al.* 2002) revealed that after 5-10 years, the plant assemblages of ecological restoration plantings had moved substantially towards the "forest" state, while agroforestry and other plantations remained more similar to pasture sites. These patterns of rainforest recovery differed markedly depending on the stratum considered. However, regardless of stratum, levels of 'movement' differed between regions and between types of plantings. Similarly, type of restoration differed in proportions of recruited taxa of different growth form and origin. The two regions differ in the composition and timing of the establishment of introduced taxa, which in association with management regime, influences the trajectory of rainforest restoration.

Correlations of the frequency of introduced plants with the MDS ordination of native taxa revealed that 53 of 83 introduced taxa (only those encountered at more than 2 sites were included) were significantly ($p < 0.05$) associated with the ordination. None of the taxa were most associated with tropical old plantations or forest reference sites. Few introduced taxa dominated sites except in the subtropics where young plantations and regrowth were dominated by *Cinnamomum camphora*, *Lantana camara* var. *camara* *Ligustrum lucidum* and *Ligustrum sinense*. Other dominant taxa included *Panicum maximum* (one of few taxa most associated with the tropics), *Ageratina adenophora*, *Ageratum houstonianum*, *Ageratina riparia* and *Solanum mauritianum*.

Most introduced taxa within the regions are able to thrive throughout the landscape, and the climate of the two regions is similar. The management history and regional context (longer period of clearing and more intensive management of plantations in the subtropics) have provided the context for the current pattern. Thus, the future will see an increase in the weediness of restoration in the tropics.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

This research has been used to derive biodiversity values of reforestation in rainforest landscapes of tropical and sub-tropical Australia and to design cost-effective restoration projects for degraded rainforest lands.

Sponsors / Supporters / Collaborators

Several biologists are involved in research in program 5.2 (Biodiversity values in reforestation) of the Rainforest CRC. The team is led by Carla Catterall (Griffith University), and includes expertise in mites and soil invertebrates (Heather Proctor – see Proctor *et al.* in press), mammals (John Kanowski) rainforest structure (John Kanowski – see Kanowski *et al.* in review), plants (Grant Wardell-Johnson, Nigel Tucker, Robert Kooyman and Steven McKenna), vertebrates, particularly birds (Terry Reis, Carla Catterall), and design and analysis (John Kanowski, Carla Catterall, Grant Wardell-Johnson). There are several PhD students also associated with this work.

Possible future directions / recommendations / related future work

Current work includes more detailed categorisation of the 1000 plus species encountered in the two regions to determine whether guilds of species can be defined. This may allow the grouping of species with similar behaviour, and predictions of change in different sites. We are also currently designing research programs to investigate species assemblages associated with particular dominant introductions (particularly *Cinnamomum camphora*) and more detailed investigations of the 'dry rainforest' environments in the agricultural and forest context.

New Wet Tropics Natural Resource Management Plan

Nigel Weston

Rainforest CRC

PROJECT BEING PRESENTED

New Wet Tropics NRM Planning Project

Aim of project

A new plan that will identify targets for NRM and cost-effective actions that may be taken to achieve the targets.

Location of project

Wet Tropics region, based in Cairns (Rainforest CRC, JCU, Smithfield).

Methodology / Process

The plan is to build on existing planning and information frameworks and conform to new Commonwealth and State requirements for accreditation.

Status of project

Project is on-going, some milestones have been reached.

Results / Conclusions

Various publications released; Key Stakeholder Reference Group and Regional Science Panel formed along with Community Working Groups on biodiversity, coasts, land and water, rivers and Indigenous NRM; other planning work is continuing.

BENEFITS OF PROJECT TO WEED MANAGEMENT IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS:

The new regional plan will guide funding of local projects, including weed management in rainforests and associated ecosystems.

Sponsors / supporters / collaborators

Rainforest CRC and NRM Board (Wet Tropics), NQAA with support from three levels of government in the Wet Tropics region.

Possible future directions / recommendations / related future work

The plan must meet rigorous criteria for how it is prepared, including information in determining priorities, target-setting and implementation. The group convened at this workshop can provide valuable input in this regard.

SECTION 4

Workshop Outcomes

Research and Development Needs

The brainstorming session identified 42 research and development issues that are important for helping us understand and manage weed problems in rainforests and associated ecosystems. These issues are presented below as identified during the workshop except that they have been placed into seven groups, each containing related topics.

UNDERSTANDING WEEDS AND INVASIONS

- Improve ecological knowledge of weeds
- Studies of weed life histories under “local” conditions
- Need to understand history of problem/solution
- Role of weeds in the ecology of the systems they invade – does control bring risks?
- Can management increase the rate of succession through a weed-dominated phase?

DETECTING WEEDS, MANAGING NEW INCURSIONS AND ERADICATION

- Efficient and effective ways of locating isolated individuals of weed species would provide a basis for containment or eradication.
- Develop list of weed species that should be targeted for eradication
- Document eradication programs – what can we learn from them? (e.g. Siam weed)
- Focus on new incursions – how do we eradicate weeds, review, publicise, research
- High tech methods to detect weeds
- What is best practice for early detection of new incursions.
- What do we do about those who are introducing/promoting new weeds?
- Quantify distributions of early invaders
- Continue annual visits

PRIORITISING WEED PROBLEMS

- Rank current weed species
- Need means of prioritising weeds/weed problems – need decision support tool.
- How do we decide where to spend resources available for weed management?
- Base priorities on recognised criteria – this should be a multi-tiered system

WEED IMPACTS

- Quantify weed problems
- What are the impact of weeds on flora and fauna
- What risks do priority weeds pose to natural and agricultural systems? (There is overlap and may be benefits of combined effort.)

ENGAGING THE COMMUNITY

- Involve community in weed management
- Problem with communication between researchers and “users” – collaborative approach needed which involves community
- Need for social research – how are decisions made?
- Need to take holistic approach (not just WT WHA)
- Educate primary school children in relation to weeds
- Use cost/benefit analysis to sell weed successes

PRACTICAL SOLUTIONS TO EXISTING PROBLEMS

- Improve management of the weed environment
- Can you use plantations or other buffers to protect rainforest?
- Biological control
- Synthesise existing information on weed management – what works and what doesn't?
- Research on management strategies for weeds – adaptive management
- Refer TSCRC and others regarding adaptive management approaches
- Research designed to achieve practical outcomes
- On-ground works should have appropriate follow up strategies – “maintain the rage”
- Consolidate local plans into a regional plan
- What “on-ground” activities really address the problem at a useful temporal and spatial scale? – need to work across a range of scales
- How do we deal with “weed complexes”?
- Combine research with on-ground works
- Provide research and monitoring component to existing on-ground works
- Restoration ecology project – well defined outcome, community input, media focus
- Take pre-emptive approach to project development

RESOURCES FOR WEED RESEARCH AND DEVELOPMENT

- What can we do with a lot of money in a short time? – not eradication

Research and Development Priorities

Five priorities for research and development were identified from the outcomes of the 'brainstorming' session. These were:

1. The development of a database specific to weeds of rainforests and associated ecosystems;
2. Research on the impacts of weeds on ecological processes in rainforests;
3. Research on disturbance regimes and landscape characteristics in relation to weeds of rainforests;
4. Engagement of people in the landscape;
5. Early detection and response to new weeds.

Small working groups further developed each of these topics. The following five reports present the outcomes of this activity. Each reports under the same series of headings:

- Working group members
 - What management issue does this relate to?
 - Who would/could use the results of this project, and how?
 - Where is it relevant (geographically)?
 - What approaches/methods are appropriate?
 - What issues/challenges could arise?
 - What time-frame is involved, and what level of expertise is required?
-

WEED INFORMATION DATABASE

Report compiled by Melissa Setter and Joe Vitelli

Working Group members

Campbell Clarke
Alicia Hill
Melissa Setter
Steve Turton
Joseph Vitelli

Key question

How can we collect, collate, disseminate and usefully present fragmented current and future knowledge of weeds of rainforests and associated ecosystems?

What management issues does this relate to?

Increasing effectiveness of on-ground searches and control programs. This database would be a useful primary reference point for on-the-ground operators enabling them to easily access digestible information relevant to their control/management activities. That is, people who kill/look for weeds in the field can use it to find information to help them do their job better.

Increasing effectiveness of research. Researchers could use it to identify knowledge gaps, commonalities between weed groups, predict how particular weeds might behave, where they could grow/spread, and how they might respond to climate change. If the database were designed well, it could be interrogated in multiple ways. For example, it could be used to consider questions such as, “How many weeds are vines spread by birds?”; “What weeds can tolerate fire?” etc. This would be possible if some sections of the database were categories with a multiple-choice answer.

Preventing loss of information that is not formally recorded. Use of such a database could prevent duplication in research. It could also prevent the loss of knowledge, particularly of information that exists in non-published forms, e.g. ‘in people’s heads’; the knowledge of recognised experts, forestry workers etc. There is a lot of very valuable information that is not recorded anywhere at the present time. The database would aim to capture the failures and successes of weed control activities associated with revegetation by groups such as LandCare, BushCare, Catchment, Green Corp, NQ Afforestation, ACV, the Wet Tropics Tree Planting Scheme, the on-ground tree planting activities of Local and State governments including the Department of Main Roads revegetation program.

In general, the database would be useful for:

- Sharing information
- Capturing ecological understanding
- Summarising control information
- Describing weed distributions
- Integrating information from other countries
- Collating information on impacts and costs
- Public education
- Identifying the origins of weeds
- Identifying knowledge gaps

Who would/could use the results of this project, and how?

On-ground control operators

- better knowledge of where to look (e.g. to know whether a weed can grow in saline conditions, in dry environments etc);
- better knowledge of how to control weeds (e.g. What has worked in other countries? Is a particular weed susceptible to fire? etc);
- better awareness of current ecological knowledge that may help structure schedules for weed control (e.g. How long does it take for a weed to reach a size or age when it produces seeds? How long will seeds last in the soil? Is the seed able to withstand fire/flooding?).

Decision-makers (for allocation of resources)

- availability of information on weed problems in other countries may encourage early action in Australia;
- maximise available resources - comparing information about various weeds may help in deciding which weeds to control at certain times;
- better ecological information may support decision-making;
- minimise lag time in weed control/research – particularly relevant for potential weeds.

Researchers

- Predictive tool for spread;
- Identification of knowledge gaps – may help prioritise, and even group research to maximise resources (e.g. if interested in ten top weeds of the Wet Tropics could run a quick summary of what is and isn't known, and for example, find that 7 of them have no information about seed longevity in saline water, so could test this on all 7 species simultaneously)
- Interrogative tool – e.g. to look for any commonalities between certain weeds groups.

Where is it relevant (geographically)?

Short-term: rainforest and associated ecosystems (extent/particular regions determined by resources)

Long-term: applicable throughout Australia and internationally

Initially, the database would be aimed at capturing data for weeds of rainforests and associated ecosystems (as many as time/money allows). However, the intention would be to design a database that would be useful for basically any weed, anywhere.

What approaches/methods are appropriate?

- Database – must be interactive/dynamic to allow it to expand to reflect new knowledge/weeds etc – must be easy for people to access information and add information, but must be controlled;
- Metadata – summary of information, with different tiers/levels of information for different user groups;
- Sharing of information;
- Linking databases (GIS, Access, Spatial, Metadata)'
- Links to pictures (eg plant identification), maps (current and potential distribution);
- Easy to interrogate for specific information needs across broad user group;
- Coordinate information across agencies;
- Link this database into PestInfo, as additional layers of information;
- Explore possibilities of linking to Rod Randall's "A Global Compendium" and John Hosking's naturalised species database (Note: questions were raised as to whether this proposed database was a duplication of Randall's and Hosking's databases. Subsequent enquiries revealed that both of these are quite different from what we are

suggesting, these others are both more comprehensive in species included, and much less detailed in actual information about the weeds).

- Interviews, meetings with various people to gather information, particularly information that is in people's heads, but not necessarily written down anywhere accessible, e.g. people who are retired or have changed jobs. Payment for their time may be required.

Issues/ Challenges that could arise

- Level of detail;
- Who administers the database?
- Accessibility of information. How can it be made accessible to everyone? (website, links etc);
- How people can add their data to the database?;
- Need quality control of information that is supplied in the database (particularly how to distinguish published from anecdotal information);
- Validation of information (How and who would do this?);
- Who maintains the database?
- Intellectual property;
- Keeping it current;
- How should material be referenced?
- How can 'head' knowledge be accessed?

What time frame is involved, and what level of expertise would be required?

- Designing, and producing a draft database would take approximately 6 months (some expertise/experience with designing databases would be necessary, and some scientific background would be required to create useful categories etc).
- Processing and entering information would require 12 months or more, depending on the number of species included (person responsible would need good skills at summarising information, talking to people, investigating validity of information etc).
- Develop predictive models incorporating spread, global change, current distribution etc – additional 12-24 months (expertise required).
- Maintenance and administration of database would be necessary and would require some level of expertise/knowledge.

IMPACT OF WEEDS ON ECOLOGICAL PROCESSES IN RAINFORESTS

Report compiled by Nigel Ainsworth

Working Group members

Nigel Ainsworth
Chris Stansbury
Daniel Stock
David Westcott

Key question

How do we identify weeds that will have large effects on ecological processes (block or deflect succession, change nutrient dynamics etc.) in particular forest types/disturbance types? A matrix classifying cases by weed functional group, disturbance type, disturbance size (and possibly other factors) would be created where each cell contains a summary of current knowledge on the effects on ecological processes.

What management issues does this relate to?

Research. The organisation of existing knowledge in this way would identify gaps in current understanding. Information in each cell should be treated as a working hypothesis to be modified as more information becomes available or as specific studies to test the hypothesis are conducted.

Risk assessment. New weed species may be assigned to a functional group and the matrix may then be used to help assess what ecological processes they may affect and in what situations.

On-ground control. The matrix will help direct on-ground control to locations where it will be most effective in protecting ecological processes and may also allow prediction of what weed problems are likely to arise following different types of disturbance.

Extension. A modified version of the matrix could be helpful in explaining why certain infestations have been given priority over others.

Who would/could use the results of this project, and how?

Researchers. It appears that at present a considerable body of knowledge exists that has either not been documented or has not been drawn together in an easily accessible form. It is intended that any researcher could contribute to the matrix cells that their research relates to or could use the matrix as a rapid reference tool to identify potential future investigations and place these in a wider context of rainforest ecology.

On-ground managers. When faced with a number of weed species occurring in a range of situations, managers would be able to use the matrix to assess the likely ecological consequences at each site. Combining this knowledge with information on feasibility of control and with local conservation priorities would allow for appropriate allocation of resources.

Decision-makers. Providing a summary of current understanding of the impacts of rainforest weeds in different situations would enable decision makers to be better informed when considering activities that may cause disturbance to rainforest or when determining relative priorities of weed control and other management options.

Where is it relevant (geographically)?

Comments at the workshop indicate that weed impacts are likely to vary geographically so that the impacts of a particular group of weeds in a given disturbed situation might be different according to location. Modified versions of the matrix could be produced for rainforest in different areas. Initially much of the information might then consist of extrapolations from knowledge in other regions, with this being replaced by more specific information as it became available. The most sensible approach would be to commence with the geographical area which has most existing information and then to modify the content of matrix cells as required to produce versions for use elsewhere.

What approaches/methods are appropriate?

Step 1. Classify disturbance according to several ecologically relevant criteria. Suggestions include area disturbed, degree of canopy destruction, nutrient loss, shape of disturbed area, duration of disturbance (infrequent logging versus long term presence of a road), proximity to other disturbed areas.

Step 2. Collate existing information on individual weed species impacts. Identify functional groups of weeds that appear to affect ecological processes similarly.

Step 3. The matrix of disturbance attributes by weed functional group generates cells, some of which may be completed using existing data. On-going or planned research projects that will complete further cells should be identified at this stage. Cells for which information appears to be absent, sparse or contradictory should be evaluated to see whether they represent an important situation (occurring relatively often or affecting particularly valuable forest) and if so these should be the priority for further research. Research could include trials of weed growth under different controlled conditions, manipulative field experiments and observational studies of outcomes after previous disturbance events.

Issues/ Challenges that could arise:

- It may be difficult to classify multi-disturbance situations in a meaningful way, for example, when an initial disturbance followed by a disturbance of a different type.
- Defining disturbance events in detail using continuous measures of many factors might give the best understanding of the processes involved, but to assist on-ground management and decision makers, it would be necessary to have some agreed basis for presenting the information in a simpler form.

What time frame is involved, and what level of expertise would be required?

This question was not considered in detail. One suggestion was that a graduate employed full-time for six months would, with suitable supervision in the early stages, be able to locate and collate existing information and produce the first version of a matrix. Following that the idea would be that anyone with research data or observations to add would be encouraged to provide updates in the form of a very brief summary, a reference to the full data and an indication of the cell(s) to which they considered their information relevant.

DISTURBANCE REGIMES AND LANDSCAPE CHARACTERISTICS

Report compiled by Grant Wardell-Johnson

Working Group members

Tony Grice

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Grant Wardell-Johnson

Key question

Do disturbance regimes/ecosystems that are associated with weed invasions share particular characteristics (may be dependent on spatial and temporal scale)?

In particular:

1. Are there different suites of weeds associated with different types of rainforest?
Hypothesis: Different rainforest types are invaded by different suites of weeds.
2. Are riparian zones different from other parts of the rainforest landscape in relation to weeds? Do riparian zones “behave” like other linear arrangements in the landscape? Is there a distinct suite of riparian rainforest weeds? If so, what are the characteristics of this suite?
Hypothesis: Rainforest riparian zones are more prone to weed invasion than adjacent non-riparian rainforest.
Hypothesis: Rainforest riparian zones are invaded by different suites of weeds than other parts of the rainforest landscape.
3. What are the characteristics of the disturbance regimes of rainforest landscapes? Are rainforest interiors more resistant to weed invasion than rainforest edges?
Hypotheses: Edges may be more seriously infested by weeds because of weed dispersal patterns or because they provide suitable habitat for the weeds (light, temperature, moisture), Hypothesis: Different weeds have different levels of tolerance to the conditions in the interior.
Hypothesis: Some weed species may change conditions so that they can progressively move into the interior.

What management issues does this relate to?

- If different suites of weeds invade different rainforest types, then management decisions that set priorities for action in terms of weed species and site will vary. This raises questions about the role of fragmentation in weed occurrence and control.
- If riparian zones behave differently from other parts of the landscape, it would help target weed management (i.e. where in space).
- How do we manage the disturbance regime in the face of weed threats? This question relates to both the maintenance of intact rainforest and areas that are being restored to rainforest. Knowledge of the differing capacities of weed species will help decide priorities for weed management and design management practices for forest edges.

Who would/could use the results of this project, and how?

Each of these key questions presents and opportunity to:

- improve approaches to restoration of degraded rainforest or for recovery of rainforest (hence practitioners of rainforest restoration would be key clients)
- more carefully target parts of the rainforest landscape or times when particular control mechanisms or management practices can be most cost effectively applied (hence managers, policy makers and those prioritising funding for landscape management activities).

Where is it relevant (geographically)?

Each of the three key questions is relevant to all parts of the rainforest landscape as:

- there is likely to be geographical variation in the associations between rainforest types and particular weed guilds;
- questions about riparian rainforest habitat are relevant to all rainforest landscapes, because these questions also target the role of fragmentation in weed occurrence and control;
- questions about edge effects are relevant to a wide geographical area, but there may be a need to tailor management to different rainforest types, landscapes etc;
- all key questions relate to lands requiring restoration, hence a need for a broad geographic context.

What approaches/methods are appropriate?

- Existing quadrat-based information (databases) dealing with rainforest floristics would be explored. These sites can be revisited to document weed occurrence and abundance. Some of this work can be commenced through a review of existing information (e.g. Rainforest CRC, 5.2 data bases) and on-ground experience.
- As there is an interaction between landscape and management history, research on riparian zones would obviously need to be done in specific landscape types with similar management history. Some of this work can be commenced through a review of existing information (e.g. Rainforest CRC, 5.2 data bases) and on-ground experience.
- Research on edge effects and weed guild would require sufficient understanding of species ecology and behaviour to determine their capacity to invade rainforest edges and interiors. This could include their presence in the seed rain on edges and in the interior, their dispersal patterns, germination and growth requirements; could be done experimentally in the field or through glasshouse etc work; could undertake manipulative experiments on forest edges or “Natural experiments”. Some of this work can be commenced through a review of existing information (e.g. Rainforest CRC, 5.2 data bases), information currently being compiled through Rainforest CRC 5.2, and on-ground experience.

Issues/ Challenges that could arise:

Each of these key questions has a major research and integration component that would require funding, commitment and some design development. Components of these key questions would be suitable as honours, Masters and PhD programs. Much of the initial work is technical and collative, and could be carried out by competent technical staff.

What time frame is involved, and what level of expertise would be required?

Initial development of each of these projects could be achieved within a 1-2 year period with competent technical staff and a relatively low budget (mostly collation, literature review and some data-base work). However, serious commitment to attending to the research questions, and genuinely adding information that will make a serious difference to weed

management across the landscape requires a longer time frame and higher level commitment (3-7 year period) requiring technical design and analysis, GIS, botanical and landscape expertise.

Each of the key questions would undoubtedly require some quadrat or site-based floristic and habitat research within particular geographic regions or habitats considered of highest priority.

ENGAGEMENT OF PEOPLE IN THE LANDSCAPE

Report compiled by Catherine Hulm

Working Group members

Catherine Hulm
Stuart Worboys
Anne Portess
Brendan Malone
Jean Fenton
Jim Mitchell
Nigel Weston
Peter James
Peter Thompson

Key question

How do we make the community relevant to researchers/bodies? Can we 'make the community a resource not an end user'?

What management issues does this relate to?

The project crosses all management issues that have an associated community implementation or education component.

The project would be particularly useful for identifying issues, priorities, monitoring and review and asset allocation for research and onground programs.

Who would/could use the results of this project, and how?

Community organisations and Researchers. The project would set a benchmark for community involvement in research projects and development a framework that other institutions and community organisations could follow

Decision-makers and Funding Bodies. The project would ensure that decision makers and funding bodies could have confidence that resources would be allocated in the most appropriate areas

Where is it relevant (geographically)?

Anywhere where the aim is setting research areas/programs to ensure community driven research that is relevant to onground applications

What approaches/methods are appropriate?

Involvement

- Development of a framework for the CRC and stakeholders that includes meaningful stakeholder involvement into project design as a compulsory step.
- Stakeholders consultation for input into research questions to ensure that they will have relevant outcomes
- Identification of key stakeholders, interested stakeholders, and general stakeholders with engagement strategies designed accordingly. Engagement strategies need to be dynamic as relevant stakeholders change as the focus and direction of the project/program changes from information gathering, planning, project development and implementation
- Continuous consultation process throughout the entire project/program life not just at the end

Information Sharing

- Development of communication strategies that address all stages of project/program development and implementation
- Identification of user groups and appropriate communication mediums for effective delivery of information to user groups
- Inclusion of community representatives for the development of extension material
- Utilisation of existing resources within the CRC (program support) and create an environment where feedback is turned into better outcomes and practical materials
- Development of protocols within the CRC that results in an environment of open information sharing
- Engagement of existing community support staff as a conduit between researchers and the community to ensure that information is being delivered in an effective manner
- Development of advocacy/networking systems to work with potentially troublesome stakeholders

Monitoring and Evaluation

- Create linkages with current research being undertaken on monitoring and evaluation (eg. Savannah CRC Theme 4) to utilise information on attributes of successful and unsuccessful projects
- Design performance criteria to monitor social outcomes of projects
- Develop performance criteria for implementation programs that measures community capacity building components of project/programs

Issues/ Challenges that could arise:

- Ensuring that long-term research outcomes and objectives are not compromised
- Resource allocation for community engagement is appropriate for the project/program
- That the community is not consulted to saturation point
- That consultation and engagement remains relevant

What time frame is involved, and what level of expertise would be required?

- Designing of community involvement framework – approx 6 months (expertise/experience with community development processes is essential)
- Development of information sharing protocols – 6 months (person would require knowledge of CRC operational arrangements and community organisations in the area)
- Development of performance criteria – 12 months (person would require expertise in monitoring and evaluation frameworks))
- Development of communication strategies – ongoing with the development of new project/program (expertise in communications strategies and community development processes)

PROTOCOLS FOR BEST PRACTICE FOR EARLY DETECTION AND RESPONSE TO NEW WEEDS IN RAINFORESTS AND ASSOCIATED ECOSYSTEMS

Report compiled by Barbara Waterhouse and Catherine Ticehurst

Working Group members

Leasie Felderhof
Rick Roush
Catherine Ticehurst
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Garry Werren

Key question

How can we more efficiently detect individuals and small populations of “new” weeds (ie. new incursions or recent naturalisations)?

What management issues does this relate to?

- **Identification of “future” weeds.** Despite the use of thorough weed risk assessment procedures to prevent introduction of weedy species, it is inevitable that new plant species will continue to naturalise and become invasive in Australia. Many of these “future” weeds are probably already present in botanical gardens, nurseries and private “collections”, but have yet to naturalise. Future climate change may favour the naturalisation and spread of species that do not have a history of invasiveness. Despite the most stringent of quarantine precautions, a small proportion of new invaders will probably be accidentally introduced as contaminants.
- **Early detection and response strategies.** To minimise future environmental and economic harm caused by weeds, development of efficient and cost effective early detection and response strategies is imperative.
- **Rainforest protection from weeds.** Australian rainforest ecosystems are fragmentary, relictual and limited in extent. Climate change, land clearing, human population growth and development of associated infrastructure in rainforest regions, places these ecosystems under severe threat. The disturbed areas thus created are pre-disposed to weed invasion. Therefore, measures to prevent or minimise new incursions in rainforests are essential.

Who would/could use the results of this project, and how?

There are three main facets of early detection and response for end-user involvement:

- detection or recognition of an invasive species, which should then lead to identification and verification of the correct name for that species;
- weeds identified as new naturalisation records or new to geographic region/habitat type should trigger reporting;
- implementation of appropriate response.

End-users include the interested public and government organisations (eg. Landcare and conservation groups, state and federal environmental protection agencies and natural resource managers, herbaria, agronomists).

Where is it relevant (geographically)?

Australia-wide, based on localised response strategies. Early recognition of, and response to new invaders is important across the broad range of environments (and land use practices) throughout Australia, and not restricted to rainforest ecosystems. Strategies will need to be tailored to suit particular ecosystems. For example techniques used to locate isolated

invasive shrubs in tropical rainforests may be vastly different from those used to locate isolated shrubs in grasslands.

What approaches/methods are appropriate?

*Note: Program 1 of the Weeds CRC is currently investigating methods of early detection, reporting and response to new weeds in close collaboration with a project entitled “Best practice for management of new incursions” under Program 4 of the Weeds CRC. Further work specifically undertaken to enhance early detection and response to weeds of rainforests would usefully link with these projects.

Analysis of current processes in early detection, notification and response to new weeds

1. Review current methods for detection (and identification) of new weeds: For example:
 - *State weed strategies (eg, Victorian Weed Alert Network)*
 - *Northern Australia Quarantine Strategy (NAQS)*
 - *National Park and State Forest weed strategies. Regular inspection for weeds at these sites*
 - *Crop-based inspection for new weeds by agronomists and agricultural consultants/pest spotters*
 - *Ad hoc submission of specimens to herbaria (or other botanists) by weed officers and members of the public*
 - *Members of public “report” new weeds to weed and extension officers (specimen needs to be obtained)*
 - *Weed identification workshops (eg. for landcare groups, field naturalist groups)*
2. Review current methods for reporting new weed naturalisations: For example:
 - *New naturalisation reports to OCPPO (Office of the Chief Plant Protection Officer) which are then circulated to all states via Australian Weeds Committee delegates or equivalent*
 - *Protocol followed by NAQS*
 - *NSW State Herbarium Weed Alert service*
 - *Queensland Herbarium “new naturalisation” reports to Queensland Department of Natural Resources and Mines*
 - *Victorian weedspotters network?*
 - *Arrangements at local government level for new distribution records (as distinct from new naturalisations)?*
3. Review current methods for response to new weeds: For example:
 - *Commonwealth Alert lists for environmental and agricultural weeds*
 - *Strategic Weed Eradication and Education Program (SWEEP) managed by Queensland Natural Resources and Mines*
 - *Case studies of weeds first reported by NAQS in Queensland and Northern Territory (national cost-sharing arrangements for response)*
 - *Responses by local councils or National Park authorities etc*

Identify strengths, weaknesses and gaps

- Are reporting and response mechanisms clearly delineated and understood?
- Are weed risk assessments applied consistently for each new naturalisation record?
- Are new naturalisation records for species not mentioned by legislation (ie not pre-emptively declared) treated in the same way as species that have been pre-emptively declared?

- Include 'near miss' analysis
- Weed database availability?

Determine strategic approach

- Is a species-specific, site-specific or regional-approach most appropriate? Does 'one solution fit all' or are there 'multiple solutions'?
- Is it appropriate to use target lists? If used, are they regularly reviewed and up-dated?
- Examine feasibility of using sentinel sites (for example rubbish dumps; botanic gardens, herbalists, permaculture plots etc) as key areas for early detection (scope for collaboration with Weeds CRC Program 1)
- Is it possible to target internet distribution of potential weeds?

Develop best practice policy document

- Joint CRC exercise (possibly co-ordinated by Program 4 Weeds CRC)
- Circulate to state and local government agencies for consideration and trial

Community engagement (facilitated by Weeds CRC)

- Value add by enlisting extra sets of 'eyes and ears' amongst groups with an interest in maintaining a weed-free environment (e.g Society for Growing Australian Plants; field naturalists clubs; bird-watchers; etc)
- Develop special 'task force' of weed watchers. Includes local council pest officers, botanists; environmental consultants
- Look at interstate examples (e.g. Victorian weedspotters network)

Technical possibilities

- GIS modelling
- Remote sensing: develop library of spectral signatures; catalogue and refine existing resources/technology; take advantage of seasonal differences in foliage colour and density (some species only); investigate novel instruments for remote sensing (e.g remote controlled aircraft)

Ecological research

- Links between target plants and vectors (eg. birds and bats as dispersal agents)
- Modelling potential roosts and flight paths (with the aim of selecting target areas for attention)
- Do birds and bats "dump ballast" before flight (risk assessment of weed seed deposition at either end of journey)
- Sentinel sites

Issues/ Challenges that could arise:

- Need for improved awareness of the importance of early recognition of new invaders. The general public needs to know where they can get weeds identified.
- Implementation of consistent early detection and response strategies between different regions and states.
- Seeds purchased through the internet are cause for concern. What is the current status of quarantine checks on incoming mail from overseas? Are letter class items still exempt from inspection?

The government's Increased Quarantine Interception (IQI) goal is to screen 100% of incoming mail. This has been implemented. However, this does not mean that every incoming item of mail is opened. X-ray equipment and detector dogs are also used. Detector dogs have demonstrated extreme sensitivity for detection of plant material.

What time frame is involved, and what level of expertise would be required?

Time frame for steps 1-4 = ca. 1 year, and for steps 6-7 = 3 year research projects. A high level of experience/expertise is required for the establishment of early detection and response strategies/programs. Once in place, interested parties need to be trained, based on their level of participation, experience, and the local weed strategy.

Research and Development Recommendations

The following summarises general recommendations from the workshop. They have been grouped under four headings. Several of the research areas that are highlighted can be related to existing work that is taking place within the CRC for Australian Weed Management. For example, research in relation to weed risk assessment and the management of new incursions is the focus of Program 1: Weed Incursion and Risk Management. Similarly, there are projects within WEEDS CRC and the Rainforest CRC on the important process of bird-aided dispersal of plants.

WEED RISK ASSESSMENT AND PREVENTION OF NEW INCURSIONS

- Refine systems of risk assessment to identify species that pose threats to Australian rainforests and associated ecosystems. Develop a capacity to predict risk from species that are already present in Australia but which have not yet become invasive or that are not yet present in Australia but that are invasive in neighbouring regions or other climatically similar parts of the world. Explore the value of functional trait analysis as a means of identifying risk of weediness.
- Examine the risks of weeds entering Australia from the north via migratory frugivorous birds and bats.
- Develop and institute effective measures to prevent the introduction of new weed species and appropriately resourced strategic weed management of species already present.

DETECTING AND MANAGING NEW INCURSIONS

- Assemble and collate information and techniques used in the management of new incursions, for example, *Chromolaena odorata* and *Mikania micrantha*, in tropical Queensland to help develop effective incursion detection and management protocols, that is, to learn from experience.
- Develop effective and efficient methods (techniques and protocols) for detecting incursions of new weed species early in the invasion process. These methods must be suitable for detecting small populations of new introductions and recently naturalised species.
- Develop and implement protocols for appropriate rapid responses to new weed incursions. Ensure adequate resources over appropriate time-frames.
- Assemble and collate currently available ecological information on 'new' weed species that are invasive in Australia but that do not have a history of being weedy elsewhere (e.g. *Brillantaisia lamium*, *Miconia racemosa*).
- Develop and apply improved eco-climatic modelling of the potential distributions and habitat preferences of recently naturalised weed species.
- Examine the possibilities of practical, cost-effective weed detection and mapping using remote-sensing techniques.

UNDERSTANDING WEED INVASION PROCESSES

- Conduct genetic studies to determine the geographical origin of important weed species, particularly where multiple introductions are suspected (e.g. *Mikania micrantha*). Studies are especially important in cases where biological control is being contemplated as a long-term management strategy.
- Assemble and collate life history and general ecological information on important current weed species growing under 'local, rainforest' conditions. Compare this information with that from native ranges. Undertake research to fill any critical knowledge gaps. For species that are targeted for eradication, the scope and time-frame of such work should be limited to those aspects that are most important for developing and implementing the eradication programs.
- Identify the factors that facilitate weed invasion into rainforests and associated ecosystems. Determine ways in which these factors can be managed to reduce weed invasions.
- Examine variation between rainforest types in the species/functional groups of weeds that invade them. Use this as a basis for developing weed management practices and strategies appropriate to different rainforest types.
- Improve understanding of the impacts of native fauna on the ecology of invasive species of rainforests and associated ecosystems. Especially significant are the roles of avian and mammalian vectors of weed dispersal agents, given the importance of frugivory in Australian rainforests.
- Improve knowledge and understanding of the effects of weeds on biodiversity and ecological processes of rainforests and associated ecosystems. Simple indices of biodiversity, for example the use of key indicator species, may be useful for documenting impacts on biodiversity.
- Determine the impacts and ability of vine species to invade and transform rainforest edges, gaps and intact canopies.

IMPROVING WEED MANAGEMENT

- Undertake research into the biological control of rainforest weeds. Some work on biological control of weed species relevant to rainforests is underway, for example, on cat's claw creeper, Madeira vine¹ and lantana. Other possible targets for biological control include pond apple, chinese celtis, asparagus fern (*A. africanus*); broad-leaved pepper and mistflower.
- Review currently available economic information in relation to weed management in rainforests and associated ecosystems. Develop guidelines/decision support based this information.
- Document the levels of success and sustainability of weed management practices and programs.
- Develop and test techniques for reducing the chances of weeds invading rainforests. For example, does "edge sealing" protect rainforest margins?
- Develop and implement ways for effectively engaging in weed management the human communities of rainforest areas.

¹ Research has identified a potential biological agent for Madeira vine but resources are not currently available to undertake the necessary host-specificity testing.

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Appendix 1

WEED SPECIES LIST

This list includes all weed species referred to in this report. Bebawi and Campbell (2002) also provided a list of priority weeds of the wet and dry tropics.

No.	Scientific Name	Common Name
1	<i>Ageratina adenophora</i>	crofton weed
2	<i>Ageratina riparia</i>	mistflower
3	<i>Ageratum conyzoides</i>	billy goat weed
4	<i>Ageratum houstonianum</i>	floss flower
5	<i>Allamanda cathartica</i>	golden trumpet vine
6	<i>Andropogon gayanus</i>	gamba grass
7	<i>Annona glabra</i>	pond apple
8	<i>Anredera cordifolia</i>	Madeira vine
9	<i>Aristolochia ringens</i>	Dutchman's pipe
10	<i>Arundina bambusaefolia</i>	orchid
11	<i>Brachiaria mutica</i>	parā grass
12	<i>Brillantaisia lamium</i>	brillantaisia
13	<i>Cardiospermum grandiflorum</i>	balloon vine
14	<i>Cardiospermum halicacabum</i>	heart seed
15	<i>Chromolaena odorata</i>	Siam weed, chromolaena
16	<i>Cinnamomum camphora</i>	camphor laurel
17	<i>Cleome aculeata</i>	spider flower
18	<i>Clidemia hirta</i>	Koster's curse or soap bush
19	<i>Clitoria ternatea</i>	butterfly pea
20	<i>Cyperus aromaticus</i>	navua sedge
21	<i>Dalbergia sissoo</i>	dalbergia
22	<i>Elephantopus mollis</i>	tobacco weed
23	<i>Euphorbia heterophylla</i>	milkweed
24	<i>Harungana madagascariensis</i>	harungana
25	<i>Hiptage benghalensis</i>	hiptage
26	<i>Hymenachne amplexicaulis</i>	hymenachne, olive hymenachne
27	<i>Ipomoea cairica</i>	morning glory
28	<i>Ipomoea purpurea</i>	morning glory
29	<i>Lantana camara</i>	lantana
30	<i>Leucaena leucocephala</i>	leucaena
31	<i>Ligustrum lucidum</i>	large-leaved privet
32	<i>Ligustrum sinense</i>	small-leaved privet
33	<i>Limnocharis flava</i>	yellow burrhead, limnocharis
34	<i>Lycopodium clavatum</i>	lycopodium
35	<i>Macfadyena unguis-cati</i>	cat's claw creeper
36	<i>Macroptilium atropurpureum</i>	siratro
37	<i>Miconia affinis</i>	miconia
38	<i>Miconia calvescens</i>	miconia
39	<i>Miconia racemosa</i>	camasey felpa
40	<i>Mikania micrantha</i>	mikania vine, mile-a-minute
41	<i>Mimosa diplotricha</i>	giant sensitive tree
42	<i>Momordica charantia</i>	bitter melon
43	<i>Ochna serrulata</i>	ochna
44	<i>Panicum maximum</i>	Guinea grass

45	<i>Parmentiera edulis</i>	cucumber tree
46	<i>Passiflora foetida</i>	stinking passionflower
47	<i>Phytolacca rivinoides</i>	Venezuelan pokeweed
48	<i>Piper aduncum</i>	tree pepper
49	<i>Eupatorium catarium</i>	praxelis
50	<i>Protoasparagus africanus</i>	bridal creepers/asparagus ferns
51	<i>Rhodomyrtus tomentosa</i>	downy rose myrtle
52	<i>Salvia coccinea</i>	mint weed
53	<i>Sansevieria trifasciata</i>	mother-in-law's tongue
54	<i>Selaginella vogelii</i>	peacock fern
55	<i>Senna hirsuta</i>	hairy senna
56	<i>Senna obtusifolia</i>	sicklepod
57	<i>Solanum mauritianum</i>	wild tobacco bush
58	<i>Solanum seaforthianum</i>	Brazilian nightshade
59	<i>Spathodea campanulata</i>	African tulip
60	<i>Sphagneticola trilobata</i>	Singapore daisy
61	<i>Stachytarpheta</i> spp.	snakeweed
62	<i>Syagrus romanzoffiana</i>	queen palm
63	<i>Syngonium podophyllum</i>	American evergreen
64	<i>Thunbergia laurifolia</i>	blue trumpet vine
65	<i>Thunbergia grandiflora</i>	trumpet vine, thunbergia
66	<i>Tithonia diversifolia</i>	Japanese sunflower
67	<i>Tradescantia fluminensis</i>	wandering jew
68	<i>Turbina corymbosa</i>	turbine vine

Appendix 2

WORKSHOP PROGRAM

Day 1 Wednesday, November 6 2002

SESSION 1: Chair – Dr Tony Grice (Weeds CRC, CSIRO)

830-915 Invited papers

1245-1345 Lunch

SESSION 2: Chair – Ms Melissa Setter (Rainforest CRC, DNRM)

1345-1530 Presentations on research and development activities

1530-1545 Afternoon tea

1545-1700 “Brainstorming” the research and development issues
Facilitator: Dr Jim Mitchell (Rainforest CRC, DNRM)

Day 2 Thursday, November 7 2002

SESSION 3: Chair – Ms Barbara Waterhouse (Weeds CRC, AQIS)

0830-0900 Review of progress.

0900-1030 Identifying research and development priorities – discussion.

1030-1100 Morning tea

1100-1230 Refining research and development proposals – small group activity

1230-1330 Lunch

SESSION 4: Chair – Mr Garry Werren (ACTFR, JCU)

1330-1500 Reporting on small group activities

1500-1530 Concluding comments

Appendix 3

LIST OF WORKSHOP ATTENDEES

Name	Affiliation	Address	Email
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